SPES PUMP

CHARACTERIZATION

M. Rigamonti
O. Vescovi

SIET - NT/54

This work, part of ENEA's LWR Safety Research Program was performed in the frame of ENEA-SIET contract.
(milestone NE AE 10)

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	REV.	N. PAGG.	DATA DI EMISSIONE	FIRMA	VISTO
SIET NT/45	0	7	30.12.87		

LISTA DI DISTRIBUZIONE

SIET

C. MEDICH	1
C. MERLI	1
R. RAVETTA	1
M. RIGAMONTI	1
O. VESCOVI	1
ARCH./SIET	1

ENEA

A. ANNUNZIATO	TERM/MEP/SISREF	1
G. CAPUANO	TERM/RISIL	1
P. FICARA	TERM/RISIL	1

C O N T E N T S

1. INTRODUCTION

The SPES recirculation pump characterization is required in order to obtain experimental information concerning ISP test (LOFW + DELAYED EFW). During such test the pump operates in the following conditions:

a) pump operating at nominal conditions (3200 RPM, 0.014 m^3/s) with single phase fluid

b) pump in coastdown mode with rotational speed decreasing from the nominal value to zero (single phase fluid)

c) unfed pump with fluid in single and two phase conditions (natural circulation).

In order to obtain homologous curves in the first quadrant with fluid in single phase conditions an experimental work has been carried out concerning conditions of points a) and b). To obtain experimental data related to point c) conditions (dragged rotor) measurements have been carried out during single phase natural circulation test. The experimental measurements have been carried out using RP-1 pump; for the tests concerning points a) and b) a proper circuit has been used.

2. EXPERIMENTAL LOOP

The tests concerning points a) and b) (ch. 1) have been performed using the loop nr. 1 of the SPES plant bypassing downcomer and power channel by means a pipe (2" sch 40) connecting steam generator inlet to cold leg (fig. 1). This line has been provided with a manual control valve to vary the loop pressure drops. The cold legs nr. 2,3 and the channel side downcomer have been locked.

3. EXPERIMENTAL TEST DESCRIPTION

Five tests have been carried out (test "A", "B", "C", "D", "E").

3.1. Test "A"

The following parameters have been measured:

- mass flowrate (F - 110P)
- pump head (DP - 100P)
- outlet fluid temperature (T - 101P)
- pump rotational speed (RPM - RP1)
- outlet pressure (P - 027P)
- pump electrical power (WEL)

the test has been performed in the following experimental conditions:

- rotational speed $\cong$ 2728 RPM ($\omega \cong$ 285 RAD/s)
- volumetric flowrate from 0.003 m^3/s to 0.015 m^3/s
- single phase fluid (T $\cong$ 35 °C, P $\cong$ 2.3 MPa)

3.2. Test "B"

The same parameters of par. 3.1. have been measured in the following experimental conditions:

- rotational speed varing from 2875 RPM to 257 RPM (ω= 301 ÷ 27 RAD/s)
- volumetric flowrate varing from 0.013 m^3/s to 0.001 m^3/s
- single phase fluid (T $\cong$ 40 °C, P $\cong$ 2.2 MPa).

3.3. Test "C"

The test has been carried out measuring the pump electrical power and the rotational speed with number of RPM decreasing from nominal value to zero in the following conditions:

- fluid = air
- pressure = atmospheric
- pump head $\cong$ zero

Such test permits to obtain the friction torque behaviour versus the rotational speed ω .

3.4. Test "D"

This test has been performed measuring rotational speed versus time ($\omega = f(t)$) during pump coast-down with the following conditions:

- fluid = water
- temperature $\cong$ 300 °C
- pressure $\cong$ 15.5 MPa

3.5. Test "E"

The test is consisted in the measure of the pump pressure drops and the rotational speed during the single phase natural circulation experiments (unfed pump).

