Attachment 2

DARMATT firewrap material cable ampacity derating factor calculation

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COMMONWEALTH EDISON COMPANY

TITLE PAGE

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X SAFETY RELATED NON-SAFETY RELATED

CALCULATION TITLE
Darmatt firewrap material cable ampacity derating factor calculation

EQUIP NUMBER(S) various	STATION /UNIT Byron/Braidwood	SYSTEM various

REV.	CHRON#	PREPARER DATE	REVIEWER DATE	APPROVER DATE
0	210548	Roman Gesior Roman Gesior 8/30/94	B. Perchiazzi B. Perchiazzi 9/1/94 G.J. Hinshaw (S&L)* Greg J. Hinshaw 9/1/94	B. Rybak B. Rybak 9-2-94
1	210740 (2 RGD 1/3/95)	Roman Gesior 1/3/95	B. Perchiazzi 1/3/95	B. Rybak B. Rybak 1/3/95
2	210744	Roman Gesior 1/20/95	B. Perchiazzi 1/23/95	B. Rybak 1/23/95

* Reviewer of calculation methodology.

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DESCRIPTION OF REVISIONS/REASONS FOR CHANGE

Revision 1:

To make calculation parameter changes result directly in a solution without requiring manual iteration. The new format using Mathcad "ROOT" command allows for a direct solution resulting from parameter changes. The calculation structure was changed to make the calculation more clear regarding applicable inputs, equations and solutions. And finally an additional case was run to add a 4" conduit condition. This was done at the request of Byron Station. Additionally a correction was made to one of the cases results. The results of the calculation do not change from this revision, Only the presentation changes.

Revision 2:

To make editorial changes, no technical changes are made.

AFFECTED PAGES

PAGES	REV.	DESCRIPTION
all	0	initial Issue
all	1	Change iteration process to utilize Mathcad built in "Root" command which iterates for a solution. Entire calculation restructured to provide calculation of each case individually and not as a vector as was done for Rev. 0. Also a case was added to the conduit section of the calculation which calculates the derate for a 4" conduit with a 500 kcmil cable, per request of Byron Station. Also a change to section 4.6.5 case 47 and 48 is made, the results were switched in the original calculation.
7, 129	2	clarify that the vertical length design inputs are used to determine relative derating of vertical trays, and all cases considered in Rev. 0 of the calculation are included in Rev. 1.

4.1 **Purpose/Scope**

The purpose of this calculation is to determine the amount of cable ampacity derating required for 1 and 3 hour fire barriers installed utilizing Darmatt firewrap material. The scope of this calculation covers 4 sizes of cable trays (12" x 4", 18" x 4", 24" x 6" and 24" x 4") and 3 different depth of fill of cable (1", 2" and 3"). The calculation will also evaluate the relative derating for a vertical cable tray (24" x 12") relative to an unwrapped horizontal cable tray. Also the ampacity of cable in conduit installed with Darmatt firewrap will be compared to the ampacity in conduit without firewrap.

4.2 **Methodology**

Wrapped Cable Tray

The allowable heat generation for a tightly covered cable tray is first calculated. The allowable heat intensity versus depth of fill for an uncovered cable tray (see figure 1)is derated by 15% for the covered cable tray.

The total thermal resistance of the cable mass, air space and cable tray is then determined. The allowable heat generation for a tightly covered cable tray is used to calculate the surface temperature of the cable tray. The difference between the rated conductor temperature and this surface temperature is then divided by the allowable heat generation for a tightly covered cable tray in order to obtain an equivalent thermal resistance from the conductor metal to surface of the tightly covered cable tray (see figure 2). The surface temperature of the tightly covered cable tray, TGS, is found by manually adjusting this value until QTGS, the calculated value of the total heat transferred from the closed cable tray surface, nearly matches QCB, the allowable heat generation in a tightly covered cable tray.

Next, a composite thermal resistance of the Darmatt firewrap and an assumed air gap (to compensate for potential installation problems and firewrap thickness variations) is calculated and added to the equivalent resistance from the conductor metal to the surface of the cable tray which was calculated previously.

The same formulas for the total heat transfer (convection and radiation) from the tray surface to the surroundings, as modified for the higher emissivity of the Darmatt material as compared to the galvanized steel, are then used to calculate the total heat

transfer (convection and radiation) from the wrapped cable tray to the surroundings (see figure 3).

The surface temperature of the wrapped cable tray, TWT, is manually adjusted using the MATHCAD program until the calculated maximum temperature of the conductor, TCCR, is nearly equal to the rated conductor temperature, TCR. The variable, calculated rated conducted temperature, TCCR, is calculated from the formula TCCR=TWT+QTWT*RTOT, where QTWT is the total heat transfer from the wrapped cable tray, and RTOT is the total thermal resistance from the conductor metal to the surface of the firewrap.

Since the heat generated in the cable is proportional to the square of the current, the square root of the ratio of the allowable heat for a wrapped cable tray to an unwrapped cable tray is the ampacity factor. The derate factor is 1 minus the ampacity factor.

The above method is repeated for 4 different size cable trays for a 1, 2 and 3 inch depth of fill and for a 1 hour and 3 hour fire barrier.

Vertical Cable Trays

The same methodology was used for evaluating the relative derating for vertical cable trays. The calculation was done for 2 tray lengths (30' and 19') to evaluate the effect on ampacity derating by the length of the tray. The calculation was performed for two actual lengths of tray and not per linear foot of tray as was done for the horizontal trays. An assumption is made that the relative thermal resistance of the cable mass and vertical tray assembly is the same as for a horizontal tray cable mass and tray assembly of equal size and material. A 24" wide tray is used for the vertical tray ampacity derating calculation because it was found in the horizontal tray calculation to provide the highest derating. Per Reference 1 vertical trays are 12" deep.

Conduit

The methodology used for evaluating the relative ampacity derating in conduit is similar. The overall thermal resistance of the conduit system is calculated. This includes resistance from the cable insulation and jacket, resistance from the air space between the conduit and the cable, the conduit wall thickness and finally the firewrap material for a 1 and 3 hour fire barrier. The total heat generated from the system per linear foot is calculated at the surface of the

firewrap material. This includes heat transfer by convection and radiation. This provides two unknowns, the firewrap surface temperature and the total heat generated. The firewrap surface temperature is iterated in the equations for total heat transferred until the conductor temperature converges on the rated conductor temperature, 90°C.

From this value, for the total heat transferred compared to the value for an unwrapped conduit, the ampacity derating value can be obtained similar to that discussed above for a cable tray. The calculation was performed using 3/4" conduit and 6" conduit as they bound the conduit sizes used at the site.

Vertical Conduit

The same methodology was used for evaluating the relative derating for vertical conduit. The calculation was done for 2 conduit lengths (30' and 19') to evaluate the effect on ampacity derating by the length of the conduit. The calculation was performed for two actual lengths of conduit and not per linear foot of conduit as was done for the horizontal conduit. An assumption is made that the relative thermal resistance of the cable mass and vertical conduit is the same as for a horizontal conduit and cable mass of equal size and material. The vertical conduit calculation is performed using the worst case cable from the horizontal calculation (3/C 500 kcmil (600V)).

4.3 Design Inputs

1. The ambient temperature is 40°, 50°, and 60°C (Reference 1), the calculation is performed for a 40°C ambient methods for ampacity deratings for other ambient temperatures is provided in the conclusion.

2. The cable trays are 12 x 4, 18 x 4, 24 x 4, 24 x 6 (includes 2" side rail) and 24 x 12 (vertical only) all dimensions are in inches (Reference 1). The 24 x 8 (includes 4" additional side rail) is bounded by the 24 x 4 inch size tray and is therefore not evaluated.

3. Depth of fill considered will be 1", 2", and 3" (Reference 1)

4. The allowable heat intensity is 6.7, 2.8, and 1.6 ($W/ft\text{-}in^2$) for 1", 2", and 3" depth of fill respectively (Reference 2 page 25)

5. A tightly covered cable tray requires a 15% ampacity derating (Reference 3 Table III)

6. The emissivity of a galvanized, iron, bright surface is .23 (Reference 7 page 4-111)

7. The emissivity of Darmatt surface is .7 (Reference 8)

8. The rated conductor temperature is 90°C (Reference 9 page 3 section 3.2)

9. The thermal conductivity of air is .0158 Btu/hr-ft-°F at 104 °F linearly interpolated from data in Reference 7 page 4-94

10. The thermal conductivity of the Darmatt material is 0.783 Btu-in/hr-ft^2-°F or 0.0653 Btu/hr-ft-°F @ 156°F mean (Reference 8)

11. The Darmatt firewrap material has the following total thickness' including tolerance for the 1 hour and 3 hour barrier, respectively: 1.25", 2.61" Reference 8. For conduit the thickness is 1.25" and 3.00" for a 1 hour and 3 hour barrier respectively.

12. The Stephan-Boltzman constant is equal to 0.1713*10^{-8} Btu/hr-ft^2-°R^4 (Reference 7 page 4-108).

13. The vertical length of a wrapped cable tray is 30 and 19 ft. These values are used to determine the relative derating of vertical cable trays compared to horizontal trays. Because this calculation is intended to cover generic installation of Darmatt 30 ft is selected to envelope maximum vertical length. The 19 ft is used to show the relative affects of length on the ampacity derating. The ampacity derating factor for vertical trays will be qualified by this length. R2

14. Thermal resistivity of the cable insulation, jacket, and overall jacket is 500 °C-cm/Watt, (Reference 9 Table 1 & 2).

15. Thermal resistivity of conduit wall is 2.08 °C-cm/Watt (Reference 9 Table 2)

16. Parameters of the selected cables are identified below (Reference 12 Table C) these cables were selected to provide a representative sample of cable installations to provide a relative value of derating of cable in wrapped conduit to cable in wrapped cable trays.

Cable Descr.	Cable SI#	Overal OD	1/C OD	Insul. Thick.	Jacket Thick.	Overal Jacket
1/C-8	363E38	.34	.34	.045	n/a	.03
3/C-6	363F17	.87	.33	.06	n/a	.06
3/C-2	363D35	1.90	.632	.14	.03	.08
3/C 500kcm	363D38	3.34	1.193	.14	.05	.14

Note: All dimensions are in inches where 1 mil = .001 inch

17. Conduit sizes used to perform this review are 3/4", *4"* and 6". Two sizes were selected *(3/4" and 4")* to bound the relative affect of conduit diameter (Reference 1).

18. Conduit outside diameter is 1.05", *4.5"* and 6.625" for a 3/4", *4"* and 6" conduit respectively (Reference 11).

19. Conduit wall thickness is .107", *.225"* and .266" for 3/4", *4"* and 6" conduit respectively (Reference 11).

20. The ampacity derating for a covered cable tray is 15% (Reference 3 Table 3).

4.4 Assumptions

1. The increase in surface area available for convection and radiation caused by wrapping the tray will be ignored on the basis that the heat flow through the corners of the firewrap is non-uniform. This assumption does not require validation because it provides a conservative result.

2. A 1/16" air gap is assumed in the Darmatt system installation even though installation is expected to be consistent from the cable tray to ambient with no gaps (Reference 8). This will allow for potential

installation problems and variations in the Darmatt thickness.

3. There are no gaps at the corners of the Darmatt boards which would allow air flow from the cable tray. This assumption is conservative because it reduces the heat transfer from the wrapped cable tray to the surroundings and therefore does not require validation.

4. No contact resistance between boards and cable tray is considered, the boards will adhere directly to the cable tray and any contact resistance will be minimal.

5. The heat intensification values obtained from Reference 2 assume a 24" wide tray. The Reference also indicates that for other tray widths such as 18" and 36" results are close to those for a 24" width since about 2/3 of the heat is dissipated by radiation and since h (heat transfer coefficient for convection) is proportional to $W^{-1/4}$ (width of tray).

6. The thermal resistance of a vertical tray cable mass, tray assembly and Darmatt fire wrap is the same as a horizontal tray mass, tray assembly and Darmatt fire wrap of same geometric dimensions since it is a function of the material properties and thickness.

4.5 References

1. Byron NDIT No. BYR-94-029 approved July 1994 (Attachment 1)

2. Lasalle calculation 4266-EAD-13, Rev. 0 titled "Cable Tray Heat Intensity", transmitted via S & L EDIT BB-EXT-0836 dated July 21, 1994 (Attachment 2)

3. Tests at Braidwood Station on the effects of fire stops on the ampacity rating of power cables, Proceedings of the American Power Conference, 1982, by Haddad, Bloethe, Lamken, Stolt, Sykora (Attachment 3)

4. Fundamentals of Heat and Mass Transfer, 2nd Edition, J. Wiley and Sons, F. Incropera and D. DeWitt

5. Heat Transfer, J. Holman, McGraw Hill Book Company, 1968 (Attachment 4)

6. Heat Transfer Data Book, D. Kaminsky, General Electric Co, 1977 (Attachment 5)

7. Standard Handbook for Mechanical Engineers, Baumeister and Marks, 7th Edition

8. Darmatt Material Specification Sheets transmittal from

Transco, Letter date July 27, 1994 (Attachment 6)

9. Sargent and Lundy Electrical Standard, ESA-105, Rev. 8-4-86.

10. Sargent and Lundy Calculation for LaSalle Station 4266/19G52 Rev. 0.

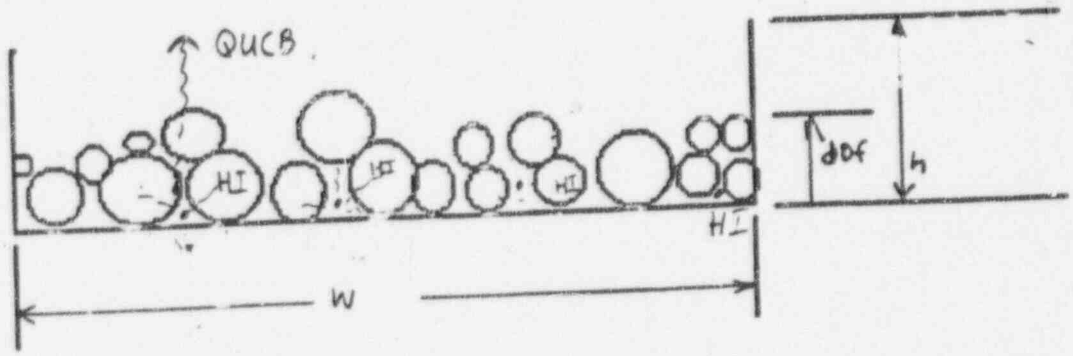
11. Allied galvanized rigid conduit specifications, NEIS-CAT-205, CAT NO: ATC-L-1127-3, Rev. 1/92.

12. Electrical Installation Standard, EIS N-EM-0035 Table C, Rev. 5.

FIGURE 1

Uncovered Cable Tray

o TAR

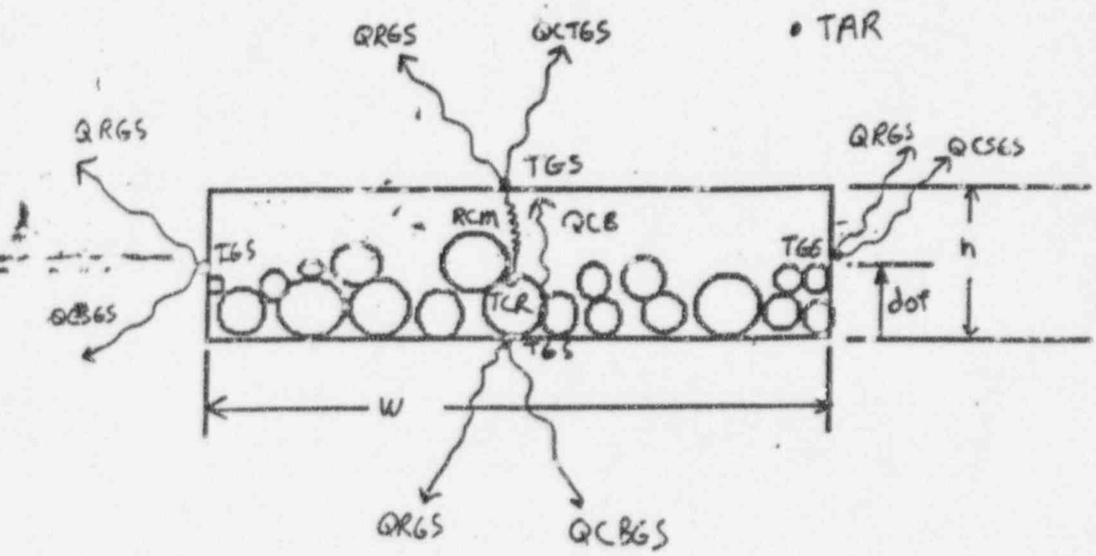


$$QUCB = HI \cdot A_{eq}$$

$$A = w \cdot dof \left(\frac{\pi}{4}\right)$$

FIGURE 2

Tightly Covered Cable Tray



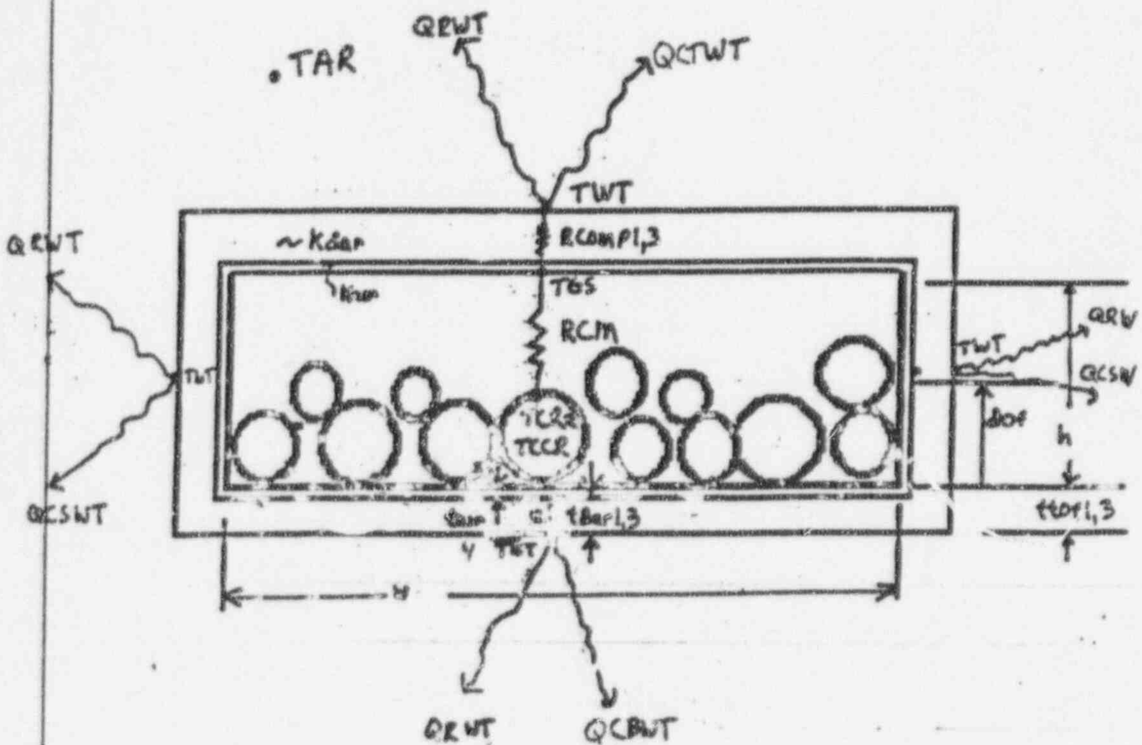
QTGS = QRGS + QCSGS + QCTGS + QCBGS

$\approx$ QCB , $RCM = \frac{TCR - TGS}{QCB}$

FIGURE 2

FIGURE 3

WRAPPED CABLE TRAY



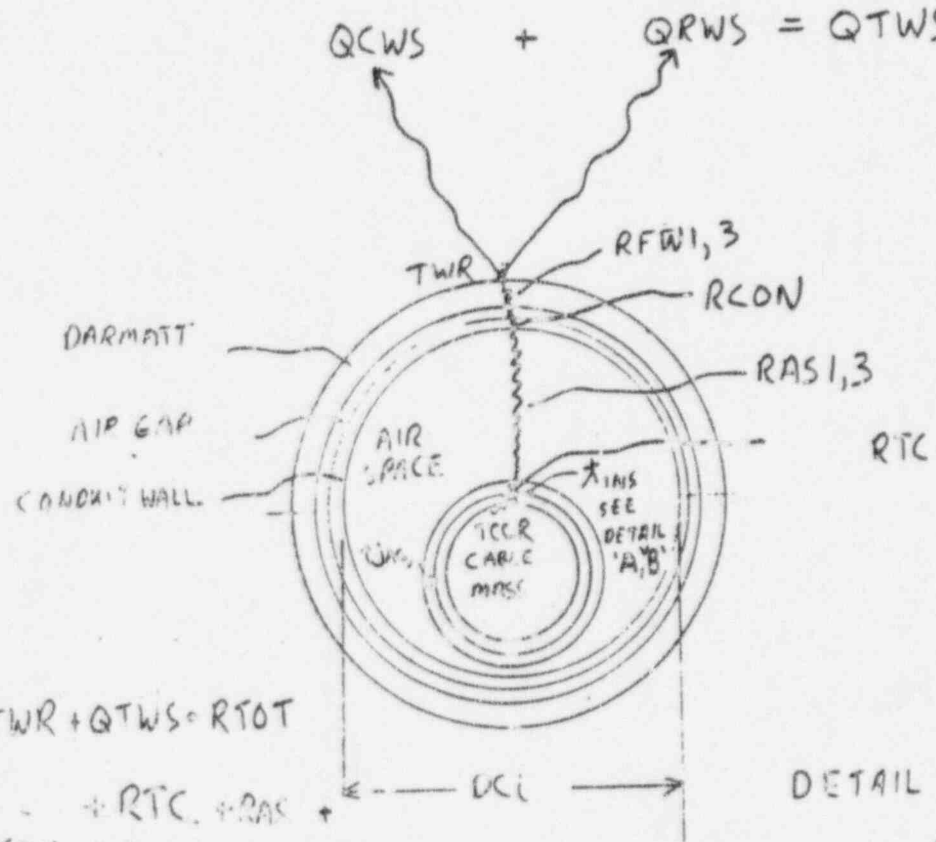
QTWT = QRWT + QCSWT + QCTWT + QCBWT

TCCR = TWT + QTWT · RTOT

RTOT = RCM + RCOMP

FIGURE 3

FIGURE 4



TCCR = TWR + QTWS · RTOT

RTOT = + RTC + RAS + RCON + RFW1,3

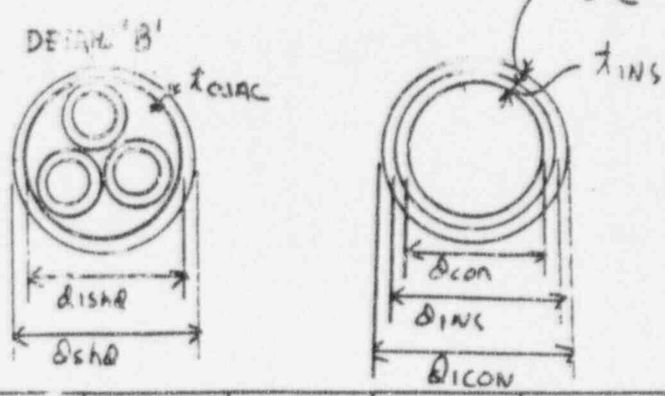


FIGURE 4

4.6.1 Calculation of Ampacity Derating for Horizontal Cable Trays

The equations for the first case will be developed and described in detail. For the remaining cases only the inputs, equations and outputs will be presented. The cases are ordered such that the corresponding 3 hour case follows the 1 hour case. The case number is the same as in revision 0 of the calculation and therefore does not follow numerically in order.

Case 1

Calculation of Cable Ampacity Derating For a 12" x 4" Cable Tray With 1" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

The cross sectional area of the cable tray is equal to the depth of fill times the tray width. The cross sectional area of the cable tray must be multplied by π/4 in order to obtain the equivalent cable area because the cable mass area will not be a perfect block but will have air voids due to the shape of the cable (Ref. 2 page 8 Attachment 2).

For a 1 hour fire barrier

$dof := 1$ The depth of fill in inches (reference 1, Attachment 1)

$w := 12$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 4$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 9.425$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

The allowable heat generation for an uncovered cable tray is found by multiplying the equivalent cable area by the allowable heat intensity as taken from calculation 4266-EAD-13 (Ref. 2 page 25 Attachment 2)

$HI := 6.7$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 63.146$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 215.589$

Allowable heat generation for tighly covered cable trays (Figure 2)

From tests at the Braidwood Station on the effects of Fire Stops on the ampacity Rating of Power Cables (Ref. 3 page 740, Attachment 3), there is a 15% derating in the conductor ampacity for a tightly covered tray. The allowable heat from the cable tray will be decreased by the square of the ampacity derating for each value.

$Q = I^2R$ and for the derated tray $Q' = ((1-.15)I)^2R$ where I and R are the same

$Q/Q' = I^2/(1-.15)^2 I^2$ this leads to $Q' = Q(1-.15)^2$

$QCB := (1-.15)^2 \cdot QUCB$ — Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 155.763$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

Radiation heat transfer is given by the following formula (Ref.4 pg 23 table 1.5)

$QR = \sigma\epsilon A(T1^4 - T2^4)$

Where QR is the heat dissipated by radiation
$\sigma = .1713 \cdot 10^{-8}$ is the Stephan-Boltzman constant ($Btu/hr\text{-}ft^2\text{-}R^4$) (Ref. 4)
ϵ is the surface emissivity

A is the surface area in ft^2
T1 is the surface temperature in degrees Rankine
T2 is the ambient temperature in degrees Rankine
Area of radiating surface per linear foot of tray is the perimeter for unit length (1 ft)

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ — Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 2.667$ — Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ — Stephan Boltzmann Constant in $Btu/hr\text{-}ft^2\text{-}R^4$

$\epsilon GS := .23$ — Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ — The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273) \cdot \frac{9}{5}$ — The ambient temperature in degrees Rankine

TAR = 563.4

TGS = 600 Cable tray surface temperature in degrees Rankine.

These values are presented here because the calculational program used requires the variables to be defined prior to the equation. The value of galvanized steel surface temperature, TGS is iterated in the equation below (which is further developed later) until a solution of the total heat transferred from the galvanized steel tray, QTGS converges on the allowable heat of a tightly covered tray (QCB). The terms QRGS, QCSGS, QCTGS and QCGGS are a function of TGS, as defined below.

$$QTGS(TGS) = QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$$

$$QRGS(TGS) = \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4\right]$$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

A heat balance is performed such that the allowable heat generated from the covered tray is equal to the heat lost through convection and radiation . The heat balance is a function of TGS. The net heat balance must be zero. This is peformed by using the Mathcad Root command. The convection and radiation equations are developed below.