4. ESPERIMENTAL RESULTS

4.1. Tests "A" and "B" experimental results

The experimental results of the tests "A" and "B" are shown in tab. 1 and 2. The errors reported in the tables are statistical errors (maximum scatter related to average value). The pumps head calculation has been performed using the following xpression:

$$H = \frac{\Delta P}{\rho \cdot g} \frac{V_2^2 - V_1^2}{2g} + (Z_2 - Z_1)$$

where:

ΔP = pressure drops across the pump (Pa)

V_1 = inlet fluid speed (m/s)

V_2 = outlet fluid speed (m/s)

$Z_2 - Z_1$ = geodetic difference between pump suction and discharge

The characteristic curve (head - volumetric flowrate) at 2728 RPM is shown in fig. 2. The nominal rotational speed (3200 RPM) has not been reached because an anomalous high temperature value of a pump bearing was observed probably due to an insufficient lubrication. The trends of the pump head versus rotational speed and volumetric flowrate (with different number of RPM) are shown in figg. 3 and 4.

The experimental results obtained in tests "A" e "B" allow to draw the head-flowrate and the engine torque homologous curves in the first quadrant (fig. 5 and fig. 6). The variables reported in these figures are undimensional parameters and have the following meaning:

$h = \frac{H}{H_o}$ $\qquad H_o = 71.9$ m

$\alpha = \frac{\omega}{\omega_o}$ $\qquad \omega_o = 301.1$ RAD/s (2875 RPM)

$V = \frac{Q}{Q_o}$ $\qquad Q_o = 0.013$ m^3/s

$\beta = \frac{Cm}{Co}$ $\qquad Co = 49.85$ N.m

For $0 \leq \frac{\alpha}{V} \leq 1$ the curves $\frac{h}{V^2} = f(\frac{\alpha}{V})$ and $\frac{\beta}{V^2} = f(\frac{\alpha}{V})$ have been drawn

for $0 \leq \frac{V}{\alpha} \leq 1$ the curves $\frac{h}{\alpha^2} = f(\frac{V}{\alpha})$ and $\frac{\beta}{\alpha^2} = f(\frac{V}{\alpha})$ have been drawn.

The numerical values corresponding to fig. 5 and fig. 6 are shown in tab. 3.

4.2. Hydraulic torque (CHY)

The hydraulic torque is defined by means the following relations:

(1) $CHY = Cm - Cf(\omega)$

(2) $Cm = \frac{WEL \cdot \eta_{EL}}{\omega}$

where:

η_{EL} = 0.883 (electrical efficiency given by the supplier)

Cm = engine torque

Cf = friction torque

WEL = pump electrical power

The Cf trend versus ω can be approximately obtained from the results of test "C". Infact when the pump operates in air the hydraulic torque is negligible and the friction torque results, by the relation (1), equal to the engine torque. The friction torque trend versus rotational speed may be defined by means the following experimental relation computed from results of test "C", shown in tab. 4, by means of analytical best fit:

$$Cf = 6.1481 + 0.05115.W - 3.7.10^{-5}. W^2 \qquad (N.m)$$

The behaviour of friction torque versus ω is shown in fig. 7.

4.3. Pump coastdown behaviour

The pump coastdown ($\omega = f(t)$) has been measured starting from conditions shown in 3.4. The measured behaviour is presented in tab. 5 and fig. 8.

4.4. Unfed pump pressure drop

The pressure drops across the pump have been measured in single phase natural circulation conditions. The measured experimental data are presented in tab. 6.