Convection Formula(s)

Convective heat transfer is given by the following formula (Ref. 4 page 65 equation 3.8). This will be applied to the sides, top and bottom of the cable tray below.

QC=hA(T1-T2)

Where QC is the heat dissipated by convection Btu/hr
h is the convection heat transfer coefficient Btu/hr-°F-ft^2
A is the particular area under consideration in ft^2
T1 is the surface temperature in degrees R or degrees F
T2 is the ambient temperature in degrees R or degrees F
since this is a ΔT the unit of degree F and degree R do not matter

Sides (2 total)

From table 7-4 of Ref. 5 (Attachment 4) the convective heat transfer coefficient, Btu/hr-°F-ft^2 for vertical planes or cylinders is $h = .29(\Delta T/L)^{.25}$. This equation will apply to the tray sides with L equal to h_i/12 feet. Since air flow in the area is expected to be laminar the use of this equation is valid.

$$hsGS(TGS) = .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $\quad AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing upward is $h = .27(\Delta T/L)^{.25}$. This equation will apply to the top of the cable tray with L equal to $w_i/12$.

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$ATS := \frac{w}{12}$ $\quad ATS = 1$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing downward is $h = .12(\Delta T/L)^{.25}$. This equation will apply to the bottom of the cable tray with L equal to $w_i/12$ feet.

$$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $\quad AB = 1$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray by convection and radiation in Btu/hr-ft. TGS will be iterated in this equation for a solution of QTGS.

$$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$$

$TGS := root(QTGS(TGS) - QCB, TGS)$ This equation is solved by iteration in the Mathcad program until the difference is zero.

$TGS = 621.962$ This provides a solution for TGS in degrees R.

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 155.762$ $QRGS(TGS) = 51.363$ $QCSGS(TGS) = 41.22$

$QCTGS(TGS) = 43.74$ $QCBGS(TGS) = 19.44$ $QCB = 155.763$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

The resistance is equal to the temperature drop from the conductor to the cable tray surface divided by the allowable heat.

$R = \Delta T/Q$ Ref. 4 page 64 equation 3.6

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$$RCM := \frac{TCR - TGS}{QCB}$$

$RCM = 0.202$

This value represent the thermal resistance, ° F-hr-ft/Btu, from cable mass to surface of cable tray including air space in the tray.

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

The following formula will be used to calculate the thermal resistance of the Darmatt fire wrap material:

R=(1/ka)/((e1/b1+.54) + (e2/b2+.54) + (e1/b3+.54) + (e2/b4+.54))
(Ref. 6 section 502.4 pg 5 Attachment 5)

where k is the thermal conductivity of the Darmatt and e1,e2,b1,b2,b3, and b4 are constants defining the tray/wrap configuration, a = 1 ft for unit length (Ref. 2).

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

kdar := .0653 (.783 Btu-in/hr-ft^2-°F)/12 in/ft conductivity of Darmatt in Btu/hr-ft-°F Input 10

kair := .0158 conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 4$

$e2 := w$ $e2 = 12$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11} + .54\right) + \left(\frac{e2}{b21} + .54\right) + \left(\frac{e1}{b31} + .54\right) + \left(\frac{e2}{b41} + .54\right)}$$

$Rcomp1 = 0.655$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

$RTOT1 = 0.857$ in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

TWT Iterated value of the surface temperature of the wrapped cable tray. This value is iterated until the calculated rated conductor temperature of the cable mass, TCCR, equals the rated conductor temperature, TCR, in the heat transfer equations below. This iteration provides a solution for the total heat transferred from the wrapped tray, QTWT, which is then used to calculate the ampacity factor AF. The temperature of the wrapped tray, TWT, is identified early in the equation development because this calculational program requires the variables to be defined first. The variables QRWT, QCSWT, QCTWT and QCBWT are a function of TWT and are derived later in this section.

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$

$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$

Calculated rated conductor temperature, TCCR, in °R. Wrapped tray surface temperature, TWT, will be iterated until the calculated rated conductor temperature, TCCR, converges on rated conductor tempeature, TCR.

$TWT := 586$

Surface temperature of a wrapped tray °R, this is the first guess required for the Mathcad program to perform the iteration.

Radiation heat tranfer formula

The radiation heat transfer equation used in section B of this calculation is used again here

$\varepsilon A := .7$

Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4 \right]$

Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$

Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$

Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12} \right)} \right]^{.33}$$

$QCBWT(TWT) := hbWT(TWT) \cdot AB \cdot (TWT - TAR)$

Convective heat transfer from the bottom of t wrapped cabie tray in Btu/hr-ft

Total Heat Transfer — Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$

$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$	Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR
$TCR = 653.4$	Rated conductor temperature 90 °C
$TWT := root(TCCR(TWT) - TCR, TWT)$	This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.
$TCCR(TWT) = 653.4$	The calculated rated conductor temperature, TCCR, equals the rated conductor temperature, TCR, therefore a solution of TWT and QTWT is obtained.
$TWT = 584.54$	Surface temperature of the wrapped tray
$QTWT(TWT) = 80.355$	Total heat transferred

G. Ampacity Factor

The ampacity factor is equal to the square root of the ratio of the allowable heats of a wrapped cable tray to an unwrapped cable tray.

$Q = I^2R$ and $Q' = (afI)^2R$ $Q'/Q = (afI)^2R/RI^2 = (af)^2I^2/I^2$

Therefore $af = (Q'/Q)^{1/2}$

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.611$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

The ampacity derating factor is calculated from the ampacity factor AF as follows:

Ampacity derate factor = 1 - Amapcity Factor (AF)

$ADF := 1 - AF$

$ADF = 0.389$

Case 13

Calculation of Ampacity Derating For a 12" x 4" Cable Tray With 1" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

tdar3 := 2.61 Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

ttot3 := tdar3 + (x·tair) ttot3 = 2.868 Total thickness including equivalent air space

e1 := h e1 = 4 b13 := ttot3 b23 := ttot3 b33 := ttot3 b43 := ttot3

e2 := w e2 = 12 b13 = 2.868 b23 = 2.868

b33 = 2.868 b43 = 2.868

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

Rcomp3 = 1.15 Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

RTOT3 := RCM + Rcomp3

RTOT3 = 1.352 in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

TCCR3(TWT) := TWT + QTWT(TWT)·RTOT3

TCR = 653.4

TWT := root(TCCR3(TWT) - TCR, TWT)

TCCR3(TWT) = 653.4

TWT = 578.556

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

AF = 0.507 Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

ADF := 1 - AF ADF = 0.493 Ampacity derating factor

Case 2

Calculation of Cable Ampacity Derating For a 18" x 4" Cable Tray With 1" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 1$	The depth of fill in inches (reference 1, Attachment 1)	
$w := 18$	Width of cable tray in inches (reference 1, Attachment 1)	
$h := 4$	Height cable tray in inches (Ref. 1 Attachment 1)	
$Aeq := \left(\frac{\pi}{4}\right)\cdot dof\cdot w$	$Aeq = 14.137$	Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 6.7$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI\cdot(Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 94.719$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 323.383$

Allowable heat generation for tighly covered cable trays (Figure 2)

$QCB := (1-.15)^2\cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr ft

$QCB = 233.645$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right)\cdot(h+w)$	Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length
$AT = 3.667$	Total Radiating area per linear ft
$\sigma := .1713\cdot 10^{-8}$	Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 page 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273)\cdot\frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma\cdot\varepsilon GS\cdot AT\cdot\left[(TGS)^4 - TAR^4\right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29\cdot\left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$AS := 2\cdot\frac{h}{12}$ $AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS)\cdot AS\cdot(TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 1.5$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS)\cdot ATS\cdot(TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 1.5$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS)\cdot AB\cdot(TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TGS)$

$TGS = 630.623$

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 233.644$ $QRGS(TGS) = 82.919$ $QCSGS(TGS) = 48.976$

$QCTGS(TGS) = 70.441$ $QCBGS(TGS) = 31.307$ $QCB = 233.645$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu

$RCM = 0.097$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ [(.783 Btu-in/hr-ft²-°F)/12 in/ft] conductivity of Darmatt in Btu/hr ft-°F input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x\cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 4$

$e2 := w$ $e2 = 18$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

Rcomp1 = 0.489 Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

RTOT1 := RCM + Rcomp1

RTOT1 = 0.586 in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

TWT := 601 guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

εA := .7 Emissivity of the Darmatt fire wrap (Ref. 6 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12\cdot\left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCBWT(TWT) := hbWT(TWT)\cdot AB\cdot(TWT - TAR)$ Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer — Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$TCCR(TWT) := TWT + QTWT(TWT)\cdot RTOT1$ Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$ Rated conductor temperature 90 °C

$TWT := root(TCCR(TWT) - TCR, TWT)$ This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 586.123$ Surface temperature of the wrapped tray

$QTWT(TWT) = 114.757$ Total heat transferred

G. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.596$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Amapcity Factor (AF)

$ADF := 1 - AF$

$ADF = 0.404$

Case 14

Calculation of Ampacity Derating For a 18" x 4" Cable Tray With 1" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 4$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 18$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.875$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RCM + Rcomp3$

$RTOT3 = 0.973$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 579.169$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.486$ Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.514$ Ampacity derating factor

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Case 3

Calculation of Cable Ampacity Derating For a 24" x 6" Cable Tray With 1" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 1$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 6$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 18.85$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 6.7$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 126.292$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 431.178$

Allowable heat generation for tighly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 311.526$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigh and width (for top, bottom and both sides) times 1 ft unit length

$AT = 5$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 page 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273)\cdot\frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma\cdot\varepsilon GS\cdot AT\cdot\left[(TGS)^4 - TAR^4\right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29\cdot\left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$AS := 2\cdot\frac{h}{12}$ $AS = 1$ The total area of two sides of the cable tray for 1 linear foot of tray in ft²/ft.

$QCSGS(TGS) := hsGS(TGS)\cdot AS\cdot(TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS)\cdot ATS\cdot(TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft²-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS)\cdot AB\cdot(TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)

TGS := root(QTGS(TGS) - QCB, TGS)

TGS = 631.668

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

QTGS(TGS) = 311.525 QRGS(TGS) = 115.142 QCSGS(TGS) = 67.675

QCTGS(TGS) = 89.106 QCBGS(TGS) = 39.603 QCB = 311.526

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

TCC := 90 Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

TCR = 653.4

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu

RCM = 0.07

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

tdar1 := 1.25 thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

tair := .0625 thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

kdar := .0653 [(.783 Btu-in/hr-ft^2-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft- °F input 10

kair := .0158 conductivity of air at 104 F in Btu/hr-ft-°F input 9

$x := \frac{kdar}{kair}$ x = 4.133 equivalent thickness of Darmatt for 1/16" air, multiplier

ttot1 := tdar1 + (x·tair) ttot1 = 1.508 Equivalent thickness of Darmatt in inches

e1 := h e1 = 6

e2 := w e2 = 24 b11 := ttot1 b21 := ttot1 b31 := ttot1 b41 := ttot1

b11 = 1.508 b21 = 1.508 b31 = 1.508 b41 = 1.508

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$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

$Rcomp1 = 0.365$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

$RTOT1 = 0.435$ in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

$TWT := 601$ guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)} \right]^{.25}$$

$$QCBWT(TWT) := hbWT(TWT) \cdot AB \cdot (TWT - TAR)$$

Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$$

Calculated maximum temperature of the conductor ºR, the equations will be iterated until TCCR converges on TCR

$$TCR \equiv 653.4$$

Rated conductor temperature 90 ºC

$$TWT := root(TCCR(TWT) - TCR, TWT)$$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$$TCCR(TWT) = 653.4$$

$$TWT = 586.279$$

Surface temperature of the wrapped tray

$$QTWT(TWT) = 154.327$$

Total heat transferred

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

$AF = 0.598$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 − Ampacity Factor (AF)

$$ADF := 1 - AF$$

$$ADF = 0.402$$

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Case 15

Calculation of Ampacity Derating For a 24" x 6" Cable Tray With 1" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 6$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.664$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RCM + Rcomp3$

$RTOT3 = 0.733$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 579.081$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.485$ Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.515$ Ampacity derating factor

Case 4

Calculation of Cable Ampacity Derating For a 24" x 4" Cable Tray With 1" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 1$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 4$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 18.85$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 6.7$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 126.292$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 431.178$

Allowable heat generation for tighly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 311.526$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 4.667$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 page 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273) \cdot \frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{.2} \right)} \right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)

TGS := root(QTGS(TGS) − QCB, TGS)

TGS = 636.58

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

QTGS(TGS) = 311.526 QRGS(TGS) = 116.678 QCSGS(TGS) = 54.46

QCTGS(TGS) = 97.191 QCBGS(TGS) = 43.196 QCB = 311.526

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

TCC := 90 Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

TCR = 653.4

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu

RCM = 0.054

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

tdar1 := 1.25 thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

tair := .0625 thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

kdar := .0653 [(.783 Btu-in/hr-ft²-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F Input 10

kair := .0158 conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ x = 4.133 equivalent thickness of Darmatt for 1/16" air, multiplier

ttot1 := tdar1 + (x·tair) ttot1 = 1.508 Equivalent thickness of Darmatt in inches

e1 := h e1 = 4

e2 := w e2 = 24 b11 := ttot1 b21 := ttot1 b31 := ttot1 b41 := ttot1

b11 = 1.508 b21 = 1.508 b31 = 1.508 b41 = 1.508

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

$Rcomp1 = 0.39$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

$RTOT1 = 0.444$ in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

$TWT := 601$ guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{L}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)} \right]^{.25}$$

$QCBWT(TWT) := hbWT(TWT) \cdot AB \cdot (TWT - TAR)$ Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer — Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$ Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$ Rated conductor temperature 90 °C

$TWT := root(TCCR(TWT) - TCR, TWT)$ This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 587.183$ Surface temperature of the wrapped tray

$QTWT(TWT) = 149.211$ Total heat transferred

G. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.588$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Ampacity Factor (AF)

$ADF := 1 - AF$

$ADF = 0.412$

Case 16

Calculation of Ampacity Derating For a 24" x 4" Cable Tray With 1" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 4$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.706$ Thermal resistance of a 3 hour fire barrier wrapped tray in ºF-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RCM + Rcomp3$

$RTOT3 = 0.76$ in ºF-hr-ft/Btu

C. Total heat transferred from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 579.574$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$ $AF = 0.475$ Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.525$ Ampacity derating factor

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Case 5

Calculation of Cable Ampacity Derating For a 12" x 4" Cable Tray With 2" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 2$ The depth of fill in inches (reference 1, Attachment 1)

$w := 12$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 4$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 18.85$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 2.8$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 52.779$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 180.194$

Allowable heat generation for tighly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 130.19$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 2.667$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273) \cdot \frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft²/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 1$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft²-degree F

$AB := \frac{w}{12}$ $AB = 1$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

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Total Heat Transfer

QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)

TGS := root(QTGS(TGS) − QCB, TGS)

TGS = 613.921

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

QTGS(TGS) = 130.189 QRGS(TGS) = 43.389 QCSGS(TGS) = 34.271

QCTGS(TGS) = 36.367 QCBGS(TGS) = 16.163 QCB = 130.19

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

TCC := 90 Rated conductor temperature in degrees centigrade (Ref 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

TCR = 653.4

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu

RCM = 0.303

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 8)

tdar1 := 1.25 thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

tair := .0625 thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

kdar := .0653 [(.783 Btu-in/hr-ft²-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F Input 10

kair := .0158 conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ x = 4.133 equivalent thickness of Darmatt for 1/16" air, multiplier

ttot1 := tdar1 + (x·tair) ttot1 = 1.508 Equivalent thickness of Darmatt in inches

e1 := h e1 = 4

e2 := w e2 = 12 b11 := ttot1 b21 := ttot1 b31 := ttot1 b41 := ttot1

b11 = 1.508 b21 = 1.508 b31 = 1.508 b41 = 1.508

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

Rcomp1 = 0.655 Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

RTOT1 := RCM + Rcomp1

RTOT1 = 0.958 in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

TWT := 601 guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

εA := .7 Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)} \right]^{.25}$$

$$QCBWT(TWT) := hbWT(TWT) \cdot AB \cdot (TWT - TAR)$$

Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$$

Calculated maximum temperature of the conductor ºR, the equations will be iterated until TCCR converges on TCR

$$TCR := 653.4$$

Rated conductor temperature 90 ºC

$$TWT := root(TCCR(TWT) - TCR, TWT)$$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$$TCCR(TWT) = 653.401$$

$$TWT = 582.935$$

Surface temperature of the wrapped tray

$$QTWT(TWT) = 73.527$$

Total heat transferred

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

$AF = 0.639$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Ampacity Factor (AF)

$$ADF := 1 - AF$$

$$ADF = 0.361$$

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Case 17

Calculation of Ampacity Derating For a 12" x 4" Cable Tray With 2" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 4$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 12$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 1.15$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RCM + Rcomp3$

$RTOT3 = 1.453$ in °F-hr-ft/Btu

C. Total heat transferred from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 577.741$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR. for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.538$ Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.462$ Ampacity derating factor

Case 6

Calculation of Cable Ampacity Derating For a 18" x 4" Cable Tray With 2" Depth of Fill and a 1 Hour Firewrap.

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 2$ The depth of fill in inches (reference 1, Attachment 1)

$w := 18$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 4$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 28.274$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 2.8$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 79.168$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 270.291$

Allowable heat generation for tightly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 195.285$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 3.667$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273) \cdot \frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft²/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 1.5$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)} \right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft²-degree F

$AB := \frac{w}{12}$ $AB = 1.5$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)

TGS := root(QTGS(TGS) − QCB, TGS)

TGS = 621.426

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

QTGS(TGS) = 195.285 QRGS(TGS) = 69.88 QCSGS(TGS) = 40.749

QCTGS(TGS) = 58.608 QCBGS(TGS) = 26.048 QCB = 195.285

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

TCC := 90 Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

TCR = 653.4

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu.

RCM = 0.164

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

tdar1 := 1.25 thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

tair := .0625 thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

kdar := .0653 [(.783 Btu-in/hr-ft^2-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F Input 10

kair := .0158 conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ x = 4.133 equivalent thickness of Darmatt for 1/16" air, multiplier

ttot1 := tdar1 + (x·tair) ttot1 = 1.508 Equivalent thickness of Darmatt in inches

e1 := h e1 = 4

e2 := w e2 = 18 b11 := ttot1 b21 := ttot1 b31 := ttot1 b41 := ttot1

b11 = 1.508 b21 = 1.508 b31 = 1.508 b41 = 1.508

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

$Rcomp1 = 0.489$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

$RTOT1 = 0.652$ in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

$TWT := 601$ guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)} \right]^{.25}$$

$$QCBWT(TWT) := hbWT(TWT) \cdot AB \cdot (TWT - TAR)$$

Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$$

Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$$TCR = 653.4$$

Rated conductor temperature 90 °C

$$TWT := root(TCCR(TWT) - TCR, TWT)$$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$$TCCR(TWT) = 653.4$$

$$TWT = 584.5$$

Surface temperature of the wrapped tray

$$QTWT(TWT) = 105.595$$

Total heat transferred

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

$AF = 0.625$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Ampacity Factor (AF)

$$ADF := 1 - AF$$

$$ADF = 0.375$$

Case 18

Calculation of Ampacity Derating For a 18" x 4" Cable Tray With 2" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

tdar3 := 2.61 Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

ttot3 := tdar3 + (x·tair) ttot3 = 2.868 Total thickness including equivalent air space

e1 := h e1 = 4 b13 := ttot3 b23 := ttot3 b33 := ttot3 b43 := ttot3

e2 := w e2 = 18 b13 = 2.868 b23 = 2.868

b33 = 2.868 b43 = 2.868

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13}+.54\right)+\left(\frac{e2}{b23}+.54\right)+\left(\frac{e1}{b33}+.54\right)+\left(\frac{e2}{b43}+.54\right)}$$

Rcomp3 = 0.875 Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

RTOT3 := RCM + Rcomp3

RTOT3 = 1.039 in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

TCCR3(TWT) := TWT + QTWT(TWT)·RTOT3

TCR = 653.4

TWT := root(TCCR3(TWT) − TCR, TWT)

TCCR3(TWT) = 653.4

TWT = 578.398

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$ AF = 0.517 Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

ADF := 1 − AF ADF = 0.483 Ampacity derating factor

Case 7

Calculation of Cable Ampacity Derating For a 24" x 6" Cable Tray With 2" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 2$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 6$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 37.699$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 2.8$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 105.558$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 360.388$

Allowable heat generation for tightly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 260.38$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 5$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273)\cdot\frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma\cdot\varepsilon GS\cdot AT\cdot\left[(TGS)^4 - TAR^4\right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29\cdot\left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$AS := 2\cdot\frac{h}{12}$ $AS = 1$ The total area of two sides of the cable tray for 1 linear foot of tray in ft²/ft.

$QCSGS(TGS) := hsGS(TGS)\cdot AS\cdot(TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS)\cdot ATS\cdot(TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft²-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS)\cdot AB\cdot(TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

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Total Heat Transfer

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TGS)$

$TGS = 622.325$

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 260.38$ $QRGS(TGS) = 96.995$ $QCSGS(TGS) = 56.303$

$QCTGS(TGS) = 74.133$ $QCBGS(TGS) = 32.948$ $QCB = 260.38$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-h-ft/Btu

$RCM = 0.119$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 8, Att. C).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ [(.783 Btu-in/hr-ft²-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 6$

$e2 := w$ $e2 = 24$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

$Rcomp1 = 0.365$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

$RTOT1 = 0.484$ in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

$TWT := 601$ guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12\cdot\left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$$QCBWT(TWT) := hbWT(TWT)\cdot AB\cdot(TWT - TAR)$$

Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT)\cdot RTOT1$$

Calculated maximum temperature of the conductor ºR, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$

Rated conductor temperature 90 ºC

$TWT := root(TCCR(TWT) - TCR, TWT)$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 584.631$

Surface temperature of the wrapped tray

$QTWT(TWT) = 141.943$

Total heat transferred

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

$AF = 0.628$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Ampacity Factor (AF)

$ADF := 1 - AF$

$ADF = 0.372$

Case 19

Calculation of Ampacity Derating For a 24" x 6" Cable Tray With 2" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ — Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $\quad ttot3 = 2.868$ — Total thickness including equivalent air space

$e1 := h \quad e1 = 6 \qquad b13 := ttot3 \quad b23 := ttot3 \quad b33 := ttot3 \quad b43 := ttot3$

$e2 := w \quad e2 = 24 \qquad b13 = 2.868 \quad b23 = 2.868$

$b33 = 2.868 \quad b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.664$ — Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RC[illegible]1 + Rcomp3$

$RTOT3 = 0.783$ — in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 578.317$

D. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $\quad AF = 0.516$ — Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $\quad ADF = 0.484$ — Ampacity derating factor

Case 8

Calculation of Cable Ampacity Derating For a 24" x 4" Cable Tray With 2" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 2$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 4$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right)\cdot dof\cdot w$ $Aeq = 37.699$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 2.8$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI\cdot(Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 105.558$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 360.388$

Allowable heat generation for tighly covered cable trays (Figure 2)

$QCB := (1-.15)^2\cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 260.38$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right)\cdot(h+w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 4.667$ Total Radiating area per linear ft

$\sigma := .1713\cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273) \cdot \frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TGS)$

$TGS = 626.595$

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 260.38$ $QRGS(TGS) = 98.176$ $QCSGS(TGS) = 45.336$

$QCTGS(TGS) = 80.908$ $QCBGS(TGS) = 35.959$ $QCB = 260.38$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu

$RCM = 0.103$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 3 Att. 6).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ [(.783 Btu-in/hr-ft²-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F Input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 4$

$e2 := w$ $e2 = 24$

$b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

Rcomp1 = 0.39 Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

RTOT1 := RCM + Rcomp1

RTOT1 = 0.493 in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

TWT := 601 guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$$QCBWT(TWT) := hbWT(TWT) \cdot AB \cdot (TWT - TAR)$$

Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$$

Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$ — Rated conductor temperature 90 °C

$$TWT := root(TCCR(TWT) - TCR, TWT)$$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

TCCR(TWT) = [illegible]

$TWT = 585.542$ — Surface temperature of the wrapped tray

$QTWT(TWT) = 137.718$ — Total heat transferred

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

$AF = 0.618$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Ampacity Factor (AF)

$$ADF := 1 - AF$$

$$ADF = 0.382$$

Case 20

Calculation of Ampacity Derating For a 24" x 4" Cable Tray With 2" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

tdar3 := 2.61 — Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

ttot3 := tdar3 + (x·tair)   ttot3 = 2.868 — Total thickness including equivalent air space

e1 := h   e1 = 4   b13 := ttot3   b23 := ttot3   b33 := ttot3   b43 := ttot3

e2 := w   e2 = 24   b13 = 2.868   b23 = 2.868

b33 = 2.868   b43 = 2.868

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13}+.54\right)+\left(\frac{e2}{b23}+.54\right)+\left(\frac{e1}{b33}+.54\right)+\left(\frac{e2}{b43}+.54\right)}$$

Rcomp3 = 0.706 — Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

RTOT3 := RCM + Rcomp3

RTOT3 = 0.809 — in °F-hr ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

TCCR3(TWT) := TWT + QTWT(TWT)·RTOT3

TCR = 653.4

TWT := root(TCCR3(TWT) − TCR, TWT)

TCCR3(TWT) = 653.4

TWT = 578.826

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$ AF = 0.506 — Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

ADF := 1 − AF   ADF = 0.494 — Ampacity derating factor

Case 9

Calculation of Cable Ampacity Derating For a 12" x 4" Cable Tray With 3" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 3$ — The depth of fill in inches (reference 1, Attachment 1)

$w := 12$ — Width of cable tray in inches (reference 1, Attachment 1)

$h := 4$ — Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ — $Aeq = 28.274$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 1.6$ — The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ — The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 45.239$

$QUCB := \frac{QUCW}{.2929}$ — The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 154.452$

Allowable heat generation for tightly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ — Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 111.591$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ — Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 2.667$ — Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ — Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273)\cdot\frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma\cdot\varepsilon GS\cdot AT\cdot\left[(TGS)^4 - TAR^4\right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29\cdot\left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$AS := 2\cdot\frac{h}{12}$ $AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS)\cdot AS\cdot(TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 1$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS)\cdot ATS\cdot(TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 1$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS)\cdot AB\cdot(TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)