N		ω		Wel		F-110P		Q		DP-100P		H		T-101P		P-027P		Cm	
RPM	± %	RAD/s	± %	kW	± %	Kg/s	± %	m^3/s	± %	kPa	± %	m	± %	°C	± %	MPa	± %	N.m	± %
2725	0.8	285.4	0.8	12.8	13.7	2.86	1.1	0.003	1.1	702.81	0.2	72.46	0.2	32.8	0.5	2.33	1.6	39.6	13.7
2727	0.8	285.6	0.8	13	13.3	3.70	1.1	0.004	1.1	697.64	0.3	71.93	0.3	32.9	0.5	2.31	2.0	40.19	13.3
2731	0.7	286	0.7	13.2	14.9	5.70	0.5	0.006	0.6	689.76	0.2	71.17	0.2	34.2	0.4	2.31	1.6	40.75	14.9
2728	0.6	285.7	0.6	13.4	14.8	6.63	0.5	0.007	0.5	685.05	0.2	70.70	0.2	34.9	0.6	2.29	6.8	41.41	14.8
2731	0.7	286	0.7	13.4	14.4	7.21	0.4	0.007	0.4	682.54	0.4	70.47	0.4	35.5	1.0	2.32	2.1	41.37	14.4
2735	0.8	286.4	0.8	13.6	13.6	8.00	0.4	0.008	0.4	675.41	0.3	69.74	0.3	36.4	0.7	2.32	1.8	41.93	13.6
2735	0.7	286.4	0.7	14.4	13.3	9.04	0.4	0.009	0.4	669.83	0.3	69.18	0.3	37.1	0.5	2.32	1.8	44.40	13.3
2709	0.9	283.7	0.9	13.7	11.7	9.64	0.7	0.010	0.7	653.75	1.3	67.56	1.3	37.6	0.4	2.33	1.8	42.64	11.7
2726	0.7	285.5	0.7	14.1	7.6	11.03	0.3	0.011	0.2	644.65	0.3	66.63	0.3	38.3	0.6	2.31	2.4	43.61	7.6
2729	0.5	285.8	0.5	14.3	7.2	11.46	0.2	0.012	0.2	640.97	0.3	66.27	0.3	39.1	0.4	2.31	2.1	44.18	7.2
2728	0.7	285.7	0.7	14.5	8.3	12.14	0.2	0.012	0.2	634.27	0.4	65.59	0.4	39.4	0.7	2.30	2.3	44.81	8.3
2727	0.7	285.6	0.7	14.8	7.7	13.19	0.2	0.013	0.2	620.99	0.3	64.28	0.2	40.8	0.4	2.30	1.9	45.76	7.7
2731	1.4	286	1.4	15.1	8.7	14.03	0.1	0.014	0.1	610.94	0.6	63.27	0.5	41.7	0.4	2.29	3.5	46.62	8.8
2724	0.6	285.3	0.6	15.1	7.6	14.51	0.1	0.015	0.1	605.42	0.3	62.71	0.3	42.5	0.3	2.31	2.7	46.73	7.6

TAB. 1 - TEST "A"

N		ω		W_{el}		F-110P		Q		DP-100P		H		T-101P		P-027P		Cm	
RPM	± %	RAD/s	± %	kW	± %	Kg/s	± %	m^3/s	± %	KPa	± %	m	± %	°C	± %	MPa	± %	N.m	± %
2875	0.8	301.1	0.8	17.0	12.5	13.36	0.2	0.013	0.2	695.38	0.4	71.94	0.4	42.0	0.5	2.31	1.8	49.85	12.5
2480	0.6	259.7	0.6	11.4	13.8	11.33	0.2	0.011	0.2	520.86	0.5	54.00	0.5	42.0	0.4	2.24	1.7	38.76	13.8
1982	0.9	207.6	0.9	5.9	16.2	9.10	0.7	0.009	0.7	335.21	1.5	34.92	1.4	41.1	0.3	2.18	1.9	25.09	16.2
1748	3.4	183.1	3.4	3.8	21.5	7.94	0.6	0.008	0.4	260.42	0.8	27.22	0.8	40.9	0.4	2.17	2.9	16.32	21.8
1474	1.2	154.4	1.2	-	-	6.74	0.7	0.007	0.7	189.96	1.9	19.98	1.8	40.2	0.4	2.12	2.2	-	-
1254	1.0	131.3	1.0	-	-	5.63	0.6	0.006	0.6	135.75	1.3	14.40	1.2	39.7	0.6	2.10	4.7	-	-
1027	1.2	107.5	1.2	-	-	4.63	0.8	0.005	0.8	92.93	1.8	10.00	1.7	38.9	0.4	2.10	2.1	-	-
741	2.1	77.6	2.1	-	-	3.31	1.4	0.003	1.4	47.56	3.0	5.34	2.8	38.7	0.5	2.09	2.8	-	-
499	6.5	52.3	6.5	-	-	2.20	2.7	0.002	2.7	19.70	8.7	2.48	7.2	38.5	0.6	2.07	2.4	-	-
257	4.9	26.9	4.9	-	-	1.23	6.4	0.001	6.4	2.64	49.7	0.73	18.6	38.0	0.5	2.08	3.1	-	-