TGS := root(QTGS(TGS) − QCB, TGS)

TGS = 607.868

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

QTGS(TGS) = 111.592 QRGS(TGS) = 37.59 QCSGS(TGS) = 29.218

QCTGS(TGS) = 31.005 QCBGS(TGS) = 13.78 QCB = 111.591

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

TCC := 90 — Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ — Rated conductor temperature in degrees Rankine

TCR = 653.4

$RCM := \frac{TCR - TGS}{QCB}$ — Resistance of the cable mass in °F-hr-ft/Btu

RCM = 0.408

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

tdar1 := 1.25 — thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

tair := .0625 — thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

kdar := .0653 — [(.783 Btu-in/hr-ft²-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F Input 10

kair := .0158 — conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ x = 4.133 equivalent thickness of Darmatt for 1/16" air, multiplier

ttot1 := tdar1 + (x·tair) ttot1 = 1.508 Equivalent thickness of Darmatt in inches

e1 := h e1 = 4

e2 := w e2 = 12

b11 := ttot1 b21 := ttot1 b31 := ttot1 b41 := ttot1

b11 = 1.508 b21 = 1.508 b31 = 1.508 b41 = 1.508

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11} + .54\right) + \left(\frac{e2}{b21} + .54\right) + \left(\frac{e1}{b31} + .54\right) + \left(\frac{e2}{b41} + .54\right)}$$

$Rcomp1 = 0.655$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

$RTOT1 = 1.063$ in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

$TWT := 601$ guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12\cdot\left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$$QCBWT(TWT) := hbWT(TWT)\cdot AB\cdot(TWT - TAR)$$

Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT)\cdot RTOT1$$

Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$

Rated conductor temperature 90 °C

$$TWT := root(TCCR(TWT) - TCR, TWT)$$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 581.526$

Surface temperature of the wrapped tray

$QTWT(TWT) = 67.606$

Total heat transferred

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

$AF = 0.662$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Ampacity Factor (AF)

$$ADF := 1 - AF$$

$ADF = 0.338$

Case 21

Calculation of Ampacity Derating For a 12" x 4" Cable Tray With 3" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 4$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 12$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 1.15$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RCM + Rcomp3$

$RTOT3 = 1.558$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 576.99$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$ $AF = 0.563$ Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.437$ Ampacity derating factor

Case 10

Calculation of Cable Ampacity Derating For a 18" x 4" Cable Tray With 3" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 3$ The depth of fill in inches (reference 1, Attachment 1)

$w := 18$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 4$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 42.412$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 1.6$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 67.858$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 231.678$

Allowable heat generation for tighly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 167.387$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 3.667$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273)\cdot\frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma\cdot\varepsilon GS\cdot AT\cdot\left[(TGS)^4 - TAR^4\right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

<u>Convection Formula(s)</u>

<u>Sides (2 total)</u>

$$hsGS(TGS) := .29\cdot\left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$AS := 2\cdot\frac{h}{12}$ $AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS)\cdot AS\cdot(TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 1.5$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS)\cdot ATS\cdot(TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

<u>Bottom</u>

$$hbGS(TGS) := .12\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 1.5$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS)\cdot AB\cdot(TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)

TGS := root(QTGS(TGS) − QCB, TGS)

TGS = 614.492

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

QTGS(TGS) = 167.387   QRGS(TGS) = 60.425   QCSGS(TGS) = 34.756

QCTGS(TGS) = 49.989   QCBGS(TGS) = 22.217   QCB = 167.387

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

TCC := 90   Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

TCR = 653.4

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu

RCM = 0.232

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

tdar1 := 1.25   thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

tair := .0625   thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

kdar := .0653   [(.783 Btu-in/hr-ft²-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F Input 10

kair := .0158   conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ x = 4.133   equivalent thickness of Darmatt for 1/16" air, multiplier

ttot1 := tdar1 + (x·tair)   ttot1 = 1.508   Equivalent thickness of Darmatt in inches

e1 := h   e1 = 4

e2 := w   e2 = 18

b11 := ttot1   b21 := ttot1   b31 := ttot1   b41 := ttot1

b11 = 1.508   b21 = 1.508   b31 = 1.508   b41 = 1.508

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

Rcomp1 = 0.489 Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

RTOT1 = 0.721 in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

TWT := 601 guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment C)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)} \right]^{.25}$$

$QCBWT(TWT) := hbWT(TWT) \cdot AB \cdot (TWT - TAR)$ Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$

$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$ Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$ Rated conductor temperature 90 °C

$TWT := root(TCCR(TWT) - TCR, TWT)$ This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.401$

$TWT = 583.056$ Surface temperature of the wrapped tray

$QTWT(TWT) = 97.538$ Total heat transferred

G. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.649$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Amapcity Factor (AF)

$ADF := 1 - AF$

$ADF = 0.351$

Case 22

Calculation of Ampacity Derating For a 18" x 4" Cable Tray With 3" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 4$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 18$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.875$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RCM + Rcomp3$

$RTOT3 = 1.108$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 577.677$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.543$ Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.457$ Ampacity derating factor

Case 11

Calculation of Cable Ampacity Derating For a 24" x 6" Cable Tray With 3" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 3$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 6$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 56.549$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 1.6$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 90.478$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 308.904$

Allowable heat generation for tighly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 223.183$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 5$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273)\cdot\frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma\cdot\varepsilon GS\cdot AT\cdot\left[(TGS)^4 - TAR^4\right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29\cdot\left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$AS := 2\cdot\frac{h}{12}$ $AS = 1$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS)\cdot AS\cdot(TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS)\cdot ATS\cdot(TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS)\cdot AB\cdot(TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)

TGS := root(QTGS(TGS) − QCB, TGS)

TGS = 615.28

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

QTGS(TGS) = 223.183 QRGS(TGS) = 83.84 QCSGS(TGS) = 48.018

QCTGS(TGS) = 63.225 QCBGS(TGS) = 28.1 QCB = 223.183

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

TCC := 90 Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

TCR = 653.4

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu

RCM = 0.171

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

tdar1 := 1.25	thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).
tair := .0625	thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.
kdar := .0653	[(.783 Btu-in/hr-ft^2-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F input 10
kair := .0158	conductivity of air at 104 F in Btu/hr-ft-°F input 9

$x := \frac{kdar}{kair}$ x = 4.133 equivalent thickness of Darmatt for 1/16" air, multiplier

ttot1 := tdar1 + (x·tair) ttot1 = 1.508 Equivalent thickness of Darmatt in inches

e1 := h e1 = 6

e2 := w e2 = 24 b11 := ttot1 b21 := ttot1 b31 := ttot1 b41 := ttot1

b11 = 1.508 b21 = 1.508 b31 = 1.508 b41 = 1.508

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

$Rcomp1 = 0.365$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

$RTOT1 = 0.536$ in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

$TWT := 601$ guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

Bottom of Wrapped Tray

$$hbWT(TWT) := .12\cdot\left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$$QCBWT(TWT) := hbWT(TWT)\cdot AB\cdot(TWT - TAR)$$

Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT)\cdot RTOT1$$

Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$$TCR = 653.4$$

Rated conductor temperature 90 °C

$$TWT := root(TCCR(TWT) - TCR, TWT)$$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$$TCCR(TWT) = 653.4$$

$$TWT = 583.166$$

Surface temperature of the wrapped tray

$$QTWT(TWT) = 131.048$$

Total heat transferred

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

$AF = 0.651$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Amapcity Factor (AF)

$$ADF := 1 - AF$$

$$ADF = 0.349$$

Case 23

Calculation of Ampacity Derating For a 24" x 6" Cable Tray With 3" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 6$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.664$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RCM + Rcomp3$

$RTOT3 = 0.834$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 577.602$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.542$ Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.458$ Ampacity derating factor

Case 12

Calculation of Cable Ampacity Derating For a 24" x 4" Cable Tray With 3" Depth of Fill and a 1 Hour Firewrap

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 3$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 4$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 56.549$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 1.6$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 90.478$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 308.904$

Allowable heat generation for tightly covered cable trays (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 223.183$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the height and width (for top, bottom and both sides) times 1 ft unit length

$AT = 4.667$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273)\cdot\frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 610$ Guess Cable tray surface temperature in degrees Rankine.

$QRGS(TGS) := \sigma\cdot\varepsilon GS\cdot AT\cdot\left[(TGS)^4 - TAR^4\right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29\cdot\left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$AS := 2\cdot\frac{h}{12}$ $AS = 0.667$ The total area of two sides of the cable tray for 1 linear foot of tray in ft²/ft.

$QCSGS(TGS) := hsGS(TGS)\cdot AS\cdot(TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

Top

$$htGS(TGS) := .27\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS)\cdot ATS\cdot(TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

Bottom

$$hbGS(TGS) := .12\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft²-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS)\cdot AB\cdot(TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)

TGS := root(QTGS(TGS) − QCB, TGS)

TGS = 619.06

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

QTGS(TGS) = 223.183 QRGS(TGS) = 84.785 QCSGS(TGS) = 38.682

QCTGS(TGS) = 69.034 QCBGS(TGS) = 30.682 QCB = 223.183

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

TCC := 90 Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273)\cdot\frac{9}{5}$ Rated conductor temperature in degrees Rankine

TCR = 653.4

$RCM := \frac{TCR - TGS}{QCB}$ Resistance of the cable mass in °F-hr-ft/Btu

RCM = 0.154

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

tdar1 := 1.25 thickness of Darmatt in inches for a 1 hour barrier (Ref. 3 Att. 6).

tair := .0625 thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

kdar := .0653 [(.783 Btu-in/hr ft^2-°F)/12 in/ft] conductivity of Darmatt in Btu/hr-ft-°F Input 10

kair := .0158 conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ x = 4.133 equivalent thickness of Darmatt for 1/16" air, multiplier

ttot1 := tdar1 + (x·tair) ttot1 = 1.508 Equivalent thickness of Darmatt in inches

e1 := h e1 = 4

e2 := w e2 = 24 b11 := ttot1 b21 := ttot1 b31 := ttot1 b41 := ttot1

b11 = 1.508 b21 = 1.508 b31 = 1.508 b41 = 1.508

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11}+.54\right)+\left(\frac{e2}{b21}+.54\right)+\left(\frac{e1}{b31}+.54\right)+\left(\frac{e2}{b41}+.54\right)}$$

$Rcomp1 = 0.39$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap

$RTOT1 := RCM + Rcomp1$

$RTOT1 = 0.544$ in °F-hr-ft/Btu

F. Calculation of total heat transfer due to radiation and convection

Total heat transfered from the wrapped cable tray

$TWT := 601$ guess Surface temperature of a wrapped tray °R

First guess in the iteration of the total heat transferred equations listed below.

Radiation heat tranfer formula

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AT \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr-ft.

Convective Heat Transfer

Sides of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AS \cdot ((TWT) - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

Top of Wrapped Tray

$$htWT(TWT) := .27 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$QCTWT(TWT) := htWT(TWT) \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

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Bottom of Wrapped Tray

$$hbWT(TWT) := .12 \cdot \left[\frac{TWT - TAR}{\left(\frac{w}{12}\right)} \right]^{.25}$$

$$QCBWT(TWT) := hbWT(TWT) \cdot AB \cdot (TWT - TAR)$$

Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT) + QCTWT(TWT) + QCBWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$$

Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$

Rated conductor temperature 90 °C

$TWT := root(TCCR(TWT) - TCR, TWT)$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 584.07$

Surface temperature of the wrapped tray

$QTWT(TWT) = 127.526$

Total heat transferred

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$$

$AF = 0.643$ Ampacity factor for Darmatt firewrap material

H. Ampacity Derating Factor

Ampacity derate factor = 1 - Ampacity Factor (AF)

$ADF := 1 - AF$

$ADF = 0.357$

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Case 24

Calculation of Ampacity Derating For a 24" x 4" Cable Tray With 3" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 4$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.706$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap

$RTOT3 := RCM + Rcomp3$

$RTOT3 = 0.86$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped cable tray with a 3 hour fire barrier

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 578.121$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology will be used as was used on the 1 hour barrier solution.

D. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB}}$ $AF = 0.532$ Ampacity factor for Darmatt firewrap material

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.468$ Ampacity derating factor

4.6.2 Calculation of Ampacity Derating for Vertical Cable Trays

The methodology used for calculating the ampacity derating for horizontal cable trays will be used to calculate the ampacity derating for vertical cable trays with the following exceptions. The resistance and heat transfer rates will be calculated for two vertical lengths and not per linear foot. The resistance from the horizontal trays will be used see assumption 6 and the heat transfer coefficients changed to reflect the new configuration. The equations will be developed and described in detail for the first case, (case 25) with the remaining cases only showing the inputs, equations and outputs. Per Reference 1 the depth of vertical trays is 12". The three hour cases follow the 1 hour case but maintain the case number from Rev. 0 for consistency and therefore are not in numerical order.

Case 25

Calculation of Cable Ampacity Derating For a 12" x 24" Vertical Cable Tray With 1" Depth of Fill and a 1 Hour Firewrap

The calculation of the equivalent thermal resistance of the cable mass, RCM, will be calculated for a 12" x 24" horizontal tray. This resistance will then be used to caculate the total equivalent thermal resistance of vertical cable tray of length L.

$L := 30$ Length of vertical cable tray in ft

A. Allowable heat generation calculation

Equivalent Cable Area

The cross sectional area of the cable tray is equal to the depth of fill times the tray width. The cross sectional area of the cable tray must be multplied by π/4 in order to obtain the equivalent cable area because the cable mass area will not be a perfect block but will have air voids due to the shape of the cable (Ref. 2 page 8 Attachment 2).

For a 1 hour fire barrier

$dof := 1$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 12$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 18.85$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

The allowable heat generation for an uncovered cable tray is found by multiplying the equivalent cable area by the allowable heat intensity as taken from calculation 4266-EAD-13 (Ref. 2 page 25 Attachment 2)

$HI := 6.7$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 126.292$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 431.178$

Allowable heat generation for tighly covered cable trays (Figure 2)

From tests at the Braidwood Station on the effects of Fire Stops on the ampacity Rating of Power Cables (Ref. 3 page 740, Attachment 3), there is a 15% derating in the conductor ampacity for a tightly covered tray. The allowable heat from the cable tray will be decreased by the square of the ampacity derating for each value.

$Q = I^2R$ and for the derated tray $Q' = ((1-.15)I)^2R$ where I and R are the same

$Q/Q' = I^2/(1-.15)^2 I^2$ this leads to $Q' = Q(1-.15)^2$

$QCB := (1-.15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 311.526$

B. Temperature of the outside of a cable tray with tight covers

To be used for determination of the cable mass resistance only, orientation does not affect the thermal resistance of the cable mass see assumption 6.

Radiation Formula

Radiation heat transfer is given by the following formula (Ref.4 pg 23 table 1.5)

$QR = \sigma \varepsilon A(T1^4 - T2^4)$

Where QR is the heat dissipated by radiation

$\sigma = .1713 \cdot 10^{-8}$ is the Stephan-Boltzman constant (Btu/hr-ft^2-R^4) (Ref. 4)

ε is the surface emissivity

A is the surface area in ft^2

T1 is the surface temperature in degrees Rankine

T2 is the ambient temperature in degrees Rankine

Area of radiating surface per linear foot of tray is the perimeter for unit length (1 ft)

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 6$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAC := 40$ The ambient temperature in degrees C (Ref. 1)

$TAR := (TAC + 273)\cdot\frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$

$TGS := 600$ Cable tray surface temperature in degrees Rankine.
The value is presented here because the calculational program used requires the variables to be defined prior to the equation. The value of galvanized steel surface temperature, TGS is iterated in the equation below (which is further developed later) until a solution of the total heat transferred from the galvanized steel tray, QTGS converges on the allowable heat of a tightly covered tray (QCB). The terms QRGS, QCSGS, QCTGS and QCGGS are a function of TGS, as defined below.

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$QRGS(TGS) := \sigma\cdot\varepsilon GS\cdot AT\cdot\left[(TGS)^4 - TAR^4\right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

The methodology used in the Mathcad software application is to show the equations as a function of TGS. Then the total heat transferred from the galvanized surface (cable tray), QTGS, has the allowable heat of a covered tray, QCB, subtracted and set equal to 0. Mathcad then iterates until a solution for TGS is reached.

<u>Convection Formula(s)</u>

Convective heat transfer is given by the following formula (Ref. 4 page 65 equation 3.8). This will be applied to the sides, top and bottom of the cable tray below.

QC=hA(T1-T2)

Where QC is the heat dissipated by convection Btu/hr
h is the convection heat transfer coefficient Btu/hr-°F-ft^2
A is the particular area under consideration in ft^2
T1 is the surface temperature in degrees R or degrees F
T2 is the ambient temperature in degrees R or degrees F
since this is a ΔT the unit of degree F and degree R do not matter

<u>Sides (2 total)</u>

From table 7-4 of Ref. 5 (Attachment 4) the convective heat transfer coefficient, Btu/hr-°F-ft^2 for vertical planes or cylinders is $h=.29(\Delta T/L)^{.25}$. This equation will apply to the tray sides with L equal to h_i/12 feet. Since air flow in the area is expected to be laminar the use of this equation is valid.

$$hsGS(TGS) := .29\cdot\left[\frac{TGS - TAR}{\left(\frac{h}{12}\right)}\right]^{.25}$$

$$AS := 2\cdot\frac{h}{12} \qquad AS = 2$$

The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$$QCSGS(TGS) := hsGS(TGS)\cdot AS\cdot(TGS - TAR)$$

Convective heat transfer from the sides of the cable tray in Btu/hr-ft-

Top

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing upward is $h=.27(\Delta T/L)^{.25}$. This equation will apply to the top of the cable tray with L equal to $w_i/12$.

$$htGS(TGS) := .27\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

$$ATS := \frac{w}{12} \qquad ATS = 2$$

Area of the top of cable tray in square ft/ft

$$QCTGS(TGS) := htGS(TGS)\cdot ATS\cdot(TGS - TAR)$$

Bottom

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing downward is $h=.12(\Delta T/L)^{.25}$. This equation will apply to the bottom of the cable tray with L equal to $w_i/12$ feet.

$$hbGS(TGS) := .12\cdot\left[\frac{TGS - TAR}{\left(\frac{w}{12}\right)}\right]^{.25}$$

Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$$AB := \frac{w}{12} \qquad AB = 2$$

Area of bottom of the cable tray in square ft/ft

$$QCBGS(TGS) := hbGS(TGS)\cdot AB\cdot(TGS - TAR)$$

Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

Total heat transfer from the unwrapped cable tray by convection and radiation in Btu/hr-ft. TGS will be iterated in this equation for a solution of QTGS.

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TGS)$

$TGS = 621.311$

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 311.526$ $QRGS(TGS) = 114.088$ $QCSGS(TGS) = 92.657$

$QCTGS(TGS) = 72.541$ $QCBGS(TGS) = 32.241$ $QCB = 311.526$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

The resistance is equal to the temperature drop from the conductor to the cable tray surface divided by the allowable heat.

$R = \Delta T/Q$ Ref. 4 page 64 equation 3.6

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ This value represent the thermal resistance, ° F-hr-ft/Btu, from cable mass to surface of cable tray including air space and tray for a horizontal tray. This resistance will be appied to a vertical tray (assumption 1) of length L.

$RCM = 0.103$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

The following formula will be used to calculate the thermal resistance of the Darmatt fire wrap material:

R=(1/ka)/((e1/b1+.54) + (e2/b2+.54) + (e1/b3+.54) + (e2/b4+.54))
(Ref. 6 section 502.4 pg 5 Attachment 5)

where k is the thermal conductivity of the Darmatt and e1,e2,b1,b2,b3, and b4 are constants defining the tray/wrap configuration, a = 1 ft for unit length (Ref. 2).

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ (.783 Btu-in/hr-ft^2-°F)/12 in/ft conductivity of Darmatt in Btu/hr-ft-°F Input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 12$

$e2 := w$ $e2 = 24$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11} + .54\right) + \left(\frac{e2}{b21} + .54\right) + \left(\frac{e1}{b31} + .54\right) + \left(\frac{e2}{b41} + .54\right)}$$

$Rcomp1 = 0.307$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap for a tray of length L

$$RTOT1 := \frac{RCM + Rcomp1}{L}$$ in °F-hr/Btu

$RTOT1 = 0.014$

F. Calculation of total heat transfer due to radiation and convection of a vertical cable tray of length L

Total heat transfered from the wrapped cable tray

TWT Iterated value of the surface temperature of the wrapped cable tray. This value is iterated until the calculated rated conductor temperature of the cable mass, TCCR, equals the rated conductor temperature, TCR, in the total heat transferred equations below. This iteration provides a solution for the total heat transferred from the wrapped tray, QTWT, which is then used to calculate the ampacity factor AF. The temperature of the wrapped tray, TWT, is identified early in the equation development because this calculational program requires the variables to be defined first. The variables QRWT and QCSWT, are a function of TWT and are derived later in this section.

Total heat transfer from the wrapped cable tray in Btu/hr

$QTWT(TWT) := (QRWT(TWT) + QCSWT(TWT))$

$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$

Calculated rated conductor temperature, TCCR, in °R. Wrapped tray surface temperature, TWT, will be iterated until the calculated rated conductor temperature, TCCR, converges on rated conductor tempeature, TCR.

$TWT := 586$ guess Surface temperature of a wrapped tray °R

Radiation heat tranfer formula

The radiation heat transfer equation used in section B of this calculation is used again here

$AR := 2 \cdot \frac{w + h}{12} \cdot L$ The radiating area of the wrapped vertical cable tray of length L in square ft

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 5 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AR \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr.

Convective Heat Transfer

Vertical Surfaces of Wrapped Tray

Because the contribution to heat transfer from the top and bottom (horizontal surfaces) of a vertical cable tray is negligible they will not be calculated, only the vertical surfaces will be calculated.

The heat transfer coefficient of vertical planes from Table 7-4 of Ref. 5 (Attachment 4), modified for this problem, is again:

$$hsWT(TWT) := .29 \cdot \left(\frac{TWT - TAR}{L}\right)^{.25}$$

The area of convective heat transfer is the same as for radiation so AR can be used to calculate the heat transfer due to convection

$QCSWT(TWT) := hsWT(TWT) \cdot AR \cdot ((TWT) - TAR)$ Convective heat transfer from the vertical surf[aces of] the wrapped vertical cable tray in Btu/hr

Total Heat Transfer

Total heat transfer from the wrapped vertical cable tray of length L in Btu/hr

$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT)$

$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$ — Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$ — Rated conductor temperature 90 °C

$TWT := root(TCCR(TWT) - TCR, TWT)$ — This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.399$ — The calculated rated conductor temperature, TCCR, equals the rated conductor temperature, TCR, therefore a solution of TWT and QTWT is obtained.

$TWT = 586.417$ — Surface temperature of the wrapped tray

$QTWT(TWT) = 4.902 \cdot 10^3$ — Total heat transferred in Btu/hr

G. Ampacity Factor

The ampacity factor is equal to the square root of the ratio of the allowable heats of a wrapped cable tray to an unwrapped cable tray.

$Q = I^2R$ and $Q' = (afI)^2R$ $Q'/Q = (afI)^2R/RI^2 = (af)^2I^2/I^2$

Therefore $af = (Q'/Q)^{1/2}$

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}} \qquad AF = 0.616$$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because it was calculated in section A per unit length

H. Ampacity Derating Factor

The ampacity derating factor is calculated from the ampacity factor AF as follows:

Ampacity derate factor = 1 - Amapcity Factor (AF)

$ADF := 1 - AF$

$ADF = 0.384$

Case 31 $L = 30$

Calculation of Ampacity Derating For a 12" x 24" Vertical Cable Tray of Length L With 1" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 12$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.562$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap for a cable tray of length L

$$RTOT3 := \frac{RCM + Rcomp3}{L}$$

RCM is obtained from the section for the 1hour case

$RTOT3 = 0.022$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped vertical cable tray with a 3 hour fire barrier and length L

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 579.58$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology and equations will be used as was used on the 1 hour barrier solution only RTOT3 changes.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}}$$ $AF = 0.507$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because QUCB is per unit length.

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.493$ Ampacity derating factor

Case 26

Calculation of Cable Ampacity Derating For a 12" x 24" Vertical Cable Tray With 1" Depth of Fill and a 1 Hour Firewrap

The calculation of the equivalent thermal resistance of the cable mass, RCM, will be calculated for a 12" x 24" horizontal tray. This resistance will then be used to caculate the total equivalent thermal resistance of vertical cable tray of length L.

$L := 19$ Length of vertical cable tray in ft

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 1$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 12$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 18.85$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 6.7$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 126.292$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 431.178$

Allowable heat generation for a tightly covered cable tray (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 311.526$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 6$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAR := 563.4$ The ambient temperature in degrees Rankine

$TGS := 600$ The value of galvanized steel surface temperature, TGS.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 2$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft-

Top

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing upward is $h = .27(\Delta T/L)^{.25}$. This equation will apply to the top of the cable tray with L equal to $w_i/12$.

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$

Bottom

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing downward is $h = .12(\Delta T/L)^{.25}$. This equation will apply to the bottom of the cable tray with L equal to $w_i/12$ feet.

$$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TGS)$

$TGS = 621.311$

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 311.526$ $QRGS(TGS) = 114.088$ $QCSGS(TGS) = 92.657$

$QCTGS(TGS) = 72.541$ $QCBGS(TGS) = 32.241$ $QCB = 311.526$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ This value represent the thermal resistance, ° F-hr-ft/Btu, from cable mass to surface of cable tray including air space and tray for a horizontal tray. This resistance will be applied to a vertical tray (assumption 1) of length L.

$RCM = 0.103$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ (.783 Btu-in/hr-ft^2-°F)/12 in/ft conductivity of Darmatt in Btu/hr-ft- °F input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 12$

$e2 := w$ $e2 = 24$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11} + .54\right) + \left(\frac{e2}{b21} + .54\right) + \left(\frac{e1}{b31} + .54\right) + \left(\frac{e2}{b41} + .54\right)}$$

$Rcomp1 = 0.307$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap for a tray of length L

$RTOT1 := \frac{RCM + Rcomp1}{L}$ $RTOT1 = 0.022$ in °F-hr/Btu

F. Calculation of total heat transfer due to radiation and convection of a vertical cable tray of length L

Total heat transfered from the wrapped cable tray

TWT Iterated value of the surface temperature of the wrapped cable tray. This value is iterated until the calculated rated conductor temperature of the cable mass, TCCR, equals the rated conductor temperature, TCR.

$TWT := 586$ guess Surface temperature of a wrapped tray °R

Radiation heat transfer formula

The radiation heat transfer equation used in section B of this calculation is used again here

$AR := 2 \cdot \frac{w + h}{12} \cdot L$ The radiating area of the wrapped vertical cable tray of length L in square ft

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRW1(TWT) := \sigma \cdot \varepsilon A \cdot AR \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr.

Convective Heat Transfer

Vertical Surfaces of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left(\frac{TWT - TAR}{L}\right)^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AR \cdot ((TWT) - TAR)$ Convective heat transfer from the vertical surfa[ces of] the wrapped vertical cable tray in Btu/hr

Total Heat Transfer

$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT)$

$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$ Calculated maximum temperature of the conductor ºR, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$ Rated conductor temperature 90 ºC

$TWT := root(TCCR(TWT) - TCR, TWT)$ This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 585.986$ Surface temperature of the wrapped tray

$QTWT(TWT) = 3.125 \cdot 10^3$ Total heat transferred in Btu/hr

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}} \qquad AF = 0.618$$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because it was calculated in section A per unit length

H. Ampacity Derating Factor

$ADF := 1 - AF \qquad ADF = 0.382$

Case 32 $L = 19$

Calculation of Ampacity Derating For a 12" x 24" Vertical Cable Tray of Length L With 1" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 12$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.562$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap for a cable tray of length L

$$RTOT3 := \frac{RCM + Rcomp3}{L}$$

RCM is obtained from the section for the 1 hour case

$RTOT3 = 0.035$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped vertical cable tray with a 3 hour fire barrier and length L

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 579.262$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology and equations will be used as was used on the 1 hour barrier solution only RTOT3 changes.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}}$$

AF = 0 [illegible]

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because QUCB is per unit length.

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.491$ Ampacity derating factor

Case 27

Calculation of Cable Ampacity Derating For a 12" x 24" Vertical Cable Tray With 2" Depth of Fill and a 1 Hour Firewrap

The calculation of the equivalent thermal resistance of the cable mass, RCM, will be calculated for a 12" x 24" horizontal tray. This resistance will then be used to caculate the total equivalent thermal resistance of vertical cable tray of length L.

$L := 30$ Length of vertical cable tray in ft

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 2$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 12$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 37.699$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 2.8$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 105.558$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 360.388$

Allowable heat generation for a tightly covered cable tray (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 260.38$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 6$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAR := 563.4$ The ambient temperature in degrees Rankine

$TGS := 600$ The value of galvanized steel surface temperature, TGS.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 2$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft-

Top

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing upward is h=.27(ΔT/L)$^{.25}$. This equation will apply to the top of the cable tray with L equal to w_i/12.

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$

Bottom

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing downward is h=.12(ΔT/L)$^{.25}$. This equation will apply to the bottom of the cable tray with L equal to w_i/12 feet.

$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

<u>Total Heat Transfer</u>

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TG)$

$TGS = 613.332$

<u>Results of the convective, radiation and total heat transferred</u>

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 260.38$ $QRGS(TGS) = 96.338$ $QCSGS(TGS) = 76.984$

$QCTGS(TGS) = 60.271$ $QCBGS(TGS) = 26.787$ $QCB = 260.38$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ This value represent the thermal resistance, ° F-hr-ft/Btu, from cable mass to surface of cable tray including air space and tray for a horizontal tray. This resistance will be applied to a vertical tray (assumption 1) of length L.

$RCM = 0.154$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ (.783 Btu-in/hr-ft^2-°F)/12 in/ft conductivity of Darmatt in Btu/hr-ft- °F Input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 12$

$e2 := w$ $e2 = 24$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11} + .54\right) + \left(\frac{e2}{b21} + .54\right) + \left(\frac{e1}{b31} + .54\right) + \left(\frac{e2}{b41} + .54\right)}$$

$Rcomp1 = 0.307$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap for a tray of length L

$RTOT1 := \frac{RCM + Rcomp1}{L}$ $RTOT1 = 0.015$ in °F-hr/Btu

F. Calculation of total heat transfer due to radiation and convection of a vertical cable tray of length L

Total heat transfered from the wrapped cable tray

TWT Iterated value of the surface temperature of the wrapped cable tray. This value is iterated until the calculated rated conductor temperature of the cable mass, TCCR, equals the rated conductor temperature, TCR.

$TWT := 586$ guess Surface temperature of a wrapped tray °R

Radiation heat transfer formula

The radiation heat transfer equation used in section B of this calculation is used again here

$AR := 2 \cdot \frac{w + h}{12} \cdot L$ The radiating area of the wrapped vertical cable tray of length L in square ft

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AR \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr.

<u>Convective Heat Transfer</u>

<u>Vertical Surfaces of Wrapped Tray</u>

$$hsWT(TWT) := .29 \cdot \left(\frac{TWT - TAR}{L}\right)^{.25}$$

$$QCSWT(TWT) := hsWT(TWT) \cdot AR \cdot ((TWT) - TAR)$$

Convective heat transfer from the vertical surfaces of the wrapped vertical cable tray in Btu/hr

<u>Total Heat Transfer</u>

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$$

Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$$TCR = 653.4$$

Rated conductor temperature 90 °C

$$TWT := root(TCCR(TWT) - TCR, TWT)$$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$$TCCR(TWT) = 653.4$$

$$TWT = 584.606$$

Surface temperature of the wrapped tray

$$QTWT(TWT) = 4.479 \cdot 10^3$$

Total heat transferred in Btu/hr

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}} \qquad AF = 0.644$$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because it was calculated in section A per unit length

H. Ampacity Derating Factor

$$ADF := 1 - AF \qquad ADF = 0.356$$

Case 33 $L = 30$

Calculation of Ampacity Derating For a 12" x 24" Vertical Cable Tray of Length L With 2" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 12$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.562$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap for a cable tray of length L

$$RTOT3 := \frac{RCM + Rcomp3}{L}$$

RCM is obtained from the section for the 1hour case

$RTOT3 = 0.024$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped vertical cable tray with a 3 hour fire barrier and length L

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 578.686$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology and equations will be used as was used on the 1 hour barrier solution only RTOT3 changes.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}}$$ $AF = 0.538$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because QUCB is per unit length.

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.462$ Ampacity derating factor

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Case 28

Calculation of Cable Ampacity Derating For a 12" x 24" Vertical Cable Tray With 2" Depth of Fill and a 1 Hour Firewrap

The calculation of the equivalent thermal resistance of the cable mass, RCM, will be calculated for a 12" x 24" horizontal tray. This resistance will then be used to caculate the total equivalent thermal resistance of vertical cable tray of length L.

$L := 19$ Length of vertical cable tray in ft

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 2$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 12$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 37.699$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 2.8$ The allowable heat intensity in watts/ft-in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 105.558$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 360.388$

Allowable heat generation for a tightly covered cable tray (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 260.38$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 6$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAR := 563.4$ The ambient temperature in degrees Rankine

$TGS := 600$ The value of galvanized steel surface temperature, TGS.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 2$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft-

Top

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing upward is h=.27(ΔT/L)$^{.25}$. This equation will apply to the top of the cable tray with L equal to w_i/12.

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$

Bottom

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing downward is h=.12(ΔT/L)$^{.25}$. This equation will apply to the bottom of the cable tray with L equal to w_i/12 feet.

$$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TGS)$

$TGS = 613.332$

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 260.38$ $QRGS(TGS) = 96.338$ $QCSGS(TGS) = 76.984$

$QCTGS(TGS) = 60.271$ $QCBGS(TGS) = 26.787$ $QCB = 260.38$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ This value represent the thermal resistance, ° F-hr-ft/Btu, from cable mass to surface of cable tray including air space and tray for a horizontal tray. This resistance will be appied to a vertical tray (assumption 1) of length L.

$RCM = 0.154$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

$tair := .0525$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ (.783 Btu-in/hr-ft^2-°F)/12 in/ft conductivity of Darmatt in Btu/hr-ft-°F Input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 12$

$e2 := w$ $e2 = 24$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11} + .54\right) + \left(\frac{e2}{b21} + .54\right) + \left(\frac{e1}{b31} + .54\right) + \left(\frac{e2}{b41} + .54\right)}$$

$Rcomp1 = 0.307$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap for a tray of length L

$RTOT1 := \frac{RCM + Rcomp1}{L}$ $RTOT1 = 0.024$ in °F-hr/Btu

F. Calculation of total heat transfer due to radiation and convection of a vertical cable tray of length L

Total heat transferred from the wrapped cable tray.

TWT Iterated value of the surface temperature of the wrapped cable tray. This value is iterated until the calculated rated conductor temperature of the cable mass, TCCR, equals the rated conductor temperature, TCR.

$TWT := 586$ guess Surface temperature of a wrapped tray °R

Radiation heat transfer formula

The radiation heat transfer equation used in section B of this calculation is used again here

$AR := 2 \cdot \frac{w + h}{12} \cdot L$ The radiating area of the wrapped vertical cable tray of length L in square ft

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AR \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr.

Convective Heat Transfer

Vertical Surfaces of Wrapped Tray

$$hsWT(TWT) := .29 \cdot \left(\frac{TWT - TAR}{L}\right)^{.25}$$

$QCSWT(TWT) := hsWT(TWT) \cdot AR \cdot ((TWT) - TAR)$ — Convective heat transfer from the vertical surfaces of the wrapped vertical cable tray in Btu/hr

Total Heat Transfer

$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT)$

$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$ — Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$ — Rated conductor temperature 90 °C

$TWT := root(TCCR(TWT) - TCR, TWT)$ — This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 584.203$ — Surface temperature of the wrapped tray

$QTWT(TWT) = 2.853 \cdot 10^{3}$ — Total heat transferred in Btu/hr

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}} \qquad AF = 0.646$$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because it was calculated in section A per unit length

H. Ampacity Derating Factor

$ADF := 1 - AF \qquad ADF = 0.354$

Case 34 $L = 19$

Calculation of Ampacity Derating For a 12" x 24" Vertical Cable Tray of Length L With 2" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 12$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.562$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap for a cable tray of length L

$$RTOT3 := \frac{RCM + Rcomp3}{L}$$

RCM is obtained from th section for the 1hour case

$RTOT3 = 0.038$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped vertical cable tray with a 3 hour fire barrier and length L

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 578.385$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology and equations will be used as was used on the 1 hour barrier solution only RTOT3 changes.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}}$$ $AF = 0.539$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because QUCB is per unit length.

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.461$ Ampacity derating factor

Case 29

Calculation of Cable Ampacity Derating For a 12" x 24" Vertical Cable Tray With 3" Depth of Fill and a 1 Hour Firewrap

The calculation of the equivalent thermal resistance of the cable mass, RCM, will be calculated for a 12" x 24" horizontal tray. This resistance will then be used to caculate the total equivalent thermal resistance of vertical cable tray of length L.

$L := 30$ Length of vertical cable tray in ft

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 3$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 12$ Height cable tray in inches (Ref. 1 Attachment 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 56.549$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 1.6$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 90.478$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 308.904$

Allowable heat generation for a tightly covered cable tray (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 223.183$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 6$ Total Radiating area per linear ft

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$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAR := 563.4$ The ambient temperature in degrees Rankine

$TGS := 600$ The value of galvanized steel surface temperature, TGS.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 2$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft-

Top

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing upward is h=.27(ΔT/L)$^{.25}$. This equation will apply to the top of the cable tray with L equal to w_i/12.

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$

Bottom

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing downward is h=.12(ΔT/L)$^{.25}$. This equation will apply to the bottom of the cable tray with L equal to w_i/12 feet.

$$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TGS)$

$TGS = 607.325$

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 223.183$ $QRGS(TGS) = 83.425$ $QCSGS(TGS) = 65.587$

$QCTGS(TGS) = 51.349$ $QCBGS(TGS) = 22.822$ $QCB = 223.183$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ This value represent the thermal resistance, ° F-hr-ft/Btu, from cable mass to surface of cable tray including air space and tray for a horizontal tray. This resistance will be applied to a vertical tray (assumption 1) of length L.

$RCM = 0.206$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 3 Att. 6).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ (.783 Btu-in/hr-ft^2-°F)/12 in/ft conductivity of Darmatt in Btu/hr-ft-°F Input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 12$

$e2 := w$ $e2 = 24$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11} + .54\right) + \left(\frac{e2}{b21} + .54\right) + \left(\frac{e1}{b31} + .54\right) + \left(\frac{e2}{b41} + .54\right)}$$

$Rcomp1 = 0.307$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap for a tray of length L

$RTOT1 := \frac{RCM + Rcomp1}{L}$ $RTOT1 = 0.017$ in °F-hr/Btu

F. Calculation of total heat transfer due to radiation and convection of a vertical cable tray of length L

Total heat transfered from the wrapped cable tray

TWT — Iterated value of the surface temperature of the wrapped cable tray. This value is iterated until the calculated rated conductor temperature of the cable mass, TCCR, equals the rated conductor temperature, TCR.

$TWT := 586$ guess — Surface temperature of a wrapped tray °R

Radiation heat transfer formula

The radiation heat transfer equation used in section B of this calculation is used again here

$AR := 2 \cdot \frac{w + h}{12} \cdot L$ The radiating area of the wrapped vertical cable tray of length L in square ft

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 8 Attachment 6)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AR \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr.

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Convective Heat Transfer

Vertical Surfaces of Wrapped Tray

$$hsWT(TWT) := .29\cdot\left(\frac{TWT - TAR}{L}\right)^{.25}$$

$$QCSWT(TWT) := hsWT(TWT)\cdot AR\cdot((TWT) - TAR)$$

Convective heat transfer from the vertical surfaces of the wrapped vertical cable tray in Btu/hr

Total Heat Transfer

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT)\cdot RTOT1$$

Calculated maximum temperature of the conductor ºR, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$ — Rated conductor temperature 90 ºC

$TWT := root(TCCR(TWT) - TCR, TWT)$ — This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 583.022$ — Surface temperature of the wrapped tray

$QTWT(TWT) = 4.113\cdot 10^{3}$ — Total heat transferred in Btu/hr

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB\cdot L}} \qquad AF = 0.666$$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because it was calculated in section A per unit length

H. Ampacity Derating Factor

$ADF := 1 - AF \qquad ADF = 0.334$

Case 35 $L = 30$

Calculation of Ampacity Derating For a 12" x 24" Vertical Cable Tray of Length L With 3" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 12$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.562$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap for a cable tray of length L

$$RTOT3 := \frac{RCM + Rcomp3}{L}$$

RCM is obtained from the section for the 1hour case

$RTOT3 = 0.026$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped vertical cable tray with a 3 hour fire barrier and length L

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 577.864$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology and equations will be used as was used on the 1 hour barrier solution only RTOT3 changes.

D. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}}$$ $AF = 0.564$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because QUCB is per unit length.

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.436$ Ampacity derating factor

Case 30

Calculation of Cable Ampacity Derating For a 12" x 24" Vertical Cable Tray With 3" Depth of Fill and a 1 Hour Firewrap

The calculation of the equivalent thermal resistance of the cable mass, RCM, will be calculated for a 12" x 24" horizontal tray. This resistance will then be used to caculate the total equivalent thermal resistance of vertical cable tray of length L.

$L := 19$ Length of vertical cable tray in ft

A. Allowable heat generation calculation

Equivalent Cable Area

For a 1 hour fire barrier

$dof := 3$ The depth of fill in inches (reference 1, Attachment 1)

$w := 24$ Width of cable tray in inches (reference 1, Attachment 1)

$h := 12$ Height cable tray in inches (Ref. 1 Attachmant 1)

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ $Aeq = 56.549$ Equivalent cable area in the bottom of the cable tray in square inches

Allowable heat generation for an uncovered tray (Figure 1)

$HI := 1.6$ The allowable heat intensity in watts/ft- in^2

$QUCW := HI \cdot (Aeq)$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 90.478$

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 308.904$

Allowable heat generation for a tightly covered cable tray (Figure 2)

$QCB := (1 - .15)^2 \cdot QUCB$ Allowable heat for a tightly covered cable tray in Btu/hr-ft

$QCB = 223.183$

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

$AT := \left(\frac{2}{12}\right) \cdot (h + w)$ Area in ft^2/ft, this includes 2 times the sum of the heigth and width (for top, bottom and both sides) times 1 ft unit length

$AT = 6$ Total Radiating area per linear ft

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzmann Constant in Btu/hr-ft^2-R^4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface (Ref. 7 pg. 4-111)

$TAR := 563.4$ The ambient temperature in degrees Rankine

$TGS := 600$ The value of galvanized steel surface temperature, TGS.

$QRGS(TGS) := \sigma \cdot \varepsilon GS \cdot AT \cdot \left[(TGS)^4 - TAR^4 \right]$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft.

Convection Formula(s)

Sides (2 total)

$$hsGS(TGS) := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{h}{12} \right)} \right]^{.25}$$

$AS := 2 \cdot \frac{h}{12}$ $AS = 2$ The total area of two sides of the cable tray for 1 linear foot of tray in ft^2/ft.

$QCSGS(TGS) := hsGS(TGS) \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft-

Top

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing upward is $h = .27(\Delta T/L)^{.25}$. This equation will apply to the top of the cable tray with L equal to w_i/12.

$$htGS(TGS) := .27 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$$

$ATS := \frac{w}{12}$ $ATS = 2$ Area of the top of cable tray in square ft/ft

$QCTGS(TGS) := htGS(TGS) \cdot ATS \cdot (TGS - TAR)$

Bottom

From table 7-4 of Ref. 5 the convective heat transfer coefficient for a heated plate facing downward is $h = .12(\Delta T/L)^{.25}$. This equation will apply to the bottom of the cable tray with L equal to w_i/12 feet.

$hbGS(TGS) := .12 \cdot \left[\frac{TGS - TAR}{\left(\frac{w}{12} \right)} \right]^{.25}$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft^2-degree F

$AB := \frac{w}{12}$ $AB = 2$ Area of bottom of the cable tray in square ft/ft

$QCBGS(TGS) := hbGS(TGS) \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

Total Heat Transfer

$QTGS(TGS) := QRGS(TGS) + QCSGS(TGS) + QCTGS(TGS) + QCBGS(TGS)$

$TGS := root(QTGS(TGS) - QCB, TGS)$

$TGS = 607.325$

Results of the convective, radiation and total heat transferred

Total heat transferred, QTGS, equals the allowable heat generation of a covered tray, QCB, therefore a solution for TGS is obtained.

$QTGS(TGS) = 223.183$ $QRGS(TGS) = 83.425$ $QCSGS(TGS) = 65.587$

$QCTGS(TGS) = 51.349$ $QCBGS(TGS) = 22.822$ $QCB = 223.183$

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

$TCC := 90$ Rated conductor temperature in degrees centigrade (Ref. 9)

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ This value represent the thermal resistance, ° F-hr-ft/Btu, from cable mass to surface of cable tray including air space and tray for a horizontal tray. This resistance will be applied to a vertical tray (assumption 1) of length L.

$RCM = 0.206$

D. Thermal resistance of the Darmatt firewrap material covering the bottom, top and both sides of the tray (Figure 3)

$tdar1 := 1.25$ thickness of Darmatt in inches for a 1 hour barrier (Ref. 8 Att. 6).

$tair := .0625$ thickness of air gap, in inches, between Darmatt and cable tray per assumption 2.

$kdar := .0653$ (.783 Btu-in/hr-ft^{2}-°F)/12 in/ft conductivity of Darmatt in Btu/hr-ft-°F Input 10

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F Input 9

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$ Equivalent thickness of Darmatt in inches

$e1 := h$ $e1 = 12$

$e2 := w$ $e2 = 24$ $b11 := ttot1$ $b21 := ttot1$ $b31 := ttot1$ $b41 := ttot1$

$b11 = 1.508$ $b21 = 1.508$ $b31 = 1.508$ $b41 = 1.508$

$$Rcomp1 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b11} + .54\right) + \left(\frac{e2}{b21} + .54\right) + \left(\frac{e1}{b31} + .54\right) + \left(\frac{e2}{b41} + .54\right)}$$

$Rcomp1 = 0.307$ Thermal resistance of 1 hour barrier wrapped tray in °F-hr-ft/Btu

E. Total equivalent resistance of the cable mass and cable wrap for a tray of length L

$RTOT1 := \frac{RCM + Rcomp1}{L}$ $RTOT1 = 0.027$ in °F-hr/Btu

F. Calculation of total heat transfer due to radiation and convection of a vertical cable tray of length L

Total heat transfered from the wrapped cable tray

TWT Iterated value of the surface temperature of the wrapped cable tray. This value is iterated until the calculated rated conductor temperature of the cable mass, TCCR, equals the rated conductor temperature, TCR.

$TWT := 586$ guess Surface temperature of a wrapped tray °R

Radiation heat transfer formula

The radiation heat transfer equation used in section 3 of this calculation is used again here

$AR := 2 \cdot \frac{w + h}{12} \cdot L$ The radiating area of the wrapped vertical cable tray of length L in square ft

$\varepsilon A := .7$ Emissivity of the Darmatt fire wrap (Ref. 3 Attachment 3)

$QRWT(TWT) := \sigma \cdot \varepsilon A \cdot AR \cdot \left[(TWT)^4 - TAR^4\right]$ Radiation heat transfer from the wrapped surface of the cable tray in Btu/hr.

Convective Heat Transfer

Vertical Surfaces of Wrapped Tray

$$hsWT(TWT) := .2 \cdot \left(\frac{TWT - TAR}{L}\right)^{.25}$$

$$QCSWT(TWT) := hsWT(TWT) \cdot AR \cdot ((TWT) - TAR)$$

Convective heat transfer from the vertical surfaces of the wrapped vertical cable tray in Btu/hr

Total Heat Transfer

$$QTWT(TWT) := QRWT(TWT) + QCSWT(TWT)$$

$$TCCR(TWT) := TWT + QTWT(TWT) \cdot RTOT1$$

Calculated maximum temperature of the conductor °R, the equations will be iterated until TCCR converges on TCR

$TCR = 653.4$

Rated conductor temperature 90 °C

$TWT := root(TCCR(TWT) - TCR, TWT)$

This solves the iteration problem where the calculated rated conductor temperature minus the rated conductor temperature is equal to zero.

$TCCR(TWT) = 653.4$

$TWT = 582.645$

Surface temperature of the wrapped tray

$QTWT(TWT) = 2.619 \cdot 10^3$

Total heat transferred in Btu/hr

G. Ampacity Factor

$$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}} \qquad AF = 0.668$$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because it was calculated in section A per unit length

H. Ampacity Derating Factor

$ADF := 1 - AF \qquad ADF = 0.332$

Case 36 $L = 19$

Calculation of Ampacity Derating For a 12" x 24" Vertical Cable Tray of Length L With 3" Depth of Fill and a 3 Hour Firewrap

A. Calculate the thermal resistance for a 3 hour fire barrier

$tdar3 := 2.61$ Thickness of darmatt fire wrap for a 3 hour barrier (Ref. 8)

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 2.868$ Total thickness including equivalent air space

$e1 := h$ $e1 = 12$ $b13 := ttot3$ $b23 := ttot3$ $b33 := ttot3$ $b43 := ttot3$

$e2 := w$ $e2 = 24$ $b13 = 2.868$ $b23 = 2.868$

$b33 = 2.868$ $b43 = 2.868$

$$Rcomp3 := \frac{\frac{1}{kdar}}{\left(\frac{e1}{b13} + .54\right) + \left(\frac{e2}{b23} + .54\right) + \left(\frac{e1}{b33} + .54\right) + \left(\frac{e2}{b43} + .54\right)}$$

$Rcomp3 = 0.562$ Thermal resistance of a 3 hour fire barrier wrapped tray in °F-hr-ft/Btu

B. Total equivalent resistance of the cable mass and cable wrap for a cable tray of length L

$RTOT3 := \frac{RCM + Rcomp3}{L}$ RCM is obtained from the section for the 1hour case

$RTOT3 = 0.04$ in °F-hr-ft/Btu

C. Total heat transfered from the wrapped vertical cable tray with a 3 hour fire barrier and length L

$TCCR3(TWT) := TWT + QTWT(TWT) \cdot RTOT3$

$TCR = 653.4$

$TWT := root(TCCR3(TWT) - TCR, TWT)$

$TCCR3(TWT) = 653.4$

$TWT = 577.579$

Calculated maximum temperature of the conductor, the equation will be iterated until TCCR converges on TCR for a 3 hour fire barrier, only RTOT and TCCR will change directly as a result of the 3 hour fire barrier, the other variables will change as a result of changing TWT during iteration. The same methodology and equations will be used as was used on the 1 hour barrier solution only RTOT3 changes.

D. Ampacity Factor

$AF := \sqrt{\frac{QTWT(TWT)}{QUCB \cdot L}}$ $AF = 0.565$

Ampacity factor for Darmatt firewrap material, the allowable heat of an uncovered cable tray, QUCB, must be multiplied by L because QUCB is per unit length.

E. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.435$ Ampacity derating factor

4.6.3 Calculation of cable ampacity derating for conduit with a 3 hour firewrap barrier

Development of Equations

This section of the calculation will first develop the equations to calculate the thermal resistance of the cable mass, the conduit assembly (including air space) and the Darmatt fire barrier material. This information is then used on a case by case basis for each conduit/cable configuration to calculate the resistances for each case. The resistances are then used in determining the cable ampacity derating for the case. Because the thermal resistance is a function of the material properties and dimensions this section is applicable to vertical and horizontal conduit. Only the 3 hour firewrap case is calculated in this section because it was found to be the most limiting case for cable trays.

The methodology used to calculate the resistance for various cable configurations will be described in detail here. Then for each specific case the equations will be identified and solutions developed without detailed discussion. Additionally the resistance of the conduit and the Darmatt firewrap will be calculated here and not on a case by case basis as it will remain unchanged from case to case with the exception of when the size of conduit is varied which will be addressed for each case. | R2

A. Calculate the thermal resistance of the metal conductor surface to the surface of the cable (cable mass) see figure 4 for clarification of terms

The thermal resistance of several different conduit configurations is calculated below. This does not bound all installations in the plant however a representative sample of these configurations will be used to calculate the ampacity derating due to the fire wrap around the conduit. This ampacity derating value is used to show the relative derating of fire wrapped conduit versus unwrapped conduit and compared to the derating in wrapped cable trays.