TAB. 2 - TEST "B"

α/V	h/V^2	β/V^2	V/α	h/α^2	β/α^2
0.948	0.893	0.918	0.243	1.121	0.884
0.882	0.758	0.806	0.324	1.111	0.896
0.821	0.655	0.704	0.486	1.096	0.906
1	1	1	0.567	1.091	0.923
0.996	1.013	1.050	0.567	1.085	0.920
0.988	0.999	0.97	0.647	1.071	0.930
0.952	0.958	/	0.728	1.063	0.984
0.945	0.940	/	0.816	1.058	0.963
0.929	0.940	/	0.892	1.046	0.973
			0.973	1.022	0.984
			0.973	1.013	0.998
			1	1	1
			0.981	1.009	1.045
			0.895	1.118	/
			0.886	1.146	/
			0.861	1.284	/

Co = 49.85 N.m

Qo = 0.013 m^3/s

Wo = 301.1 rad/s

Ho = 71.9 m

$$\beta = \frac{Cm}{Co} \qquad \alpha = \frac{\omega}{\omega_o} \qquad V = \frac{Q}{Qo} \qquad h = \frac{H}{Ho}$$

TAB. 3

HOMOLOGOUS CURVE DATA

KP-1 FRICTION TORQUE

V-KP-1 V	+-%	I-KP-1 A	+-%	W-KP1 W	+-%	RPM-KP-1	+-%	RS RAD/s	+-%	Cf N.m	+-%
370.956	6.4	19.478	18.0	7342.2	22.8	3194.	0.6	334.3	0.6	19.4	22.8
373.346	5.4	17.259	19.2	6560.9	22.6	2878.	0.8	301.2	0.8	19.2	22.4
371.438	5.7	13.752	26.5	5080.1	30.9	2593.	0.9	271.4	0.9	16.5	30.6
359.680	5.1	12.096	33.5	4353.0	37.7	2319.	0.9	242.7	0.9	15.8	37.6
309.949	6.5	11.838	25.2	3554.8	25.5	2020.	1.1	211.4	1.1	14.6	25.7
260.095	8.0	10.290	34.1	2706.4	41.3	1708.	1.4	178.8	1.4	13.4	41.3
213.369	10.6	9.139	38.1	2059.2	43.2	1400.	1.3	146.5	1.3	12.4	43.5
174.035	11.3	8.645	45.4	1501.2	53.9	1116.	1.7	116.8	1.7	11.3	53.7
136.350	15.1	9.107	26.5	1278.9	37.5	831.	2.9	87.0	2.9	12.9	37.3
100.595	4.1	7.174	24.9	715.8	24.2	523.	5.0	54.8	5.0	11.5	24.8
30.534	24.3	4.193	47.7	137.6	58.3	262.	9.0	27.5	9.0	4.3	55.9