The resistance of a cylinder (across the cable insulation) is from Reference 6 section G502.4 page 9 Attachment 6:

$$R = (1/2\pi ka) * \ln r_2/r_1$$

Where R is the Thermal resistance in °R-ft-hr/Btu

k is the thermal conductivity in Btu/hr-ft-°F

a is the length which will be considered 1 since R will be calculated per unit length

r_2 is the outside diameter

r_1 is the inside diameter

Modifying for the problem to be solved provides the next equation which is obtained from reference 9.

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For a three conductor cable in a conduit

R_{ij}=.00522[(2)[p_i(ln d_i/d)+p_j(ln d_j/d_i)] + 3p_{3j}(ln (d_{3jo}/d_{3ju}))]

For triplexed cables, or for three single conductor cables in one conduit

R_{ij}=.00522[(2)[p_i(ln d_i/d)+p_j(ln d_j/d_i)]

Modifying the above two equations for three multi-conductor cables in conduit

R_{ij} = .00522[(2)[(2)[p_i(ln d_i/d) + p_j(ln d_j/d_i)] + 3_{p3j}(ln (d_{3jo}/d_{3ju})]]

Where R_{ij} is the thermal resitance from the metal conductor surface to the surface of the cable in oC-ft/Watts

p_i and p_j are the thermal resistance of the cable insulation and cable jacket which are the same in °C-cm/Watts
d_i is the outside diameter of the insulation for a single conductor, for multi conductor cables it is the outside diameter for a single conductor
d is the outside diameter of the conductor, or of 1 conductor for multi conductor cables
d_j is the outside diameter of the jacket for a single conductor cable and the outside diameter of the jacket of a single conductor for multi conductor cables
d_s is the outside diameter of the shield
d_{3ju} is the diameter under the overall sheath, in inches
d_{3jo} is the diameter over the overall sheath
.00522 is a conversion to ft from cm and combination of constants
(1/2π)(1ft/12in)(.3937in/cm)

B. Calculate the thermal resistance of the air space between the cable surface and the inside surface of the conduit

The equation for this resistance is obtained from Ref. 9 and is of the form R_{sc} =A' /(D_s' + B') with the solution in °C-ft/Watt see Figure 4.

Where A' and B' are constants determined by the material of the conduit and the surrounding medium. If the cables are centrally located inside the conduit, the temperature drop from the cables to the conduit would not depend on the material of the conduit or of the surrounding medium. However, since the cables lie on the bottom of the conduit, heat flow is not perfectly radial, and the thermal resistivities of the conduit and surrounding medium will affect the thermal resistance between the cables and the inside of the conduit. Values for A' and B' are listed below.
D'_s is the diameter in inches of the group of conductors inside the conduit. For one single conductor cable or one multiconductor cable the equivalent diameter is equal to the actual

overall diameter of the cable. When more than one single conductor cable or multi-conductor cable or one or more multiplexed cables are in the conduit, and the cables are of the same size, D_s' is determined from 1.65 (Ds), where Ds is the diameter of one of the single conductors or multiconductor cable, or the diameter of one of the conductors of a multiplexed cable, for 2 cables; 2.15 (Ds) for 3 cables, and 2.50 (Ds) for 4 cables or more. A sensitivity study will be performed to determine the relative affects of multiple cables in a conduit.

$A := 3.2$
$B := .19$

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

C. Calculate the thermal resistance through the conduit wall

This problem will be solved for two sizes of conduit, 3/4" and 6" the physical characteristics of the conduit are taken from Ref. 11

$Rcd = .00522\ \rho cd\ (\ln (D_{co}/D_{ci}))$

Where Rcd is the thermal resistance from the conduit in °C-ft/Watt
ρcd is the thermal resistivity of the conduit material in °C-cm/Watt
D_{co} and D_{ci} are the outside and inside diameter of the conduit in inches

changing the variables for this problem

$\rho cd := 2.08$ — Thermal resistivity of conduit material Ref. 9 Table 1 in °C-cm/Watt Design Input 15

$p := 1 .. 3$

$DCo_p :=$ — Outside diameter of steel conduit in inches Ref. 11 Design Input 18

1.05	3/4"
4.5	4"
6.625	6"

$tc_p :=$ — Conduit wall thickness in inches Ref. 11 Design Input 19

.107	3/4"
.225	4"
.266	6"

$DCi_p := DCo_p - 2 \cdot tc_p$

DCi_p — Inside diameter of steel conduit in inches Ref. 11

0.836	3/4"
4.05	4"
6.093	6"

$$RCON_p := .00522 \cdot \rho cd \cdot \ln\left(\frac{DCo_p}{DCi_p}\right)$$

Thermal resistance of the conduit wall °C-ft/Watt, as expected this is almost negligible

$RCON_p$

0.002	3/4"
0.001	4"
$9.089 \cdot 10^{-4}$	6"

D. Thermal resistance from Darmatt Material

The diameter of the conduit plus the Darmatt material including a 1/16" air gap is

$tdar1 := 1.25$ Thickness of Darmatt for a 1 hour fire barrier in inches

$tdar3 := 3.00$ Thickness of Darmatt for a 3 hour fire barrier in inches

$tair := .0625$ Thickness of an air gap in the system in inches

$kdar := .0653$ conductivity of Darmatt in Btu/hr-ft- °F (Ref. 8)

$kair := .0158$ conductivity of air at 104 F in Btu/hr-ft-°F (Ref. 7 page 4-94)

$x := \frac{kdar}{kair}$ $x = 4.133$ equivalent thickness of Darmatt for 1/16" air, multiplier

$ttot1 := tdar1 + (x \cdot tair)$ $ttot1 = 1.508$

$ttot3 := tdar3 + (x \cdot tair)$ $ttot3 = 3.258$

Equivalent thickness of Darmatt in inches for a 1 and 3 hour fire barrier with a 1/16" gap. Since no gap is expected in the installation and manufacturing processes (Ref. 8) this additional thickness can be considered additional margin for installation problems or thickness variations in the Darmatt boards.

$DFW1o_p := (DCo_p) + 2 \cdot ttot1$ $DFW1o_p$

4.067	3/4"
7.517	4"
9.642	6"

Outside diameter of the 1 hour fire wrapped conduit in inches for two sizes of conduit

$DFW3o_p := (DCo_p) + 2 \cdot ttot3$ $DFW3o_p$

7.567	3/4"
11.017	4"
13.142	6"

Outside diameter of the 3 hour fire wrapped conduit in inches for the two sizes of conduit

$$pfw := \frac{1}{kdar} \cdot \left(\frac{.293}{30.48 \cdot \frac{5}{9}} \right)^{-1}$$

.293 is the conversion from Btu/hr to Watts, 30.48 is the conversion from ft to cm and 5/9 is the conversion from °F to °C

$pfw = 885.037$ Thermal resistivity of Darmatt in oC-cm/Watts

$$RFW1_p = .00522 \cdot pfw \cdot \ln\left[\frac{DFW1o_p}{(DCo_p)}\right]$$

Thermal resistance of the 1 hour fire wrapped conduit in °C-ft/Watts

$$RFW3_p = .00522 \cdot pfw \cdot \ln\left[\frac{DFW3o_p}{(DCo_p)}\right]$$

Thermal resistance of the 3 hour fire wrapped conduit in °C-ft/Watts

1 hour $RFW1_p$	3 hour $RFW3_p$	size
6.255	9.124	3/4"
2.37	4.136	4"
1.734	3.164	6"

E. Calculate the area of the wrapped conduit surface

$$AW1_p = \pi \cdot \frac{DCo_p + 2 \cdot tdar1}{12}$$

Area of the wrapped conduit surface for a 1 hour barrier per linear ft in ft²/ft does not include 1/16" air gap for conservatism

$$AW3_p = \pi \cdot \frac{DCo_p + 2 \cdot tdar3}{12}$$

Area of the wrapped conduit surface for a 3 hour barrier per linear ft in ft²/ft does not include 1/16" air gap for conservatism

$AW3_p$
1.846
2.749
3.305

Only the area for the 3 hour case is shown here as the remainder of the calculation uses the limiting 3 hour case. The 1 hour values are presented above for comparison purposes only.

Selection of Cables

Cables and cable configurations were selected in order to perform an evaluation of the ampacity factor of various configurations of cables in conduit which could be found. Because the worst case ampacity derating may not have been evaluated in this section some margin is added to the final ampacity derating for cable in conduit. Factors considered in selecting the cases in this section were size of cable which could fit in the conduit, configurations with high resistance to heat transfer, and the size of power cables.

Case 37

The cable configuration to be analyzed is as follows: a single three conductor (SI#363F17 3/C - 6 (600V)) cable with a 3 hour fire barrier in 3/4 inch conduit

$pins := 500$	Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation
$dshd := .87$	Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.
$dicon := .33$	Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.
$tins := .06$	Cable insulation thickness in inches
$tjac := 0$	Thickness of cable jacket in inches
$tojac := .06$	Thickness of overall cable jacket in inches
$dcon := dicon - 2\cdot tjac - 2\cdot tins$ $dcon = 0.21$	Outside diameter of the metal conductor in inches (Ref. 12)
$dins := dicon - 2\cdot tjac$ $dins = 0.33$	Outside diameter of the cable insulation in inches
$dishd := dshd - 2\cdot tojac$ $dishd = 0.75$	Inside diameter of the overall cable jacket, in inches

A. Resistance of the cable mass (oC-ft/Watt)

For a single 3/C cable

$$RTC := .00522\cdot\left[2\cdot\left(pins\cdot\ln\left(\frac{dins}{dcon}\right)+pins\cdot\ln\left(\frac{dicon}{dins}\right)\right)+3\cdot pins\cdot\ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 3.521$$

B. Resistance of the conduit air space

$A := 3.2$

$B := .19$

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd)+B} \qquad RAS = 3.019$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON := .002$ Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

$RFW3 := 9.124$ Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$RTOT := RTC + RAS + RCON + RFW3$

$RTOT = 15.666$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit can be evaluated.

$TAR := 563.4$ Ambient air temperature in degrees R

$AW3 := 1.846$ Surface area of the fire-wrapped conduit per linear ft in ft²/ft from section E of 4.6.3

$DFW3o := 7.567$ Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated for conduit since it was shown for cable trays to be the limiting case.

$TWR := 567.7$ Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h=.27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12}\right)}\right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft²-°F, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant $Btu/hr\text{-}ft^2\text{-}R^4$

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4 \right]$ Total heat transferred by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR) this represents the solution of the total heat transfered

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 567.698$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 10.344$ $QCWS(TWR) = 3.461$ $QRWS(TWR) = 6.883$

$TWR = 567.698$ $hWC(TWR) = 0.436$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 600.1$ Initial Guess for TCS in the iteration process

$DCo := 1.05$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The convective heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27\cdot\left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)}\right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi\cdot\frac{DCo}{12}$ $ACS = 0.275$ Area of the conduit surface per linear ft in ft^2/ft from

$QCUWS(TCS) := hUCS(TCS)\cdot ACS\cdot(TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713\cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma\cdot\varepsilon CS\cdot ACS\cdot\left[(TCS)^4 - (TAR)^4\right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS)\cdot((RTOT) - (RFW3))\cdot .293\cdot\frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 15.452$ $hUCS(TCS) = 1.222$

$QRUWS(TCS) = 3.132$ $QCUWS(TCS) = 12.32$

$TCS = 600.084$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.818$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.182$ Ampacity derating factor

Case 38

The cable configuration to be analyzed is as follows: a single three conductor (SI#363F17 3/C - 6 (600V)) cables with a 3 hour fire barrier in 6 inch conduit

$pins := 500$	Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation
$dshd := .87$	Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, Design Input 16.
$dicon := .33$	Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.
$tins := .06$	Cable insulation thickness in inches
$tjac := 0$	Thickness of cable jacket in inches
$tojac := .06$	Thickness of overall cable jacket in inches
$dcon := dicon - 2 \cdot tjac - 2 \cdot tins$ $dcon = 0.21$	Outside diameter of the metal conductor in inches (Ref. 12)
$dins := dicon - 2 \cdot tjac$ $dins = 0.33$	Outside diameter of the cable insulation in inches
$dishd := dshd - 2 \cdot tojac$ $dishd = 0.75$	Inside diameter of the overall cable jacket, in inches

A. Resistance of the cable rises (oC-ft/Watt)

For a single 3/C cable (for 3 3/C cables multiply entire equation by 2)

$$RTC := .00522 \cdot \left[2 \cdot \left(pins \cdot \ln\left(\frac{dins}{dcon}\right) + pins \cdot \ln\left(\frac{dicon}{dins}\right)\right) + 3 \cdot pins \cdot \ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 3.521$$

B. Resistance of the conduit air space

$A := 3.2$ $B := .19$	Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd) + B} \qquad RAS = 3.019$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

RCON := .0009 — Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

RFW3 := 3.164 — Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$$RTOT := RTC + RAS + RCON + RFW3$$

$$RTOT = 9.705$$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by the Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit and to cable in cable tray can be evaluated.

TAR := 563.4 — Ambient air temperature in degrees Rankine

AW3 := 3.305 — Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section D of 4.6.3

DFW3o := 13.142 — Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated since it was shown for cable trays to be the limiting case.

TWR := 567.7 — Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12}\right)}\right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2-°F. DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4\right]$ Total heat transfered by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated tempprature of the conductor (TCR) this represents the solution of the total heat transfered

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 567.478$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 16.741$ $QCWS(TWR) = 5.055$ $QRWS(TWR) = 11.686$

$TWR = 567.478$ $hWC(TWR) = 0.375$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 600.1$ initial Guess for TCS in the iteration process

$DCo := 5.525$ Outside diameter of bare conduit in inches Ref. 11 Design input 13

Convection Heat Transfer

The heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27\cdot\left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)}\right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi\cdot\frac{DCo}{12}$ $ACS = 1.734$ Area of the conduit surface per linear ft in ft^2/ft

$QCUWS(TCS) := hUCS(TCS)\cdot ACS\cdot(TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713\cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emisaivity of conduit surface

$QRUWS(TCS) := \sigma\cdot\varepsilon CS\cdot ACS\cdot\left[(TCS)^4 - (TAR)^4\right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS)\cdot((RTOT) - (RFW3))\cdot .293\cdot\frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 22.001$ $hUCS(TCS) = 0.607$

$QRUWS(TCS) = 7.156$ $QCUWS(TCS) = 14.845$

$TCS = 577.501$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.872$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.128$ Ampacity derating factor

Case 39

The cable configuration to be analyzed is as follows: 3, three conductor (SI#363D35 3/C - 2 (5kV)) cables with a 3 hour fire barrier in 3/4 inch conduit

$pins := 500$ — Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation

$dshd := 1.90$ — Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.

$dicon := .632$ — Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.

$tins := .14$ — Cable insulation thickness in inches

$tjac := .030$ — Thickness of cable jacket in inches

$tojac := .08$ — Thickness of overall cable jacket in inches

$dcon := dicon - 2\cdot tjac - 2\cdot tins$ — Outside diameter of the metal conductor in inches (Ref. 12)

$dcon = 0.292$

$dins := dicon - 2\cdot tjac$ — Outside diameter of the cable insulation in inches

$dins = 0.572$

$dishd := dshd - 2\cdot tojac$ — Inside diameter of the overall cable jacket, in inches

$dishd = 1.74$

A. Resistance of the cable mass (oC-ft/Watt)

For three 3/C cables

$$RTC := .00522\cdot\left[2\cdot\left(pins\cdot\ln\left(\frac{dins}{dcon}\right)+pins\cdot\ln\left(\frac{dicon}{dins}\right)\right)+3\cdot pins\cdot\ln\left(\frac{dshd}{dishd}\right)\right]\cdot 2 \qquad RTC = 9.439$$

B. Resistance of the conduit air space

$A := 3.2$

$B := .19$

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd)\cdot 2.15 + B} \qquad RAS = 0.749$$

Thermal resistance, for 3 cables installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON := .002$	Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3
$RFW3 := 9.124$	Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$$RTOT := RTC + RAS + RCON + RFW3$$

$$RTOT = 19.313$$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by the Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit and to cable in cable tray can be evaluated.

$TAR := 563.4$	Ambient air temperature in degrees Rankine
$AW3 := 1.846$	Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section E of 4.6.3
$DFW3o := 7.567$	Outside diameter of the 3 hour fire-wrapped conduit section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated since it was shown for cable trays that the 3 hour case is limiting.

$TWR := 567.7$	Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h=.27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27\cdot\left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12}\right)}\right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft²-°F, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

<u>Radiation Heat Transfer</u>

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4 \right]$ Total heat transfered by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

<u>Total Heat Transfer</u>

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR).

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 566.974$

<u>Presentation of variables resulting from solution for TWR</u>

$QTWS(TWR) = 8.452$ $QCWS(TWR) = 2.749$ $QRWS(TWR) = 5.713$

$TWR = 566.974$ $hWC(TWR) = 0.417$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

5. <u>Calculate the allowable heat transfer for an unwrapped conduit</u>

$TCS := 6[illegible].1$ initial Guess for TCS in the iteration process

$DCo := 1.05$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27 \cdot \left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)} \right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi \cdot \frac{DCo}{12}$ $ACS = 0.275$ Area of the conduit surface per linear ft in ft²/ft

$QCUWS(TCS) := hUCS(TCS) \cdot ACS \cdot (TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713 \cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft²-K⁴

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma \cdot \varepsilon CS \cdot ACS \cdot \left[(TCS)^4 - (TAR)^4 \right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS) \cdot ((RTOT) - (RFW3)) \cdot .293 \cdot \frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 11.423$ $hUCS(TCS) = 1.148$

$QRUWS(TCS) = 2.392$ $QCUWS(TCS) = 9.031$

$TCS = 592.015$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.861$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.139$ Ampacity derating factor

Case 40

The cable configuration to be analyzed is as follows: 3, three conductor (SI#363D35 3/C - 2 (5kV)) cables with a 3 hour fire barrier in 6 inch conduit

$pins := 500$ — Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation

$dshd := 1.90$ — Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.

$dicon := .632$ — Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.

$tins := .14$ — Cable insulation thickness in inches

$tjac := .030$ — Thickness of cable jacket in inches

$tojac := .08$ — Thickness of overall cable jacket in inches

$dcon := dicon - 2 \cdot tjac - 2 \cdot tins$ — Outside diameter of the metal conductor in inches (Ref. 12)

$dcon = 0.292$

$dins := dicon - 2 \cdot tjac$ — Outside diameter of the cable insulation in inches

$dins = 0.572$

$dishd := dshd - 2 \cdot tojac$ — Inside diameter of the overall cable jacket, in inches

$dishd = 1.74$

A. Resistance of the cable mass (oC-ft/Watt)

For three 3/C cables

$$RTC := .00522 \cdot \left[2 \cdot \left(pins \cdot \ln\left(\frac{dins}{dcon}\right) + pins \cdot \ln\left(\frac{dicon}{dins}\right) \right) + 3 \cdot pins \cdot \ln\left(\frac{dshd}{dishd}\right) \right] \cdot 2 \qquad RTC = 9.439$$

B. Resistance of the conduit air space

$A := 3.2$

$B := .19$

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd) \cdot 2.15 + B} \qquad RAS = 0.749$$

Thermal resistance, for 3 cables installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON := .0009$ Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

$RFW3 := 3.164$ Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$RTOT := RTC + RAS + RCON + RFW3$

$RTOT = 13.352$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by the Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit and to cable in cable tray can be evaluated.

$TAR := 563.4$ Ambient air temperature in degrees Rankine

$AW3 := 3.305$ Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section E of 4.6.3

$DFW3o := 13.142$ Outside diameter of the 3 hour fire-wrapped conduit section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated since it was shown for cable trays that the 3 hour case is limiting.

$TWR := 567.7$ Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12}\right)}\right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in $Btu/hr\text{-}ft^2\text{-}°F$, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4 \right]$ Total heat transfered by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR).

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 566.468$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 12.314$ $QCWS(TWR) = 3.542$ $QRWS(TWR) = 8.769$

$TWR = 566.468$ $hWC(TWR) = 0.349$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 600.1$ Initial Guess for TCS in the iteration process

$DCo := 6.625$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27\cdot\left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)}\right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi\cdot\frac{DCo}{12}$ $ACS = 1.734$ Area of the conduit surface per linear ft in ft^2/ft

$QCUWS(TCS) := hUCS(TCS)\cdot ACS\cdot(TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713\cdot10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma\cdot\varepsilon CS\cdot ACS\cdot\left[(TCS)^4 - (TAR)^4\right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances in the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS)\cdot((RTOT) - (RFW3))\cdot.293\cdot\frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 14.868$ $hUCS(TCS) = 0.559$

$QRUWS(TCS) = 5.076$ $QCUWS(TCS) = 9.792$

$TCS = 573.509$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$$ $AF = 0.91$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.09$ Ampacity derating factor

Case 41

The cable configuration to be analyzed is as follows: a single three conductor (SI#363D38 3/C - 500 kcmil (5 kV)) cables with a 3 hour fire barrier in 3/4 inch conduit

$pins := 500$	Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation
$dshd := 3.34$	Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.
$dicon := 1.193$	Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.
$tins := .14$	Cable insulation thickness in inches
$tjac := .05$	Thickness of cable jacket in inches
$tojac := .14$	Thickness of overall cable jacket in inches
$dcon := dicon - 2 \cdot tjac - 2 \cdot tins$ $dcon = 0.813$	Outside diameter of the metal conductor in inches (Ref. 12)
$dins := dicon - 2 \cdot tjac$ $dins = 1.093$	Outside diameter of the cable insulation in inches
$dishd := dshd - 2 \cdot tojac$ $dishd = 3.06$	Inside diameter of the overall cable jacket, in inches

A. Resistance of the cable mass (oC-ft/Watt)

For a single 3/C cable

$$RTC := .00522 \cdot \left[2 \cdot \left(pins \cdot \ln\left(\frac{dins}{dcon}\right) + pins \cdot \ln\left(\frac{dicon}{dins}\right)\right) + 3 \cdot pins \cdot \ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 2.687$$

B. Resistance of the conduit air space

$A := 3.2$ $B := .19$	Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd) + B} \qquad RAS = 0.907$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

RCON := .002 — Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

RFW3 := 9.124 — Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

RTOT := RTC + RAS + RCON + RFW3

RTOT = 12.72

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit can be evaluated.

TAR := 563.4 — Ambient air temperature in degrees R

AW3 := 1.846 — Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section E of 4.6.3

DFW3o := 7.567 — Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated for conduit since it was shown for cable trays to be the limiting case.

TWR := 567.7 — Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12}\right)}\right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2-oF, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4\right]$ Total heat transferred by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR) this represents the solution of the total heat transfered

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 568.553$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 12.613$ $QCWS(TWR) = 4.342$ $QRWS(TWR) = 8.271$

$TWR = 568.553$ $hWC(TWR) = 0.456$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

TCS := [illegible] Initial Guess for TCS in the iteration process

$DCo := 1.05$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The convective heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27\cdot\left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)}\right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi\cdot\frac{DCo}{12}$ $ACS = 0.275$ Area of the conduit surface per linear ft in ft^2/ft from

$QCUWS(TCS) := hUCS(TCS)\cdot ACS\cdot(TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713\cdot10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma\cdot\varepsilon CS\cdot ACS\cdot\left[(TCS)^4 - (TAR)^4\right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS)\cdot((RTOT) - (RFW3))\cdot.293\cdot\frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 21.811$ $hUCS(TCS) = 1.311$

$QRUWS(TCS) = 4.284$ $QCUWS(TCS) = 17.527$

$TCS = 612.035$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.76$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.24$ Ampacity derating factor

Case 42

The cable configuration to be analyzed is as follows: a single three conductor (SI#363D38 3/C - 500 kcmil (5 kV)) cables with a 3 hour fire barrier in 6 inch conduit

pins := 500	Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation
dshd := 3.34	Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.
dicon := 1.193	Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.
tins := .14	Cable insulation thickness in inches
tjac := .05	Thickness of cable jacket in inches
tojac := .14	Thickness of overall cable jacket in inches
dcon := dicon − 2·tjac − 2·tins dcon = 0.813	Outside diameter of the metal conductor in inches (Ref. 12)
dins := dicon − 2·tjac dins = 1.093	Outside diameter of the cable insulation in inches
dishd := dshd − 2·tojac dishd = 3.06	Inside diameter of the overall cable jacket, in inches

A. Resistance of the cable mass (°C-ft/Watt)

For a single 3/C cable

$$RTC := .00522\cdot\left[2\cdot\left(pins\cdot\ln\left(\frac{dins}{dcon}\right)+pins\cdot\ln\left(\frac{dicon}{dins}\right)\right)+3\cdot pins\cdot\ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 2.687$$

B. Resistance of the conduit air space

A := 3.2 B := .19	Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd)+B} \qquad RAS = 0.907$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

RCON := .0009	Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3
RFW3 := 3.164	Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$RTOT := RTC + RAS + RCON + RFW3$

$RTOT = 6.759$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit can be evaluated.

TAR := 563.4	Ambient air temperature in degrees R
AW3 := 3.305	Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section E of 4.6.3
DFW3o := 13.142	Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated for conduit since it was shown for cable trays to be the limiting case.

TWR := 567.7	Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12} \right)} \right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft²-°F, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4\right]$ Total heat transferred by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR) this represents the solution of the total heat transfered

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 568.997$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 23.614$ $QCWS(TWR) = 7.509$ $QRWS(TWR) = 16.104$

$TWR = 568.997$ $hWC(TWR) = 0.406$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 600.1$ Initial Guess for TCS in the iteration process

$DCo := 6.6255$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The convective heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27 \cdot \left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)}\right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi \cdot \frac{DCo}{12}$ $ACS = 1.735$ Area of the conduit surface per linear ft in ft^2/ft from

$QCUWS(TCS) := hUCS(TCS) \cdot ACS \cdot (TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713 \cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma \cdot \varepsilon CS \cdot ACS \cdot \left[(TCS)^4 - (TAR)^4\right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the [illegible] fire wrap

$$TCCR(TCS) := TCS + QTUS(TCS) \cdot ((RTOT) - (RFW3)) \cdot .293 \cdot \frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 36.162$ $hUCS(TCS) = 0.674$

$QRUWS(TCS) = 11.095$ $QCUWS(TCS) = 25.057$

$TCS = 584.841$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TCR)}{QTUS(TCS)}}$ $AF = 0.808$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.192$ Ampacity derating factor

Case 42a

The cable configuration to be analyzed is as follows: a single three conductor (SI#363D38 3/C - 500 kcmil (5 kV)) cables with a 3 hour fire barrier in 4 inch conduit

$pins := 500$ Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation

$dshd := 3.34$ Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.

$dicon := 1.193$ Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.

$tins := .14$ Cable insulation thickness in inches

$tjac := .05$ Thickness of cable jacket in inches

$tojac := .14$ Thickness of overall cable jacket in inches

$dcon := dicon - 2\cdot tjac - 2\cdot tins$ Outside diameter of the metal conductor in inches (Ref. 12)

$dcon = 0.813$

$dins := dicon - 2\cdot tjac$ Outside diameter of the cable insulation in inches

$dins = 1.093$

$dishd := dshd - 2\cdot tojac$ Inside diameter of the overall cable jacket, in inches

$dishd = 3.06$

A. Resistance of the cable mass (°C-ft/Watt)

For a single 3/C cable

$$RTC := .00522\cdot\left[2\cdot\left(pins\cdot \ln\left(\frac{dins}{dcon}\right) + pins\cdot \ln\left(\frac{dicon}{dins}\right)\right) + 3\cdot pins\cdot \ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 2.687$$

B. Resistance of the conduit air space

$A := 3.2$

$B := .19$

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd) + B} \qquad RAS = 0.907$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON := .001$	Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3
$RFW3 := 4.136$	Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$$RTOT := RTC + RAS + RCON + RFW3$$

$$RTOT = 7.731$$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit can be evaluated.

$TAR := 563.4$	Ambient air temperature in degrees R
$AW3 := 2.749$	Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section D of 4.6.3
$DFW3o := 11.017$	Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated for conduit since it was shown for cable trays to be the limiting case.

$TWR := 567.7$	Surface temperature of the wrapped conduit, this value was iterated by Mathced until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12} \right)} \right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in $Btu/hr\text{-}ft^2\text{-}°F$, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4\right]$ Total heat transferred by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR) this represents the solution of the total heat transfered

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 569.171$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 20.602$ $QCWS(TWR) = 6.783$ $QRWS(TWR) = 13.819$

$TWR = 569.171$ $hWC(TWR) = 0.428$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 603.1$ Initial Guess for TCS in the iteration process

$DCo := 4.5$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The convective heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27 \cdot \left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)} \right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi \cdot \frac{DCo}{12}$ $ACS = 1.178$ Area of the conduit surface per linear ft in ft^2/ft from

$QCUWS(TCS) := hUCS(TCS) \cdot ACS \cdot (TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma := 1.713 \cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma \cdot \varepsilon CS \cdot ACS \cdot \left[(TCS)^4 - (TAR)^4 \right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS) \cdot ((RTOT) - (RFW3)) \cdot .293 \cdot \frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 33.591$ $hUCS(TCS) = 0.781$

$QRUWS(TCS) = 9.368$ $QCUWS(TCS) = 24.223$

$TCS = 589.712$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.783$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.217$ Ampacity derating factor

Case 43

The cable configuration to be analyzed is as follows: a single three conductor (SI#363D35 3/C - 2 (5 kV)) cables with a 3 hour fire barrier in 3/4 inch conduit

pins := 500	Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation
dshd := 1.90	Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.
dicon := .632	Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.
tins := .14	Cable insulation thickness in inches
tjac := .03	Thickness of cable jacket in inches
tojac := .08	Thickness of overall cable jacket in inches
dcon := dicon − 2·tjac − 2·tins	Outside diameter of the metal conductor in inches (Ref. 12)
dcon = 0.292	
dins := dicon − 2·tjac	Outside diameter of the cable insulation in inches
dins = 0.572	
dishd := dshd − 2·tojac	Inside diameter of the overall cable jacket, in inches
dishd = 1.74	

A. Resistance of the cable mass (°C-ft/Watt)

For a single 3/C cable

$$RTC := .00522\cdot\left[2\cdot\left(pins\cdot\ln\left(\frac{dins}{dcon}\right)+pins\cdot\ln\left(\frac{dicon}{dins}\right)\right)+3\cdot pins\cdot\ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 4.719$$

B. Resistance of the conduit air space

A := 3.2

B := .19

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd)+B} \qquad RAS = 1.531$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON := .002$ Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

$RFW3 := 9.124$ Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$RTOT := RTC + RAS + RCON + RFW3$

$RTOT = 15.376$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit can be evaluated.

$TAR := 563.4$ Ambient air temperature in degrees R

$AW3 := 1.846$ Surface area of the fire-wrapped conduit per linear ft in ft²/ft from section E of 4.6.3

$DFW3o := 7.567$ Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated for conduit since it was shown for cable trays to be the limiting case.

$TWR := 567.7$ Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12}\right)}\right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft²-°F, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft²-R⁴

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4 \right]$ Total heat transferred by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR) this represents the solution of the total heat transfered

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 567.769$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 10.531$ $QCWS(TWR) = 3.532$ $QRWS(TWR) = 6.998$

$TWR = 567.769$ $hWC(TWR) = 0.438$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 600.1$ Initial Guess for TCS in the iteration process

$DCo := 1.05$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The convective heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27\cdot\left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)}\right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi\cdot\frac{DCo}{12}$ $ACS = 0.275$ Area of the conduit surface per linear ft in ft^2/ft from

$QCUWS(TCS) := hUCS(TCS)\cdot ACS\cdot(TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713\cdot10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma\cdot\varepsilon CS\cdot ACS\cdot\left[(TCS)^4 - (TAR)^4\right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS)\cdot((RTOT) - (RFW3))\cdot .293\cdot\frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 15.903$ $hUCS(TCS) = 1.229$

$QRUWS(TCS) = 3.214$ $QCUWS(TCS) = 12.689$

$TCS = 600.96$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.814$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.186$ Ampacity derating factor

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Case 44

The cable configuration to be analyzed is as follows: a single three conductor (SI#363D35 3/C - 2 (5 kV)) cables with a 3 hour fire barrier in 6 inch conduit

pins := 500 — Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation

dshd := 1.90 — Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.

dicon := .632 — Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.

tins := .14 — Cable insulation thickness in inches

tjac := .03 — Thickness of cable jacket in inches

tojac := .08 — Thickness of overall cable jacket in inches

$dcon := dicon - 2 \cdot tjac - 2 \cdot tins$ — Outside diameter of the metal conductor in inches (Ref. 12)

$dcon = 0.292$

$dins := dicon - 2 \cdot tjac$ — Outside diameter of the cable insulation in inches

$dins = 0.572$

$dishd := dshd - 2 \cdot tojac$ — Inside diameter of the overall cable jacket, in inches

$dishd = 1.74$

A. Resistance of the cable mass (oC-ft/Watt)

For a single 3/C cable

$$RTC := .00522 \cdot \left[2 \cdot \left(pins \cdot \ln\left(\frac{dins}{dcon}\right) + pins \cdot \ln\left(\frac{dicon}{dins}\right)\right) + 3 \cdot pins \cdot \ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 4.719$$

B. Resistance of the conduit air space

A := 3.2

B := .19

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd) + B} \qquad RAS = 1.531$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON := .0009$ Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

$RFW3 := 3.164$ Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$RTOT := RTC + RAS + RCON + RFW3$

$RTOT = 9.415$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit can be evaluated.

$TAR := 563.4$ Ambient air temperature in degrees R

$AW3 := 3.305$ Surface area of the fire-wrapped conduit per linear ft in ft²/ft from section E of 4.6.3

$DFW3o := 13.142$ Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated for conduit since it was shown for cable trays to be the limiting case.

$TWR := 567.7$ Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12}\right)}\right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft²-°F, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

<u>Radiation Heat Transfer</u>

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4 \right]$ Total heat transferred by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

<u>Total Heat Transfer</u>

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR) this represents the solution of the total heat transfered

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 567.589$

<u>Presentation of variables resulting from solution for TWR</u>

$QTWS(TWR) = 17.234$ $QCWS(TWR) = 5.227$ $QRWS(TWR) = 12.007$

$TWR = 567.589$ $hWC(TWR) = 0.$[illegible]78

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. <u>Calculate the allowable heat transfer for an unwrapped conduit</u>

$TCS := 600.1$ Initial Guess for TCS in the iteration process

$DCo := 6.625$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The convective heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27 \cdot \left[\frac{TCS - TAR}{\left(\frac{DCo}{12} \right)} \right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi \cdot \frac{DCo}{12}$ $ACS = 1.734$ Area of the conduit surface per linear ft in ft²/ft from

$QCUWS(TCS) := hUCS(TCS) \cdot ACS \cdot (TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713 \cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma \cdot \varepsilon CS \cdot ACS \cdot \left[(TCS)^4 - (TAR)^4 \right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS) \cdot ((RTOT) - (RFW3)) \cdot .293 \cdot \frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 22.877$ $hUCS(TCS) = 0.612$

$QRUWS(TCS) = 7.406$ $QCUWS(TCS) = 15.471$

$TCS = 577.975$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.868$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.132$ Ampacity derating factor

Case 45

The cable configuration to be analyzed is as follows: three single conductor (SI#363E38 1/C - 8 (600V)) cables with a 3 hour fire barrier in 3/4 inch conduit

$pins := 500$ — Thermal reaistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation

$dshd := .34$ — Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.

$dicon := .34$ — Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.

$tins := .045$ — Cable insulation thickness in inches

$tjac := .030$ — Thickness of cable jacket in inches

$tojac := 0$ — Thickness of overall cable jacket in inches

$dcon := dicon - 2 \cdot tjac - 2 \cdot tins$ — Outside diameter of the metal conductor in inches (Ref. 12)

$dcon = 0.19$

$dins := dicon - 2 \cdot tjac$ — Outside diameter of the cable insulation in inches

$dins = 0.28$

$dishd := dshd - 2 \cdot tojac$ — Inside diameter of the overall cable jacket, in inches

$dishd = 0.34$

A. Resistance of the cable mass (oC-ft/Watt)

For three 3/C cables

$$RTC := .00522 \cdot \left[2 \cdot \left(pins \cdot \ln\left(\frac{dins}{dcon}\right) + pins \cdot \ln\left(\frac{dicon}{dins}\right) \right) \right] \qquad RTC = 3.038$$

B. Resistance of the conduit air space

$A := 3.2$

$B := .19$

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd) \cdot 2.15 + B} \qquad RAS = 3.474$$

Thermal resistance, for 3 cables installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON := .002$ Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

$RFW3 := 9.124$ Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$RTOT := RTC + RAS + RCON + RFW3$

$RTOT = 15.638$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by the Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit and to cable in cable tray can be evaluated.

$TAR := 563.4$ Ambient air temperature in degrees Rankine

$AW3 := 1.846$ Surface area of the fire-wrapped conduit per linear ft in ft²/ft from section E of 4.6.3

$DFW3o := 7.567$ Outside diameter of the 3 hour fire-wrapped conduit section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated since it was shown for cable trays that the 3 hour case is limiting.

$TWR := 567.7$ Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12} \right)} \right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft²-°F, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft²-R⁴

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4 \right]$ Total heat transfered by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR).

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 567.704$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 10.362$ $QCWS(TWR) = 3.468$ $QRWS(TWR) = 6.894$

$TWR = 567.704$ $hWC(TWR) = 0.436$

$TCCR(TWR) = 653.399$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 600.1$ Initial Guess for TCS in the iteration process

$DCo := 1.05$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27\cdot\left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)}\right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi\cdot\frac{DCo}{12}$ $ACS = 0.275$ Area of the conduit surface per linear ft in ft^2/ft

$QCUWS(TCS) := hUCS(TCS)\cdot ACS\cdot(TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713\cdot10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma\cdot\varepsilon CS\cdot ACS\cdot\left[(TCS)^4 - (TAR)^4\right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS)\cdot((RTOT) - (RFW3))\cdot .293\cdot\frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 15.495$ $hUCS(TCS) = 1.222$

$QRUWS(TCS) = 3.14$ $QCUWS(TCS) = 12.355$

$TCS = 600.167$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.818$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.182$ Ampacity derating factor

Case 46

The cable configuration to be analyzed is as follows: three single conductor (SI#363E38 1/C - 8 (600V)) cables with a 3 hour fire barrier in 6 inch conduit

pins := 500	Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation
dshd := .34	Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.
dicon := .34	Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.
tins := .045	Cable insulation thickness in inches
tjac := .030	Thickness of cable jacket in inches
tojac := 0	Thickness of overall cable jacket in inches
dcon := dicon − 2·tjac − 2·tins dcon = 0.19	Outside diameter of the metal conductor in inches (Ref. 12)
dins := dicon − 2·tjac dins = 0.28	Outside diameter of the cable insulation in inches
dishd := dshd − 2·tojac dishd = 0.34	Inside diameter of the overall cable jacket, in inches

A. Resistance of the cable mass (oC-ft/Watt)

For three 3/C cables

$$RTC := .00522\left[2\cdot\left(pins\cdot\ln\left(\frac{dins}{dcon}\right)+pins\cdot\ln\left(\frac{dicon}{dins}\right)\right)\right] \qquad RTC = 3.038$$

B. Resistance of the conduit air space

A := 3.2

B := .19

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS := \frac{A}{(dshd)\cdot 2.15 + B} \qquad RAS = 3.474$$

Thermal resistance, for 3 cables installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON := .0009$ Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

$RFW3 := 3.164$ Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$RTOT := RTC + RAS + RCON + RFW3$

$RTOT = 9.677$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by the Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit and to cable in cable tray can be evaluated.

$TAR := 563.4$ Ambient air temperature in degrees Rankine

$AW3 := 3.305$ Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section E of 4.6.3

$DFW3o := 13.142$ Outside diameter of the 3 hour fire-wrapped conduit section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated since it was shown for cable trays that the 3 hour case is limiting.

$TWR := 567.7$ Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped conduit is from Ref. 5 (Attachment 4) for horizontal cylinders for laminar flow since air flow in the area is considered minimal: $h = .27(\Delta T/d)^{.25}$

$$hWC(TWR) := .27 \cdot \left[\frac{TWR - TAR}{\left(\frac{DFW3o}{12} \right)} \right]^{.25}$$

Heat transfer coefficient of the wrapped conduit in Btu/hr-ft²-°F, DFW3o is used because it provides the equivalent diameter of the conduit including the air gap which provides a larger diameter and smaller heat transfer coefficient which is conservative

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) := hWC(TWR) \cdot AW3 \cdot (TWR - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma := .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A := .7$ Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) := \sigma \cdot \varepsilon A \cdot AW3 \cdot \left[(TWR)^4 - (TAR)^4 \right]$ Total heat transfered by radiation to the surroundings from the wrapped conduit in Watts/ft this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR).

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR'

$TWR = 567.488$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 16.788$ $QCWS(TWR) = 5.071$ $QRWS(TWR) = 11.717$

$TWR = 567.488$ $hWC(TWR) = 0.375$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 600.1$ Initial Guess for TCS in the iteration process

$DCo := 6.625$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .27 \cdot \left[\frac{TCS - TAR}{\left(\frac{DCo}{12}\right)} \right]^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi \cdot \frac{DCo}{12}$ $ACS = 1.734$ Area of the conduit surface per linear ft in ft^2/ft

$QCUWS(TCS) := hUCS(TCS) \cdot ACS \cdot (TCS - TAR)$ Heat transferred by convection in Btu/hr-ft

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713 \cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma \cdot \varepsilon CS \cdot ACS \cdot \left[(TCS)^4 - (TAR)^4 \right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS) \cdot ((RTOT) - (RFW3)) \cdot .293 \cdot \frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 22.083$ $hUCS(TCS) = 0.607$

$QRUWS(TCS) = 7.179$ $QCUWS(TCS) = 14.904$

$TCS = 577.546$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.872$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$ $ADF = 0.128$ Ampacity derating factor

4.6.4 Calculation of cable Ampacity for vertical conduit with a 3 hour fire barrier

Case 47

The cable configuration to be analyzed is as follows: a single three conductor (SI#363D38 3/C - 500 kcmil (5 kV)) cable with a 3 hour fire barrier in 6 inch conduit of length L in a vertical configuration.

The total resistance and heat transfer over length L will be calculated to identify the effects of the vertical configuration on ampacity derating factor. A single case has been selected to analyze the vertical configuration. This being the worst case from the horizontal conduit calculations. Case 42 was selected being the worst case for a realistic configuration (case 41 is not realistic as a 3/C 500 kcmil cable will not fit in a 3/4" conduit.

$L := 30$ Length of conduit in a vertical configuration in ft

$pins := 500$ Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation

$dshd := 3.34$ Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.

$dicon := 1.193$ Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.

$tins := .14$ Cable insulation thickness in inches

$tjac := .05$ Thickness of cable jacket in inches

$tojac := .14$ Thickness of overall cable jacket in inches

$dcon := dicon - 2 \cdot tjac - 2 \cdot tins$ Outside diameter of the metal conductor in inches (Ref. 12)

$dcon = 0.813$

$dins := dicon - 2 \cdot tjac$ Outside diameter of the cable insulation in inches

$dins = 1.093$

$dishd := dshd - 2 \cdot tojac$ Inside diameter of the overall cable jacket, in inches

$dishd = 3.06$

A. Resistance of the cable mass (oC-ft/Watt)

For a single 3/C cable

$$RTC = .00522\cdot\left[2\cdot\left(pins\cdot\ln\left(\frac{dins}{dcon}\right) - pins\cdot\ln\left(\frac{dicon}{dins}\right)\right) + 3\cdot pins\cdot\ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 2.687$$

B. Resistance of the conduit air space

$A = 3.2$

$B = .19$

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS = \frac{A}{(dshd) + B} \qquad RAS = 0.907$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON = .0009$ Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

$RFW3 = 3.164$ Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$$RTOT = \frac{RTC + RAS + RCON + RFW3}{L}$$

Total resistance over length L in °C/Watt

$RTOT = 0.225$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by the Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit and to cable in cable tray can be evaluated.

$TAR = 563.4$ Ambient air temperature in degrees Rankine

AW3 = 3.305 — Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section E of 4.6.3

DFW3o = 13.142 — Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated for conduit since it was shown that for cable trays the 3 hour barrier is limiting.

TWR = 567.7 — Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped vertical conduit is from Ref. 5 (Attachment 4) for vertical cylinders for laminar flow since air flow in the area is considered minimal: $h = .29(\Delta T/L)^{.25}$

$$hWC(TWR) = .29\left[\frac{TWR - TAR}{(L)}\right]^{.25}$$ Heat transfer coefficient of wrapped vertical conduit in Btu/hr-ft^2-oF.

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$QCWS(TWR) = hWC(TWR)\cdot AW3\cdot L\cdot(TWR - TAR)$ Heat transferred by convection in Btu/hr

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma = .1713\cdot 10^{-8}$ — Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A = .7$ — Emissivity of the wrapped conduit surface (Darmatt)

$QRWS(TWR) = \sigma\cdot\varepsilon A\cdot AW3\cdot L\cdot\left[(TWR)^4 - (TAR)^4\right]$ Total heat transfered by radiation to the surroundings from the wrapped conduit in Btu/hr this equation is developed in section 4.6.1.

Total Heat Transfer

$QTWS(TWR) := QRWS(TWR) + QCWS(TWR)$ Total heat transfered from the wrapped conduit

$TCCR(TWR) := TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR) this represents the solution of the total heat transfered

$TCR := 653.4$

$TWR := root(TCCR(TWR) - TCR, TWR)$ Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

$TWR = 569.99$

Presentation of variables resulting from solution for TWR

$QTWS(TWR) = 700.075$ $QCWS(TWR) = 129.719$ $QRWS(TWR) = 570.356$

$TWR = 569.99$ $hWC(TWR) = 0.199$

$TCCR(TWR) = 653.4$

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

$TCS := 580$ Initial Guess for TCS in the iteration process

$DCo := 6.625$ Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The heat transfer coefficient for the conduit is again

$$hUCS(TCS) := .29 \cdot \left(\frac{TCS - TAR}{L}\right)^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS := \pi \cdot \frac{DCo}{12}$ $ACS = 1.734$ Area of the conduit surface per linear ft in ft^2/ft

$QCUWS(TCS) := hUCS(TCS) \cdot ACS \cdot L \cdot (TCS - TAR)$ Heat transferred by convection in Btu/hr

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713 \cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma \cdot \varepsilon CS \cdot ACS \cdot L \cdot \left[(TCS)^4 - (TAR)^4 \right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS) \cdot \left[(RTOT) - \frac{RFW3}{L} \right] \cdot .293 \cdot \frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 943.192$ $hUCS(TCS) = 0.291$

$QRUWS(TCS) = 483.083$ $QCUWS(TCS) = 460.109$

$TCS = 593.793$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.862$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$

$ADF = 0.138$ Ampacity derating factor

Case 48

The cable configuration to be analyzed is as follows: a single three conductor (SI#363D38 3/C - 500 kcmil (5 kV)) cable with a 3 hour fire barrier in 6 inch conduit of length L in a vertical configuration.

The total resistance and heat transfer over length L will be calculated to identify the effects of the vertical configuration on ampacity derating factor. A single case has been selected to analyze the vertical configuration. This being the worst case from the horizontal conduit calculations. Case 42 was selected being the worst case for a realistic configuration (case 41 is not realistic as a 3/C 500 kcmil cable will not fit in a 3/4" conduit.

$L := 19$ — Length of conduit in a vertical configuration in ft

$\rho ins := 500$ — Thermal resistivity of cable insulation and jacket Ref. 9 Table 1 in °C-cm/Watt the jacket material, hypalon, has the same thermal resistivity as the insulation

$dshd := 3.34$ — Overall outside diameter of the cable including insulation, the jacket and shield, if any, in inches Ref. 12 Table C, see Design Input 16 for cable parameters.

$dicon := 1.193$ — Outside diameter of an individual conductor of multiple conductor cables or the outside diameter of a single conductor cable same as dshd, including insulation and jacket thickness in inches.

$tins := .14$ — Cable insulation thickness in inches

$tjac := .05$ — Thickness of cable jacket in inches

$tojac := .14$ — Thickness of overall cable jacket in inches

$dcon := dicon - 2 \cdot tjac - 2 \cdot tins$ — Outside diameter of the metal conductor in inches (Ref. 12)

$dcon = 0.813$

$dins := dicon - 2 \cdot tjac$ — Outside diameter of the cable insulation in inches

$dins = 1.093$

$dishd := dshd - 2 \cdot tojac$ — Inside diameter of the overall cable jacket, in inches

$dishd = 3.06$

A. Resistance of the cable mass (oC-ft/Watt)

For a single 3/C cable

$$RTC = .00522\cdot\left[2\cdot\left(pins\cdot\ln\left(\frac{dins}{dcon}\right) + pins\cdot\ln\left(\frac{dicon}{dins}\right)\right) + 3\cdot pins\cdot\ln\left(\frac{dshd}{dishd}\right)\right] \qquad RTC = 2.687$$

B. Resistance of the conduit air space

$A = 3.2$

$B = .19$

Constants to determine the thermal resistance between a cable surface and the inside of a conduit, these constants have been developed experimentally (Ref. 9)

$$RAS = \frac{A}{(dshd) + B} \qquad RAS = 0.907$$

Thermal resistance, for one cable installed in conduit, of the air space in °C-ft/Watt

C. Total Resistance

The total resistance includes the resistance of the cable mass, the air space, the conduit wall and the firewrap

$RCON = .0009$ Resistance of conduit wall in °C-ft/Watt from section C of 4.6.3

$RFW3 = 3.164$ Resistance of 3 hour firewrap in °C-ft/Watt from section D of 4.6.3

$$RTOT = \frac{RTC + RAS + RCON + RFW3}{L}$$

Total resistance over length L in °C/Watt

$RTOT = 0.356$

D. Calculation of heat transfer and ampacity factor for a horizontal conduit with 3 hour firewrap:

The equations for heat transfer from the wrapped conduit surface will be developed with the wrapped surface temperature, TWR, being iterated by the Mathcad until a solution for the calculated rated conductor temperature, TCCR, converges on the rated conductor temperature TCR. This will provide a solution of the heat transferred from a cable in a wrapped conduit (section D) and from an unwrapped conduit (section E). With this information the relative derating of a fire wrapped conduit to an unwrapped conduit and to cable in cable tray can be evaluated.

$TAR = 563.4$ Ambient air temperature in degrees Rankine

$AW3 = 3.305$ Surface area of the fire-wrapped conduit per linear ft in ft^2/ft from section E of 4.6.3

$DFW3o = 13.142$ Outside diameter of the 3 hour fire-wrapped conduit from section D of 4.6.3

Calculate the heat transfer from the wrapped conduit

Only values for the 3 hour fire barrier are calculated for conduit since it was shown that for cable trays the 3 hour barrier is limiting.

$TWR = 567.7$ Surface temperature of the wrapped conduit, this value was iterated by Mathcad until the solution for TCCR converged on the rated conductor temperature TCR

Convection Heat Transfer

The heat transfer coefficient for the wrapped vertical conduit is from Ref. 5 (Attachment 4) for vertical cylinders for laminar flow since air flow in the area is considered minimal: $h = .29(\Delta T/L)^{.25}$

$$hWC(TWR) = .29 \cdot \left[\frac{TWR - TAR}{(L)}\right]^{.25}$$ Heat transfer coefficient of wrapped vertical conduit in Btu/hr-ft^2-oF,

Calculate the total heat transferred to ambient by convection from the wrapped conduit surface

$$QCWS(TWR) = hWC(TWR) \cdot AW3 \cdot L \cdot (TWR - TAR)$$ Heat transferred by convection in Btu/hr

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the wrapped conduit surface

$\sigma = .1713 \cdot 10^{-8}$ Stephan Boltzman Constant Btu/hr-ft^2-R^4

$\varepsilon A = .7$ Emissivity of the wrapped conduit surface (Darmatt)

$$QRWS(TWR) = \sigma \cdot \varepsilon A \cdot AW3 \cdot L \cdot \left[(TWR)^4 - (TAR)^4\right]$$ Total heat transfered by radiation to the surroundings from the wrapped conduit in Btu/hr this equation is developed in section 4.6.1.