TAB. 4

KP-1 COASTDOWN

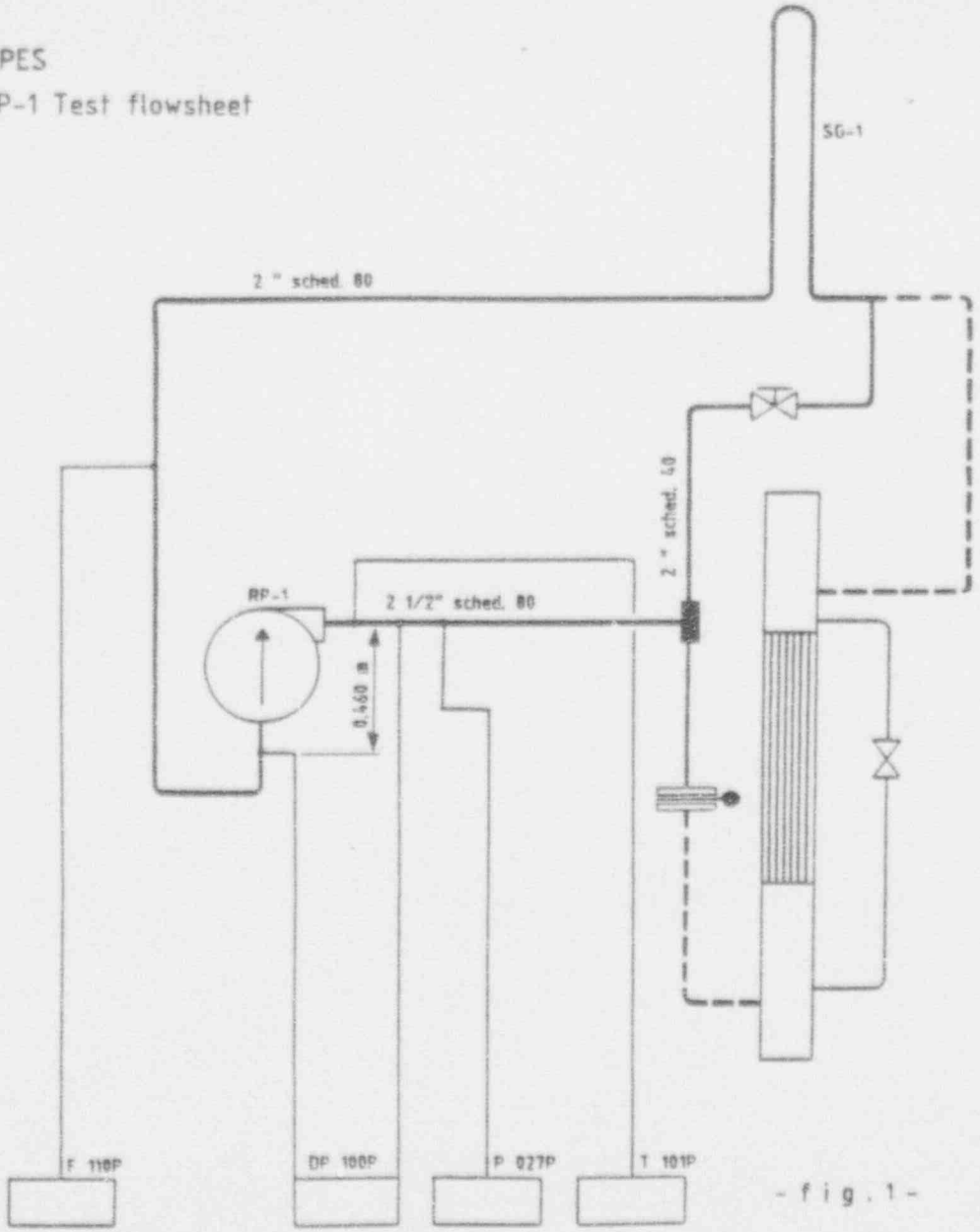
TIME sec	ω RAD/s	T-111P °C	P-027P kPa	F-110P Kg/sec	DP-100P kPa
5.01	332.7	301.7	15.40	12.68	-567.32
7.01	336.7	301.7	15.43	12.69	-568.17
9.01	331.5	301.5	15.49	12.68	-568.17
11.01	333.3	301.7	15.38	12.68	-568.60
13.01	334.2	301.7	15.49	12.71	-568.60
15.01	335.8	301.5	15.54	12.70	-568.17
17.01	333.9	301.5	15.43	12.71	-570.73
19.01	333.3	301.5	15.47	12.71	-569.02
21.01	337.6	301.5	15.58	12.70	-567.32
23.01	332.4	301.5	15.48	12.70	-569.88
25.01	334.9	301.5	15.49	12.71	-571.16
27.01	333.6	301.5	15.49	12.70	-569.02
29.01	328.4	301.5	15.55	12.70	-566.46
31.01	335.5	301.5	15.41	12.71	-569.02
33.01	332.4	301.5	15.51	12.71	-568.17
35.01	335.5	301.5	15.33	12.70	-567.32
37.01	335.2	301.5	15.41	12.71	-564.32
39.01	330.6	301.5	15.43	12.70	-569.45
41.01	333.6	301.5	15.48	12.71	-565.75
43.01	333.9	301.5	15.42	12.69	-567.32
45.01	336.4	301.5	15.43	12.70	-566.03