Total Heat Transfer

QTWS(TWR) = QRWS(TWR) + QCWS(TWR) — Total heat transfered from the wrapped conduit

$TCCR(TWR) = TWR + QTWS(TWR) \cdot (RTOT) \cdot .2938 \cdot \frac{9}{5}$ — Values of TWR are iterated until calculated rated conductor temperature, TCCR, converges on the rated temperature of the conductor (TCR) this represents the solution of the total heat transfered

TCR = 653.4

TWR = root(TCCR(TWR) − TCR, TWR) — Iteration of TWR until TCCR minus TCR equals zero, provides the solution of TWR

TWR = 569.863

Presentation of variables resulting from solution for TWR

QTWS(TWR) = 444.054 QCWS(TWR) = 89.887 QRWS(TWR) = 354.167

TWR = 569.863 hWC(TWR) = 0.221

TCCR(TWR) = 653.4

TCCR equals TCR therefore this represents the solution for TWR

E. Calculate the allowable heat transfer for an unwrapped conduit

TCS = 580 — Initial Guess for TCS in the iteration process

DCo = 6.625 — Outside diameter of bare conduit in inches Ref. 11 Design Input 18

Convection Heat Transfer

The heat transfer coefficient for the conduit is again

$$hUCS(TCS) = .29 \cdot \left(\frac{TCS - TAR}{L}\right)^{.25}$$

Calculate the total heat transferred to ambient by convection from the conduit surface

$ACS = \pi \cdot \frac{DCo}{12}$ ACS = 1.734 — Area of the conduit surface per linear ft in ft^2/ft

$QCUWS(TCS) := hUCS(TCS)\cdot ACS\cdot L\cdot (TCS - TAR)$ Heat transferred by convection in Btu/hr

Radiation Heat Transfer

Calculate the total heat transferred to ambient by radiation from the conduit surface

$\sigma = 1.713\cdot 10^{-9}$ Stephan Boltzman Constant Btu/hr-ft^2-K^4

$\varepsilon CS := .23$ Emissivity of conduit surface

$QRUWS(TCS) := \sigma\cdot \varepsilon CS\cdot ACS\cdot L\cdot \left[(TCS)^4 - (TAR)^4\right]$ Heat transferred by radiation in Btu/hr-ft

Total Heat Transfer

$QTUS(TCS) := QRUWS(TCS) + QCUWS(TCS)$ Total heat transferred by convection and radiation from the unwrapped conduit surface Btu/hr-ft

The resistances from the previous section can be used by subtracting the resistance of the Darmatt firewrap

$$TCCR(TCS) := TCS + QTUS(TCS)\cdot\left[(RTOT) - \frac{RFW3}{L}\right]\cdot .293\cdot\frac{9}{5}$$

$TCS := root(TCCR(TCS) - TCR, TCS)$ Iteration of TCS until TCCR minus TCR equals zero

Presentation of variables resulting from solution for TCS

$(QTUS(TCS)) = 607.671$ $hUCS(TCS) = 0.323$

$QRUWS(TCS) = 294.789$ $QCUWS(TCS) = 312.882$

$TCS = 592.764$

$TCCR(TCS) = 653.4$ TCCR(TCS) equals TCR so a solution for TCS is obtained

F. Calculate the ampacity factor

$AF := \sqrt{\frac{QTWS(TWR)}{QTUS(TCS)}}$ $AF = 0.855$ Ampacity factor

G. Ampacity Derating Factor

$ADF := 1 - AF$

$ADF = 0.145$ Ampacity derating factor

4.6.5 CALCULATION OF CABLE AMPACITY DERATING FACTOR AND SUMMARY

THE ATTACHED SHEET PROVIDES A SUMMARY OF THE AMPACITY DERATING FACTORS CALCULATED THROUGHOUT THE CALCULATION

Case	Tray size	Orientation	Depth of Fill	Fire rating	Ampacity factor	Derate Factor	Comments		
1	12 x 4	H	1	1	0.611	0.389			
2	18 x 4	H	1	1	0.596	0.404			
3	24 x 6	H	1	1	0.598	0.402			
4	24 x 4	H	1	1	0.588	0.412			
5	12 x 4	H	2	1	0.639	0.361			
6	18 x 4	H	2	1	0.625	0.375			
7	24 x 6	H	2	1	0.628	0.372			
8	24 x 4	H	2	1	0.618	0.382			
9	12 X 4	H	3	1	0.662	0.338			
10	18 X 4	H	3	1	0.649	0.351			
11	24 X 6	H	3	1	0.651	0.349			
12	24 X 4	H	3	1	0.643	0.357			
13	12 X 4	H	1	3	0.507	0.493			
14	18 X 4	H	1	3	0.486	0.514			
15	24 X 6	H	1	3	0.485	0.515			
16	24 X 4	H	1	3	0.475	0.525			
17	12 X 4	H	2	3	0.538	0.462			
18	18 X 4	H	2	3	0.517	0.483			
19	24 X 6	H	2	3	0.516	0.484			
20	24 X 4	H	2	3	0.506	0.494			
21	12 X 4	H	3	3	0.563	0.437			
22	18 X 4	H	3	3	0.543	0.457			
23	24 X 6	H	3	3	0.542	0.458			
24	24 X 4	H	3	3	0.532	0.468			
25	24 x 12 x 30'	V	1	1	0.616	0.384			
26	24 x 12 x 19'	V	1	1	0.618	0.382			
27	24 x 12 x 30'	V	2	1	0.644	0.356			
28	24 x 12 x 19'	V	2	1	0.646	0.354			
29	24 x 12 x 30'	V	3	1	0.666	0.334			
30	24 x 12 x 19'	V	3	1	0.668	0.332			
31	24 x 12 x 30'	V	1	3	0.507	0.493			
32	24 x 12 x 19'	V	1	3	0.509	0.491			
33	24 x 12 x 30'	V	2	3	0.538	0.462			
34	24 x 12 x 19'	V	2	3	0.539	0.461			
35	24 x 12 x 30'	V	3	3	0.564	0.436			
36	24 x 12 x 19'	V	3	3	0.565	0.435			
37	3/4" conduit	H	n/a	3	0.818	0.182	1 3/C - 6 cable 600 V	363F17	
38	6" conduit	H	n/a	3	0.872	0.128	1 3/C - 6 cable 600V	363F17	
39	3/4" conduit	H	n/a	3	0.861	0.139	3 3/C - 2 cables 5 kV	363D35	NOTE 1
40	6" conduit	H	n/a	3	0.91	0.09	3 3/C - 2 cables 5 kV	363D35	
41	3/4" conduit	H	n/a	3	0.76	0.24	1 3/C - 500 kcmil cable 5 kV	363D38	NOTE 1
42	6" conduit	H	n/a	3	0.808	0.192	1 3/C - 500 kcmil cable 5 kV	363D38	
42a	4" conduit	H	n/a	3	0.783	0.217	1 3/C - 500 kcmil cable 5 kV	363D38	
43	3/4" conduit	H	n/a	3	0.814	0.186	1 3/C - 2 cable 5 kV	363D35	NOTE 1
44	6" conduit	H	n/a	3	0.868	0.132	1 3/C - 2 cable 5 kV	363D35	
45	3/4" conduit	H	n/a	3	0.818	0.182	3 1/C - 8 cables 600 V	363E38	
46	6" conduit	H	n/a	3	0.872	0.128	3 1/C - 8 cables 600 V	363E38	
47	30' long 6" dia	V	n/a	3	0.862	0.138	1 3/C - 500 kcmil cable 5 kV	363D38	NOTE 1
48	19' long 6" dia	V	n/a	3	0.855	0.145	1 3/C - 500 kcmil cable 5 kV	363D38	

NOTE 1 Due to the outside diameter of the cable and conduit this condition cannot exist in the field but was calculated to obtain a most conservative result.

REVISION	0	1						

4.7 Conclusions

The calculation of the cable ampacity factor and derating factor for the various configurations of cable in cable trays and conduit is calculated. The maximum derating is associated with a 3 hour fire barrier with 1" depth of fill for a 4" high by 24" wide cable tray (case 16). The maximum derating for a 1 hour fire barrier is also a 1" depth of fill for a 4" high by 24" wide cable tray (case 4). The calculation also shows that cable running through a wrapped horizontal cable tray is the worst case in comparison to a wrapped vertical tray. The calculation for the vertical cable tray uses the worst case from the horizontal tray calculation (24" wide tray) and two vertical lengths 19' and 30'. Vertical cable trays are 12" deep and therefore have additional surface area to provide for increased heat transfer.

Also it was shown that the ampacity derating of cable running through wrapped conduit is not as significant as cable through cable tray. In evaluating the effects of wrapping conduit with the firewrap the ampacity rating of the cable running through the conduit and the additional ampacity derating for the firewrap must be used in evaluating the overall ampacity rating of the cable.

The results are provided in section 4.6.7 of the calculation. An overall ampacity derating value of 55% is recommended to bound horizontal and vertical cable tray installations of 1 and 3 hour fire barriers with 1, 2, and 3 inch depths of fill for the various cable tray sizes used at Byron and Braidwood.

For cable being routed in wrapped conduit and not wrapped cable tray the ampacity of the cable running through the conduit must be derated by 25% which bounds the various conduit installations and provides margin for installation uncertainties.

The length of a vertical cable tray and vertical conduit does not significantly impact the ampacity derating factor and therefore may be used independent of length.

For cable installations in ambient air temperatures in excess of 40 °C in addition to the ampacity derating due to the firewrap the cable ampacity should be derated as required per standard practices as outlined in IPCEA P46-426.

CALCULATION NO: G-63	REV. 1	PAGE 191 OF 215
REVIEWED BY: Bill Perchiazzi		DATE: 1/3/95

YES	NO			REMARKS
☑	☐	1.	IS THE OBJECTIVE OF THE ANALYSIS CLEARLY STATED?	
☑	☐	2.	ARE ASSUMPTIONS AND ENGINEERING JUDGEMENTS VALID AND DOCUMENTED?	
☐	☑	3.	ARE THERE ASSUMPTIONS THAT NEED VERIFICATION?	
☑	☐	4.	ARE THE REFERENCES (I.E. DRAWINGS, CODES, STANDARDS) LISTED BY REVISION EDITION, DATE, ETC.?	
☑	☐	5.	IS THE DESIGN METHOD CORRECT AND APPROPRIATE FOR THIS ANALYSIS?	
☑	☐	6.	IS THE CALCULATION IN COMPLIANCE WITH DESIGN CRITERIA, CODES, STANDARDS, AND REG. GUIDES?	
☑	☐	7.	ARE THE UNITS CLEARLY IDENTIFIED, AND EQUATIONS PROPERLY DERIVED AND APPLIED?	
☑	☐	8.	ARE THE DESIGN INPUTS AND THEIR SOURCES IDENTIFIED AND IN COMPLIANCE WITH UFSAR & TECH SPECS?	
☑	☐	9.	ARE THE RESULTS COMPATIBLE WITH THE INPUTS AND RECOMMENDATIONS MADE?	

10. INDICATE TYPE OF CALCULATION (HAND-PREPARED AND/OR COMPUTER-AIDED) AND METHOD OF REVIEW:

☑ HAND PREPARED DESIGN CALCULATION

THE REVIEW OF THE HAND-PREPARED DESIGN CALCULATION WAS ACCOMPLISHED BY ONE OR A COMBINATION OF THE FOLLOWING (AS CHECKED):

- ☑ A DETAILED REVIEW OF THE ORIGINAL CALCULATION
- ☑ A REVIEW BY AN ALTERNATE, SIMPLIFIED OR APPROXIMATE METHOD OF CALCULATION
- ☐ A REVIEW OF A REPRESENTATIVE SAMPLE OF REPETITIVE CALCULATIONS
- ☐ A REVIEW OF THE CALCULATION AGAINST A SIMILAR CALCULATION PREVIOUSLY PERFORMED

☐ COMPUTER AIDED DESIGN CALCULATION N/A

YES	NO		
☐	☐	11.	IS THE PROGRAM APPLICABLE TO THIS PROBLEM?
☐	☐	12.	IS THE COMPUTER PROGRAM VALIDATED PER QP 3-54?
☐	☐	13.	IS THE COMPUTER PROGRAM VALIDATED BY OTHER AE'S / ORGANIZATIONS AND HAS IT BEEN PREVIOUSLY APPLIED TO NUCLEAR PROJECTS?
☐	☐	14.	IS THE INPUT DATA IN CONFORMANCE WITH THE DESIGN INPUTS?
☐	☐	15.	ARE THE RESULTS CONSISTENT WITH THE ASSUMPTIONS AND THE INPUT DATA?
☐	☐	16.	IS A LIST OF THE PROGRAMS USED AND DATE OF EACH COMPUTER RUN REFERENCED IN THE CALCULATION?
☐	☐	17.	IS THE PROGRAM VERSION AND IT'S REVISION IDENTIFIED ON THE COMPUTER RUN?

August 5, 1994

TO: R. Gesior
NETS/M&S
Downers Grove

SUBJECT: Transmittal of NDIT #BYR-94-029 Rev. 0
Chron #0302309

Attached please find the NDIT #BYR-94-029 Rev. 0, Chron #0302309. This NDIT is provided in response to your request via letter Chron #210357 dated 7/15/94.

If there are any questions on this NDIT, please contact M. P. Patel at Byron extension 2493.

Prepared by:

M. P. Patel
SEC Mod Design
Byron Nuclear Station

MPP/cb

Attachment

cc: R. Campbell/P. Donavin
S. Javidan
G. Contrady
D. Robinson
B. Jacobs (Ewd)

h:\engr\mpp\ndit029.wpf

CECO NED NUCLEAR DESIGN INFORMATION TRANSMITTAL (NDIT)

☒ SAFETY RELATED ☐ NON-SAFETY RELATED	NDIT NO. BYR-94-029 PAGE 1 OF 2

SUBJECT: Transmittal of Requested Data Per Chron #210357, dated July 15, 1994
SENT TO (Name/Dept.): R. Gesior
DISTRIBUTION: NETS M&S, NEDCC, Site Chron, Central File, S. Javidan, G. Contrady

DESCRIPTION OF NUCLEAR DESIGN INFORMATION AND PURPOSE OF ISSUANCE:

This NDIT is provided in response to NETS M&S Group dated July 15, 1994, Chron #210357. The purpose of this NDIT is to provide Byron specific installation information for a generic cable derating calculation to be used for anticipated Darmatt fire barrier installations.

1) Ambient air temperature in past calculations have been based upon 40°C. This basis is valid, since equipment (including cable raceways) located in most of the general plant areas are rated for 40° C Ambient. Some areas may experience 50°C or 60° C ambient rating too. Derating factors for such areas should be calculated (Ref. #6).

2) The normal sizes of horizontal trays used at Byron are 12" x 4", 18" x 4", 24" x 4". There are cases where 2" or 4" additional side rails are installed. Vertical risers are also similar in width. However, vertical risers are 12" deep. The worst case from above should be used for calculational purposes (Ref. #5).

3) There are cases where cable trays are covered and there are cases where cable trays are not covered. For the purpose of this calculation, assume the worse case.

7) For answers to Items 4 thru 7, information to be submitted by TRANSCO to NETS directly.

M. P. Patel Preparer (PRINT)	EDWARD W. TOVO Reviewer (PRINT)	Richard A. Campbell Approver (PRINT)
[signature] / 8-4-94 Signature/Date	[signature] 8/5/94 Signature/Date	[signature] 8/5/94 Signature/Date

STATUS OF INFORMATION: ☒ APPROVED FOR USE ☐ PRELIMINARY

NDIT SOURCE DOCUMENT(S)

CECO NED NUCLEAR DESIGN INFORMATION TRANSMITTAL (NDIT)

NDIT NO. BYR-94-029

8) Maximum cable tray fill should be 3". S&L calculations uses design index 125% to 150% in such cases. However, calc should address 1", 2" & 3" fill cases, since it will be more convenient to apply to individual cases (Ref. #1).

9) A 15% derating for tightly closed cover trays is based on a paper presented to 44th American Power Conference in 1982 by S&L per "Tests at Braidwood Station on the effects of fire stops on the Ampacity Rating of Power Cables". For raised covers, 5% derating is used per "Stolpe" method with respect to open cable trays rating (Ref. #2).

10. Conduits in most cases used for power cables are in the following sizes: 3/4", 1", 1.5", 2", 2.5", 3", 4" and 5". These are rigid steel conduits zinc coated (per ANSI C80.1), refer to CECo EIS #N-EM 0003. Flexible conduits consist of synthetic polymer outer cover over a flexible interlocked steel core (refer to EIS #N-EM 0003) consists of continuous strip of galvanized steel (ANSI/UL 360) (Ref. #5).

11) Worse case fill for a single cable in any size conduit is 53% fill area (CECo EIS #N-C-0001).

REFERENCES

1) S&L Cable Tray Loading (S106-1) from SLICE Report.

2) J. Stolpe's paper for calculating "Ampacities for Cables in Randomly Filled Trays" presented to IEEE, July 12, 1970.

3) CECo Electrical Installation Standards
   - N-EM-0001 Rev. 3
   - N-EM-0003 Rev. 3
   - N-C-0001 Rev. 4

4) S&L DIT # DIT-BB-EXT-0730 dated 1-25-94.

5) S&L TSI Fire Wrapped Conduits & Cable Tray Report dated 12-22-92 for Several Conduits & Cable Tray Sizes.

6) Refer to UFSAR Table 3.11.2 for Plant Environment Conditions.

ATTACHMENT 2 70 of 217 195 215 G-63 REV.0

SARGENT & LUNDY
ENGINEERS

EXTERNAL DESIGN INFORMATION TRANSMITTAL

DIT-BB-EXT-0836

July 21, 1994
Project No. 9135-160
File No. 4.2 & 1.0
(DIT-BB-EXT-0836)

ComEd
Byron/Braidwood Stations - Units 1&2

CABLE AMPACITY DERATING FOR DARMATT FIRE BARRIER
MODIFICATION NO. N/A
SYSTEM CODE: N/A

Mr.R. A. Gesior
NETS Engineer
ComEd
1400 Opus Place
Downers Grove, IL 60515-5701

Dear Mr. Gesior:

In response to your request during our July 20, 1994, meeting, I am transmitting to you the LaSalle and Zion Station calculations indicated on page 2 of this External Design Information Transmittal.

If you have any questions, please feel free to contact me at (312)269-2196.

Yours very truly,

D. P. Galanis

D. P. Galanis
Senior Electrical
Project Engineer

DPG:jj
Enclosure - Addressee Only
Copies:
DDL #C200/C010
K. L. Kofron
CHRON System
G. P. Wagner
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P. R. Donavin
W. C. Cleff/I. T. Kisisel
S. Z. Haddad
J. R. Meister
P. H. Kirsch/File No. 4.2
M. S. Leutloff
D. V. Radice
D. W. Robinson
Byron/Braidwood Project File No. 1.0
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ATTACHMENT 2
CALC No. G-63 Rev0
PAGE 70 of 117

Form PI-CEC-PG-0006.1, Rev. 4 (01-28-94)

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SARGENT & LUNDY
ENGINEERS

EXTERNAL DESIGN INFORMATION TRANSMITTAL

KOJ 1-7-95

DIT-BB-EXT-00[illegible]

STATUS OF INFORMATION:

_X_ APPROVED
___ PRELIMINARY
___ REFERENCE/INFORMATION ONLY (not for design purposes)

_X_ SAFETY RELATED
___ NON-SAFETY RELATED
___ REGULATORY RELATED

IDENTIFICATION OF THE SPECIFIC DESIGN INFORMATION TRANSMITTED AND PURPOSE OF ISSUE (List any supporting documents attached to DIT by its title, revision and/or issue date, and total number of pages for each supporting document.)

Enclosed is one copy each of the following Sargent & Lundy calculations:

1. LaSalle Station Calculation 4266-EAD-13, Rev. 0, titled "Cable Tray Heat Intensity" (26 pages).

2. Zion Station Calculation 8840-EAD-002, Rev. 0, titled "Effect of 1 Hour Fire Coating on Ampacity of 600V Power Cables in 3" Conduit," (12 pages).

These calculations are transmitted to you as a reference for your preparation of a new Byron/Braidwood calculation that will establish cable ampacity derating requirements for raceways that may be wrapped with Darmatt fire barriers. Sargent & Lundy will assist you in establishing the methodology for this new calculation as well as review it upon its completion.

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PAGE 71 OF 117

SOURCE OF INFORMATION

Calc. No. N/A ___________ Report No. N/A ___________

Other ___________

D. P. Galanis	EPED	D. P. Galanis	07-21-94
Preparer	Division	Preparer's Signature	Date
N/A			
Reviewer	Division	Reviewer's Signature	Date

Form PI-CEC-PG-0006.1, Rev. 4 (01-28-94)

CAME 1 - GENERAL EAD

SARGENT & LUNDY ENGINEERS CHICAGO

Calcs. For CABLE TRAY HEAT INTENSITY		Calc. No. 4266-EAD-13	
		Rev. 0	Date 2-5-82
X Safety-Related	Non-Safety-Related	Page 1	of 26

Client	COMMONWEALTH EDISON COMPANY	Prepared by William G. Bleuthe	Date 2-5-82
Project	LASALLE	Reviewed by James M. Babrich	Date 2-8-82
Proj. No.	4266-00 Equip. No.	Approved by S. Hadland	Date 2-8-82

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I. PAGE REVISION SUMMARY

A. All Pages Are Revision 0

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This calculation has been reviewed by a detailed check of the original

TMP 2-8-82

SARGENT & LUNDY ENGINEERS CHICAGO	Calcs. For CABLE TRAY HEAT INTENSITY			Calc. No. 4266-EAD-13	
	X Safety-Related		Non-Safety-Related	Rev. 0	Date 2-5-82
				Page 8	of 26

Client	COMMONWEALTH EDISON COMPANY	Prepared by	W. G. BLOETHE	Date 2-5-82
Project	LASALLE	Reviewed by	[illegible]	Date [illegible]
Proj. No.	4266-00 Equip. No.	Approved by		Date

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F. NOTE ON THE DEFINITION OF HEAT INTENSITY

"Heat Intensity" is defined as the heat produced per unit cross sectional area of cable. Depth of fill is defined as follows:

$$\text{Depth Of Fill} = \frac{4}{\pi}\ \frac{\text{Area Of Cables}}{\text{Width Of Tray}}$$

$$\text{Depth of fill} \times \text{Width of tray} = \frac{4}{\pi}\ \text{Area of cables}$$

$$\text{Cross sectional area of tray} = \frac{4}{\pi}\ \text{Area of cables}$$

The above equations are based on the heat produced per unit cross sectional area of tray. Therefore, the heat values given by these equations must be multiplied by $\frac{4}{\pi}$ to give heat intensity.

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Rev 1-3-95

IV. APPROACH TO CALCULATIONS

A.

The calculation of the heat intensity is an iterative procedure. A value of heat intensity is assumed and the actual heat dissipated by the tray is calculated. Based on the calculated heat dissipation, a new heat intensity is calculated. This is repeated until the desired accuracy is attained.

The initial iterations have been performed in preliminary calculations. Only the last one to three iterations will be shown here.

Form GQ 3.08.1 Rev 2

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XIII. SUMMARY

A.

DEPTH OF FILL (in)	HEAT INTENSITY $(w \cdot ft^{-1} in^{-2})$
0.5	14.96
1.0	6.74
1.5	4.09
2.0	2.79
2.5	2.06
3.0	1.6
3.5	1.29
4.0	1.07

Form GO 3.08.1 Rev 2

ATTACHMENT 2

CALC No. G63 Rev 0

CABLE TRAY HEAT INTENSITY
SAFETY RELATED

6-63 REV. 0

Rev. 0 2-5-82

PROJ. No. 4266	CALC. No. EAD-13	P. 26 of 26
PROJECT LASALLE		
Prepared by W. G. BLOETHE		Date 2-5-82
Reviewed by J. M. PABICH		Date 2-8-82
Approved by		Date

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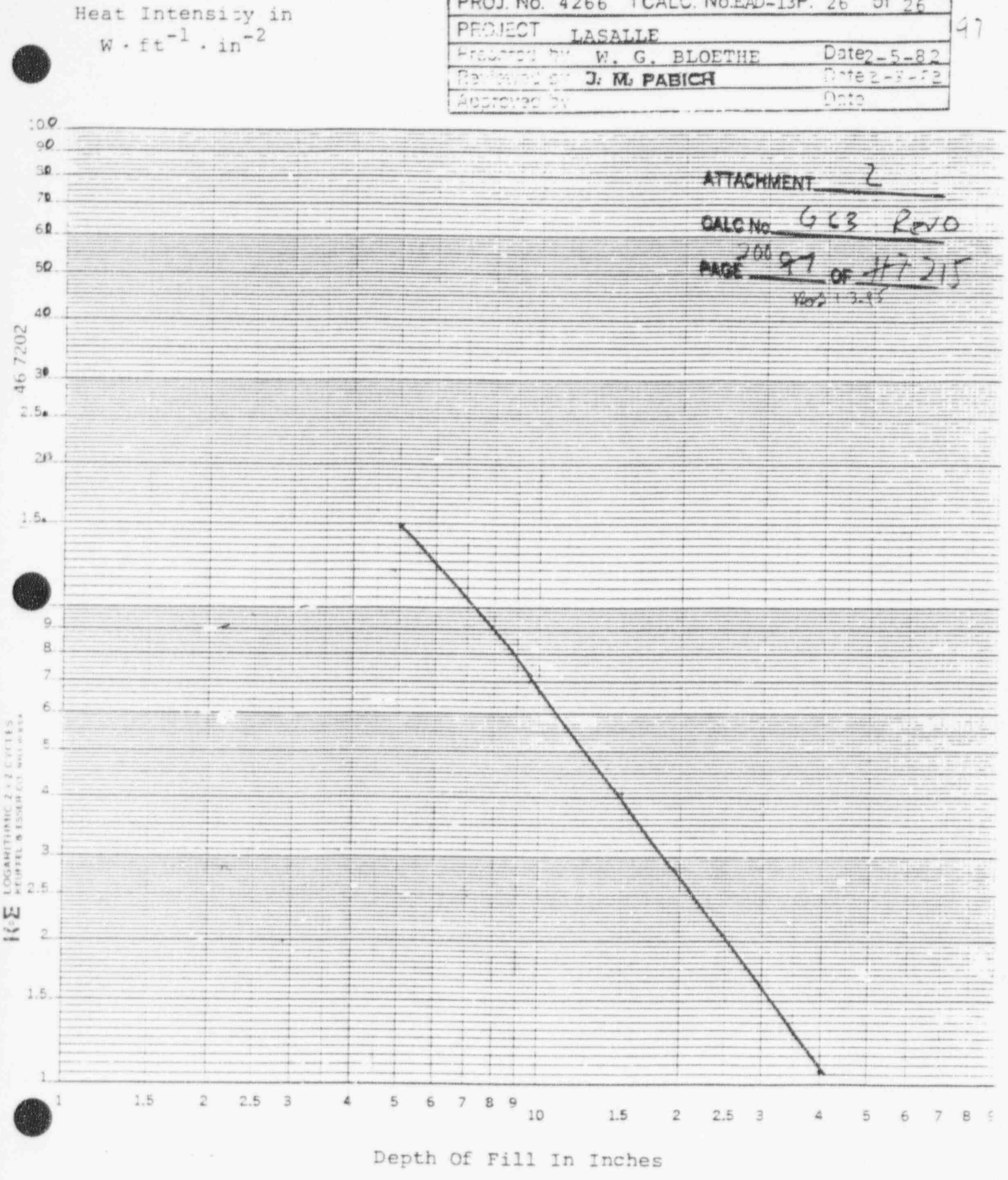
Rev 3 1-3-95



TESTS AT BRAIDWOOD STATION ON THE EFFECTS OF FIRE STOPS ON THE AMPACITY RATING OF POWER CABLES

G-63 REV. C

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~~Calc. No. 4266/19652~~
~~Rev. 0~~
~~Page A2 of~~
~~Project No. 9376-20~~

S. Z. HADDAD
and
W. G. BLOETHE
Sargent & Lundy
Chicago

D. C. LAMKEN

H. K. STOLT
and
G. SYKORA
Commonwealth Edison Company
Chicago

INTRODUCTION

A fire stop is a physical barrier constructed at a conduit or cable tray penetration through a wall or floor for the purpose of preventing the spread of a fire along the cable tray or conduit system from one area to another. The fire-stop material must completely surround and enclose the cable and tray in order to form a -resistant barrier. The fire-stop material surrounding the cables is required to have reasonably good insulating qualities and may therefore be expected to have a relatively high thermal resistance. Consequently, the maximum temperature of the conductor inside the fire stop is expected to be higher than the maximum temperature of the conductor outside the fire stop. The current-carrying capacity of cables passing through fire stops may, therefore, have to be reduced to prevent the maximum conductor temperature within the fire stop from exceeding the rated insulation temperature.

To investigate the impact of fire stops on the ampacity rating of cables, Sargent & Lundy and Commonwealth Edison Company conducted a series of fire-stop cable ampacity tests over a time period extending from December 1979 through September 1980. The results of these tests were used to design and verify a computer program developed to evaluate cable ampacity deratings for various fire-stop designs. This paper describes the test setup and procedures followed for the different types of tests conducted and presents the test results and the conclusions that can be drawn from these results.

TEST SETUP

The tests were conducted at the Braidwood Nuclear on at a location where cable tray penetrations are to be installed through a three-foot concrete wall. There are eight openings in the wall for cable tray penetrations that are arranged in four horizontal layers with two openings per layer. Ten cable trays were used in the test; four of these were installed in the top two openings (two per opening) and the remaining six were installed in the bottom three layers. These cable trays were loaded with the power cables to be tested. Two additional trays were installed and left empty since in the actual installation these trays will be loaded with control cables. Each cable tray was 18-inches wide, 4-inches deep and 20-feet long. The trays were installed through the penetrations and extended 8½-feet on each side of the three-foot thick wall.

The cables used in the test were both three conductor and triplexed cables selected to have a range of conductor size and voltage ratings to allow investigating the impact of these two parameters on the thermal behavior of the cable in the fire stop and, therefore, on the cable derating. Each cable was run in a cable tray through the wall penetration and looped back in the corresponding cable tray located in the other wall penetration at the same level. This looping process was repeated a number of times until a depth of fill of approximately two inches was achieved. In the cable crossover areas, the cables were supported on plywood to reduce the heat dissipation from the cables at these locations and thereby minimize the end effect on the temperature of the cables within the trays.

Figure 1 is an elevation view of the test installation showing the location of the cable trays and the size, type and number of cables used in each tray.

The temperatures of the cable conductors and jackets and the cable trays, wall surface and room ambient were monitored using No. 20 copper-constantan thermocouples that were recorded periodically during the test by a data logger. The thermocouples measuring the conductor temperature were placed in contact with the conductors by puncturing the insulation at an angle of 30 degrees and inserting the thermocouple head so that it made contact with the conductor. The thermocouple leads were taped to secure the thermocouple in place. A total of over 400 thermocouples was used.

Thermocouples were located at cross sections along the cable of each layer similar to those shown in Figure 2. Cross sections of thermocouples were located both inside and outside the wall. At each cross section thermocouples sensed both conductor and cable tray temperatures. Figure 3 shows the locations of thermocouples used in a typical cable tray. Additional

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TABLE II
AMPACITY DERATING AT FIRE STOPS (3-IN WALL, 10 TRAY PENETRATIONS)

Type of Fire Stop	Derating in Percent* Conductor Type					
	#1/0 8 kV	#2 5 kV	#1/0 5kV	#6 600 V	#1/0 600 V	500kCM 600 V
Gypsum fire stop at both sides of wall (each 3½" gypsum-6" thermal fiber	32	30	28	30	22	26
Modified gypsum fire stop on one side of wall (5" gypsum-4" thermal fiber	22	21	—	18	8	13
10" 20-lb/ft³ silicone** fire stop on one side of wall	23	19	20	17	8	14
6" 80-lb/ft³ silicone** fire stop on one side of wall	19	15	22***	12	8	11
3' 145-lb/ft³ silicone fire stop	16	10	15	13	10	9

$$\text{*Derating (\%)} = 100\,\frac{\text{Ampacity in Tray} - \text{Ampacity in Fire Stop}}{\text{Ampacity in Tray}}$$

**These tests approached steady-state conditions but did not completely stabilize.
***This penetration had a 3' fire stop. The derating at steady-state went up to 25%.

TABLE III
AMPACITY DERATING DUE TO CABLE COVERINGS ON AMPACITY

Application	Derating, %*
Raised pan covers	5
Tight pan covers	15
RAPCO coating (3" foam, ½" plaster)	40
Gypsum (¾" thick) coating	15
Flamastic ($^1/_{16}$" thick) coating	0
Carboline ($^1/_{16}$" thick) coating	0

*Derating (%)

$$= 100\,\frac{\text{Ampacity in Tray} - \text{Ampacity With Covers or Coating}}{\text{Ampacity in Tray}}$$

where Δt_c and Δt_f are conductor temperature rise above ambient at the cable tray and fire stop, respectively. This formula can be used to obtain the derating due to the fire stop or coating using test data to derive the temperature rise over the ambient temperature for the cable tray outside the treated area and the rise above ambient inside the fire stop or coated area.

The calculated derating factors for the various types of fire stops tested are given in *Table II*, and the derating factors for coatings and covers are given in *Table III*.

A number of miscellaneous factors seemed to affect the amount of derating caused by the fire stop:

1. Cable Size—The smaller the conductor size, the greater the increase in temperature rise within the fire stop.
2. Cable Insulation—The greater the voltage rating of the cable and, therefore, the insulation thickness, the greater the increase in temperature rise within the fire stop.
3. Cable Layout—An even and uniform layout of cables in the tray results in lower conductor temperatures. Conversely, random cable configurations and the crowding of cables into one location in the tray results in increasing the temperature in the crowded part of the tray. However, an effort is normally made to improve the layout of the cables at the fire stop. The thermal benefits resulting from the improved cable configuration at the fire stop tend to reduce the increase in conductor temperature rise at the fire stop and, therefore, reduce the magnitude of the required derating. These benefits, although difficult to quantify, indicate a measure of conservatism in the derating factors given in *Table II* since the table is based on random cable laid both inside and outside the wall.

COMPUTER PROGRAM

Based on the temperature values measured at the various critical locations in the test setup, a computer program was developed to evaluate conductor temperature rise within fire stops by modeling the thermal characteristics and physical configuration of the wall, the fire stop, the cables, and the cable tray. The test results were used to define some of the boundary conditions in the heat flow simulation. Values calculated by the program show reasonable agreement with measured values.

The program utilized network theory and finite difference techniques to solve the heat problem. The modeling method used simulates all the available heat flow paths from the cables in the fire stop to the ambient. These paths include longitudinal heat conduction along the cable tray and the radial heat conduction through the fire stop and concrete wall. The heat is then dissipated by convection and radiation from the cable tray and concrete wall.

The computer model can evaluate the required derating for fire stops of different materials, physical di-

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: Convec-
ms [4]

Table 7-4 Simplified Equations for Free Convection from Various Surfaces to Air at Atmospheric Pressure According to McAdams [4]

Surface	Laminar, $10^4 < Gr_f\,Pr_f < 10^9$	Turbulent, $Gr_f\,Pr_f > 10^9$
Vertical planes or cylinders	$h = 0.29\left(\frac{\Delta T}{L}\right)^{1/4}$	$h = 0.19(\Delta T)^{1/3}$
Horizontal cylinders	$h = 0.27\left(\frac{\Delta T}{d}\right)^{1/4}$	$h = 0.18(\Delta T)^{1/3}$
Horizontal plates:		
Heated plates facing upward or cooled plates facing downward	$h = 0.27\left(\frac{\Delta T}{L}\right)^{1/4}$ ✓	$h = 0.22(\Delta T)^{1/3}$
Heated plates facing downward or cooled plates facing upward	$h = 0.12\left(\frac{\Delta T}{L}\right)^{1/4}$ ✓	

h in Btu/hr-ft²-°F
$\Delta T = T_w - T_\infty$, °F
L = vertical or horizontal dimension, ft
d = diameter, ft

7-7 SIMPLIFIED EQUATIONS FOR AIR

Simplified equations for the heat-transfer coefficient from various surfaces to air at atmospheric pressure and moderate temperatures are given in Table 7-4.

Example 7-1

Steam at 500°F flows through a 12-in.-OD pipe which is exposed to atmospheric air at 50°F. Calculate the heat transfer per foot of length.

Solution We first determine the Grashof-Prandtl number product and then select the appropriate constants from Table 7-2 for use with Eq. (7-23). The properties of air are evaluated at the film temperature.

$$T_f = \frac{T_w + T_\infty}{2} = \frac{500 + 50}{2} = 275°F$$

$$\rho = 0.054\ lb_m/ft^3$$
$$c_p = 0.24$$
$$\mu = 1.57 \times 10^{-5}\ lb_m/ft\text{-}sec = 0.0565\ lb_m/ft\text{-}hr$$
$$k = 0.0197\ Btu/hr\text{-}ft\text{-}°F$$
$$\beta = 1.36 \times 10^{-3}\ °F^{-1}$$

$$Gr_d\,Pr = \frac{c_p g \beta (T_w - T_\infty)\rho^2 d^3}{k\mu}$$
$$= \frac{(0.24)(32.2)(3600)^2(1.36 \times 10^{-3})(500 - 50)(0.054)^2(1)^3}{(0.0197)(0.0565)}$$
$$= 1.60 \times 10^8$$

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HOLLOW RECTANGULAR CROSS SECTION - TWO-DIMENSIONAL HEAT FLOW

Inner and Outer Surface Each at a Different Uniform Temperature
Heat Input at One Surface (The Warmer One)

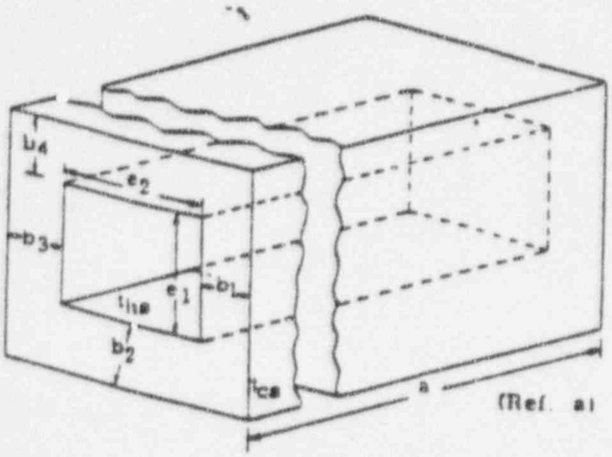
Maximum Temperature*

$t_{hs} - t_{cs} = qR$

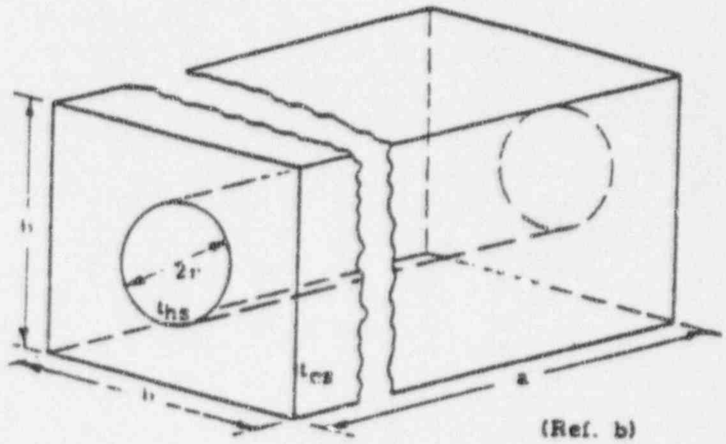
t_{hs} = temperature of hot surface

t_{cs} = temperature of cold surface

Thick Walls



(Ref. a)



(Ref. b)

$$R = \frac{1/ka}{\left(\frac{e_1}{b_1} + .54\right) + \left(\frac{e_2}{b_2} + .54\right) + \left(\frac{e_1}{b_3} + .54\right) + \left(\frac{e_2}{b_4} + .54\right)}$$

$$R = \frac{1}{2\pi ak} \ln\left(1.08\frac{b}{2r}\right)$$

REFERENCES

a. McAdams, Heat Transmission, 2nd edition, p. 26.
b. Kutateladze, S.S., "Fundamentals of Heat Transfer," Academic Press, N.Y., 1963, p. 89.

* For symbols, see Section G502.1, p. 1, and sketches above.

HOLLOW CIRCULAR CYLINDER AND SPHERE

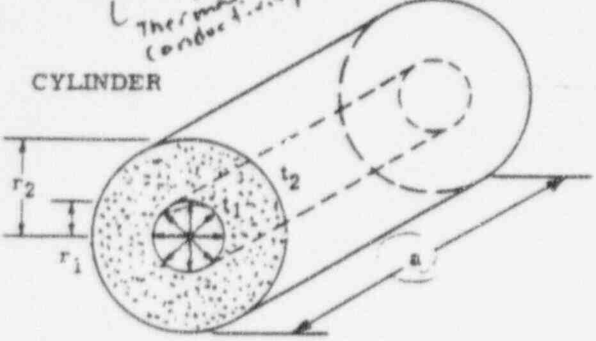
Radial Heat Flow (Axial Heat Flow Negligible)

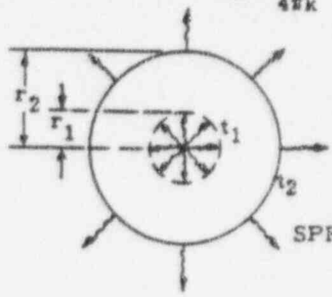
Inner and outer surfaces each at a different uniform temperature, heat input at one surface (the warmer one).

For heat input distributed throughout the material, see page 10.
For solid cylinder, see page 4.
For hollow cylinder of several layers, see page 11.

$R = \frac{1}{2\pi k a} \ln \frac{r_2}{r_1}$ (thermal conductivity)

$R = \frac{1}{4\pi k}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$





CYLINDER	SPHERE
Mean temperature t_m* for input at inner surface $t_m = t_s + \frac{q}{4\pi k a}\left[1 - \frac{2\log_e \frac{r_2}{r_1}}{\left(\frac{r_2}{r_1}\right)^2 - 1}\right]$	----
For input at outer surface, $t_m = t_1 + \frac{q}{4\pi k a}\left[\frac{2\log_e \frac{r_2}{r_1}}{1 - \left(\frac{r_1}{r_2}\right)^2} - 1\right]$	----
FOR CYLINDER Maximum temperature t_{max} (at r_1 or r_2) Exact value:* $t_{max} = t_s + \frac{q}{2\pi k a}\log_e \frac{r_2}{r_1}$ or, in terms of logarithmic mean area A_L, $t_{max} = t_s + \frac{q(r_2 - r_1)}{kA_L}$ Approximate value: $t_{max} = t_s + \frac{q(r_2 - r_1)}{kA_a}$ which is too high by: 4% 10% 15% when r_2/r_1 is: 2 3 4	FOR SPHERE Maximum temperature (at r_1) Exact value: $t_{max} = t_2 + \frac{q(r_2 - r_1)}{4\pi k r_1 r_2} = t_1 + \frac{q}{4\pi k}\left(\frac{1 - \frac{r_1}{r_2}}{r_1}\right)$ or, in terms of geometric mean area, $t_{max} = t_2 + \frac{q(r_2 - r_1)}{kA_G}$ Approximate value: $t_{max} = t_2 + \frac{q(r_2 - r_1)}{kA_a}$ is too high by: 0% 8% 25% when r_2/r_1 = 1 1.5 2

*Symbols: t_s = temperature of surface toward which heat is flowing. $t_s = t_1$ for input at outer surface. $t_s = t_2$ for input at inner surface. For other symbols see Section G502.1, p. 1, and sketches above.

ATTACHMENT 6
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Page 206 of 215

TRANSCO. PRODUCTS INC.
EXECUTIVE OFFICES
Fifty Five East Jackson Boulevard
Suite 2100
Chicago, Illinois 60604-4166
312-427-2818
Facsimile 312-427-4975

Via Facsimile (708)663-7181

July 27, 1994

Shahram Javidan
Commonwealth Edison Company
Nuclear Engineering & Technology Services
1400 Opus Place, Suite 400
Downers Grove, Illinois 60515

Subject: Darmatt KM1
Material Specification Sheets

Dear Shahram,

Attached are the latest data sheets for the DARMATT KM1 raceway for evaluation. These are the proposed products for use as raceway firewraps at the Braidwood and Byron Nuclear Power Stations.

Please note that all weights and thicknesses listed for the 1 and 3 hour systems represent the maximums, including all tolerances.

In addition, we have provided typical installation details. The typical installation of these products will not create any voids, cracks or dead air spaces.

Please review the attached data and contact us if you have any questions or require further information.

Sincerely,
TRANSCO PRODUCTS INC.

Kevin J. Hawks
Manager Fire Protection

Enclosures
cc: J. Behn w/encl.
D. Robinson w/encl.
R. Jacobs w/encl.

Attachment 6

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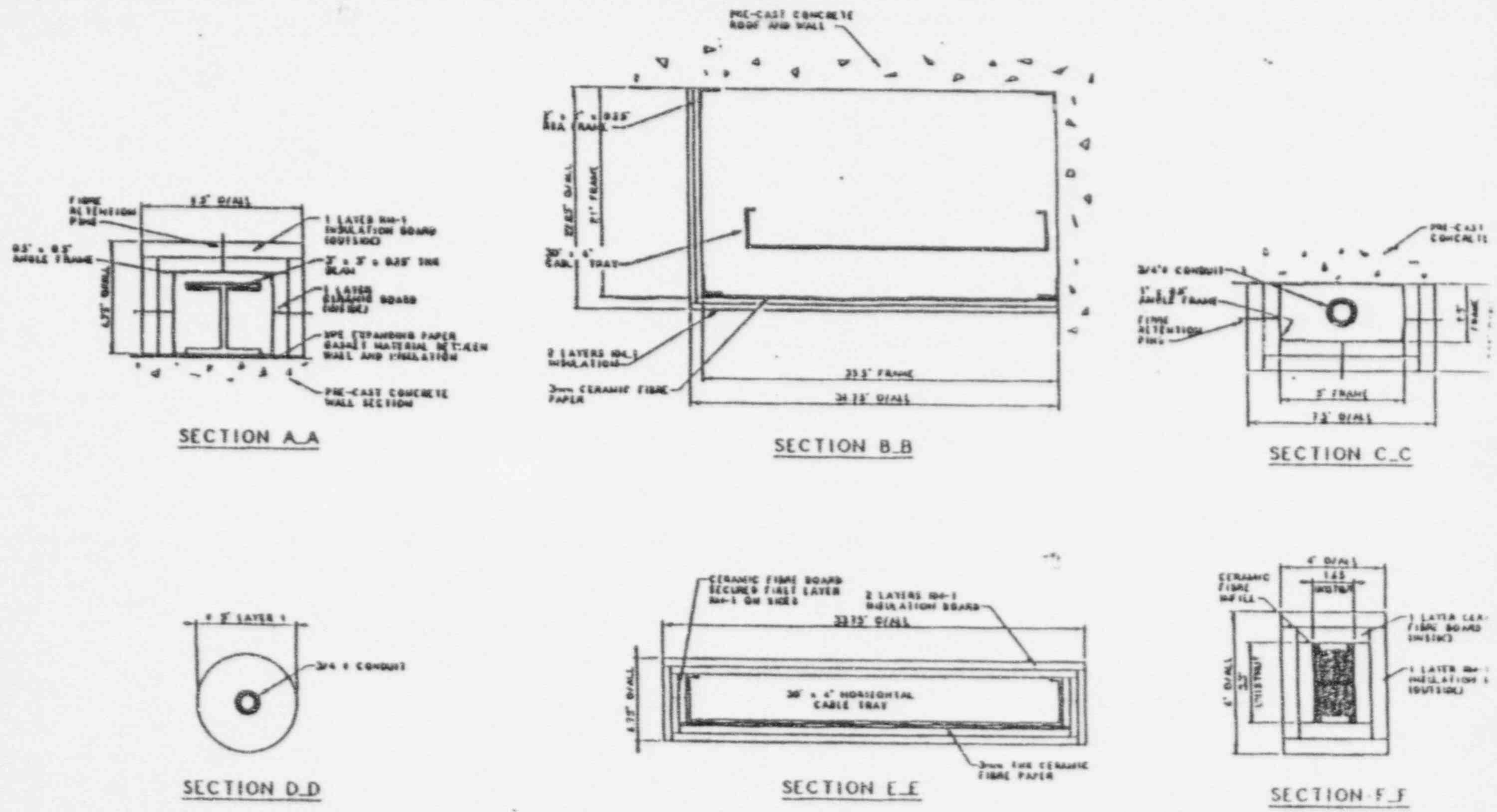
REV.0
267 ?
Page 19a of A
Rev 1-3-95

Any errors on this drawing are to be reported to the drawing office immediately/if in doubt ask



Darchem Engineering Ltd
Stillington
Stockton-on-Tees
Cleveland TS21 1LB
England

LASALLE FIRE-TEST

SECTIONS THROUGH INSULATED RAC[E]

original scale N.T.S.

310106 / DSK

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do not scale from drawing

third angle projection

order no 310106

customer LASALLE

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REV. 0
110

ATTACHMENT 6
CALC No. 663 Rev 0
PAGE ~~110~~ 208 OF ~~117~~ 215 kvs 1-3-95

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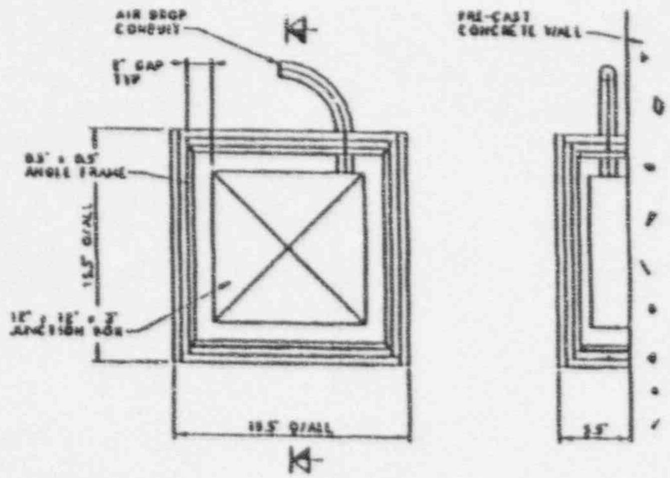
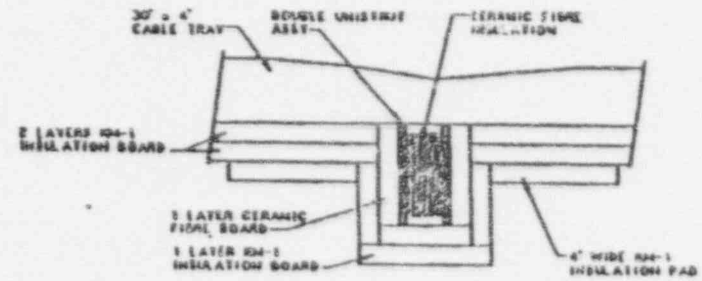


SECTION G_G



SECTION H_H

Darchem Engineering Ltd
Stillington
Stockton-on-Tees
Cleveland TS21 1LB
England

title: LASALLE FIRE-TEST
SECTIONS THROUGH INSULATED RA

	name	date
drawn	B.W.	
checked	K.M.	
approved	K.M.	

original scale: N.T.S.
drawing no: 310106 / DS
order no: 310106
customer: LASALLE

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third angle projection

Darmatt KM1
1 and 3hr Systems
Data Sheet.. DDS 006
Rev 1

- Emissivity 0.7

issued by
K J MURRAY

27. 7 . 94

6-63
REV. 0
112

ATTACHMENT 6

CALC No. G63 Rev 0

PAGE 210 ~~112~~ rev 1-7-95 OF ~~117~~ 215

Darmatt KM1:
Board for 1 hr System
Data Sheet : DDS 001
Rev 3

- Thickness 0.51" + 0.25" - 0.0
- Weight / sq ft 2.663 lbs + - 5%
- Thermal Conductivity 0.783 Btu in/hr sq ft °F @ 156 °F mean

issued by
K J MURRAY

18. 7 . 94

Darmatt KM1 : 1 Hour System

Data Sheet : DDS 001a

- Nominal Thickness 1.25"

- Weight / sq ft 6.3 lbs + - 15%

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K J Murray

ATTACHMENT 6

CALC No. G63 Rev 0

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G-63
REV. 0
114

Darmatt KM1
Board for 3 hr System
Data Sheet : DDS 002
Rev 3

- Thickness 0.59" + 0.16" - 0.0
- Weight / sq ft 2.83 lbs + - 5%
- Thermal Conductivity 0.783 Btu in/hr sq ft °F @ 156 °F mean

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K J MURRAY

27. 7 . 94

G-63
REV. 0
115

ATTACHMENT 6

CALC No. G63 Rev 0

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Darmatt KM1
3hr System
Data Sheet : DDS 002a
Rev 3

- Nominal Thickness 2.61"

- Nominal Weight / sq ft 11.1 lbs

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27. 7. 94

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REV. 0
116

ATTACHMENT 6

CALC No. G63 Rev 0

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Darmatt KM1 Conduit : 1 Hour System

Data Sheet : DDS 003a

- Nominal Thickness 1.25"
- Nominal Weight lb/ linear ft

3/4"	4.5
1"	5.1
2"	7.0
3"	9.1
4"	11.0
5"	13.0
6"	15.0

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K J MURRAY 4 . 7 . 94

K J Murray

Darmatt KM1 Conduit: 3 Hour System

Data Sheet : DDS 003b

- Nominal Thickness 3.0"
- Nominal Weight lb/ linear ft.

3/4"	17.7
1"	18.9
2"	23.3
3"	28.2
4"	32.5
5"	37.0
6"	41.6

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