47.01	335.5	301.5	15.44	12.69	-569.45
49.01	331.5	301.5	15.43	12.70	-569.02
51.01	336.1	301.7	15.32	12.70	-568.17
53.01	333.6	301.7	15.43	12.70	-566.46
55.01	336.7	301.5	15.42	12.70	-569.45
57.01	332.4	301.5	15.36	12.70	-569.45
59.01	322.3	301.7	15.42	12.70	-564.50
61.01	286.7	301.5	15.46	12.70	-443.41
63.01	215.0	301.5	15.41	11.96	-336.18
65.01	215.6	301.3	15.44	10.41	-256.20
67.01	184.0	301.1	15.53	9.02	-190.48
69.01	159.5	300.7	15.49	7.74	-138.79
71.01	134.0	300.5	15.44	6.67	-102.04
73.01	109.2	300.1	15.59	5.69	-70.00
75.01	88.6	299.9	15.59	4.84	-45.65
77.01	65.0	299.7	15.53	3.86	-25.14
79.01	48.1	299.5	15.57	3.06	-10.61
81.01	28.8	299.3	15.62	2.36	-3.35
83.01	11.7	299.3	15.70	1.76	3.06
85.01	0.6	299.1	15.58	1.34	3.91
87.01	2.5	298.9	15.73	1.10	3.91
89.01	-0.6	298.8	15.65	1.00	4.34
91.01	-2.1	298.8	15.77	1.00	3.49
93.01	2.8	298.6	15.90	1.00	5.19
95.01	1.2	298.4	15.99	1.10	3.49
97.01	-1.8	298.2	15.96	1.00	3.91
99.01	3.1	298.0	16.04	1.01	5.19

RP-1 PRESSURE DROPS IN SINGLE PHASE NATURAL CIRCULATION CONDITION

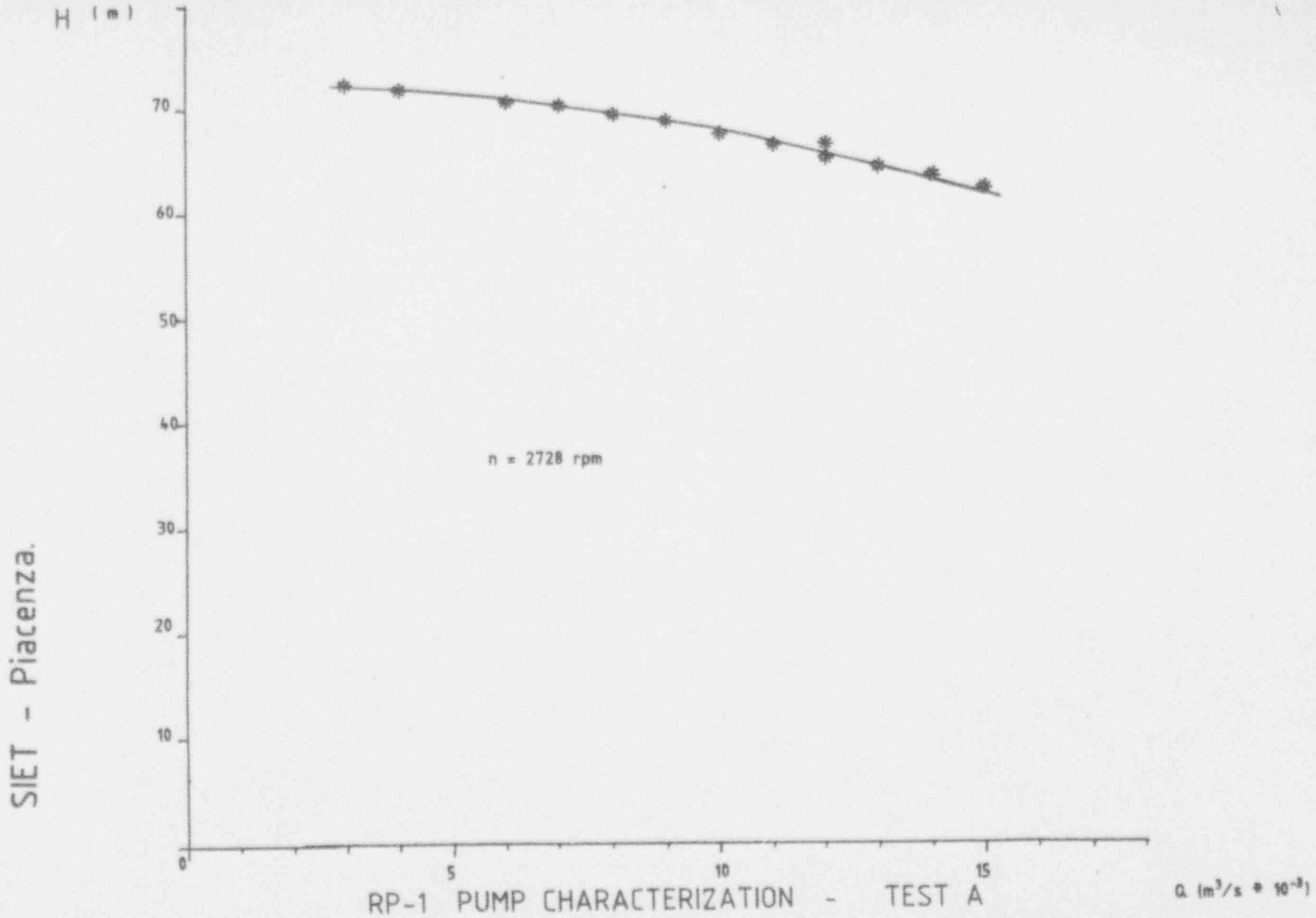
TIME sec	T-111P °C	P-027P MPa	F-110P Kg/s	DP-100P kPa	RPM-RP-1	H m
3.01	293.4	14.44	0.60	- 4.95	50.	-0.224
21.01	293.6	14.36	0.56	- 3.00	9.	0.045
41.01	293.6	14.39	0.56	- 4.46	9.	-0.157
61.01	293.8	14.35	0.57	- 3.24	6.	0.012
81.01	293.8	14.36	0.56	- 4.71	56.	-0.191
101.01	294.0	14.36	0.56	- 3.00	15.	0.045
121.01	293.8	14.33	0.55	- 3.49	32.	-0.023
141.01	293.8	14.32	0.56	- 4.22	12.	-0.124
161.01	293.8	14.32	0.56	- 2.26	9.	0.147
181.01	293.8	14.32	0.55	- 4.95	62.	-0.225
201.01	293.8	14.28	0.55	- 3.24	36.	0.012
221.01	293.6	14.30	0.56	- 3.73	38.	-0.056
241.01	293.6	14.43	0.61	- 1.78	29.	0.214
261.01	293.8	14.39	0.58	- 3.00	12.	0.045
281.01	293.6	14.41	0.58	- 4.95	6.	-0.224
301.01	293.8	14.38	0.58	- 2.51	29.	0.113
321.01	293.8	14.35	0.57	- 4.22	12.	-0.124
341.01	293.8	14.35	0.57	- 3.00	3.	0.045
361.01	293.8	14.37	0.57	- 3.73	0.	-0.056
381.01	293.8	14.33	0.57	- 4.46	12.	-0.157
401.01	293.8	14.31	0.57	- 2.02	3.	0.180
421.01	293.8	14.32	0.57	- 3.97	9.	-0.089
441.01	294.0	14.28	0.57	- 2.51	3.	0.112
461.01	293.8	14.32	0.57	- 3.73	-3.	-0.056
481.01	293.9	14.37	0.56	- 3.24	-12.	0.012

SPES

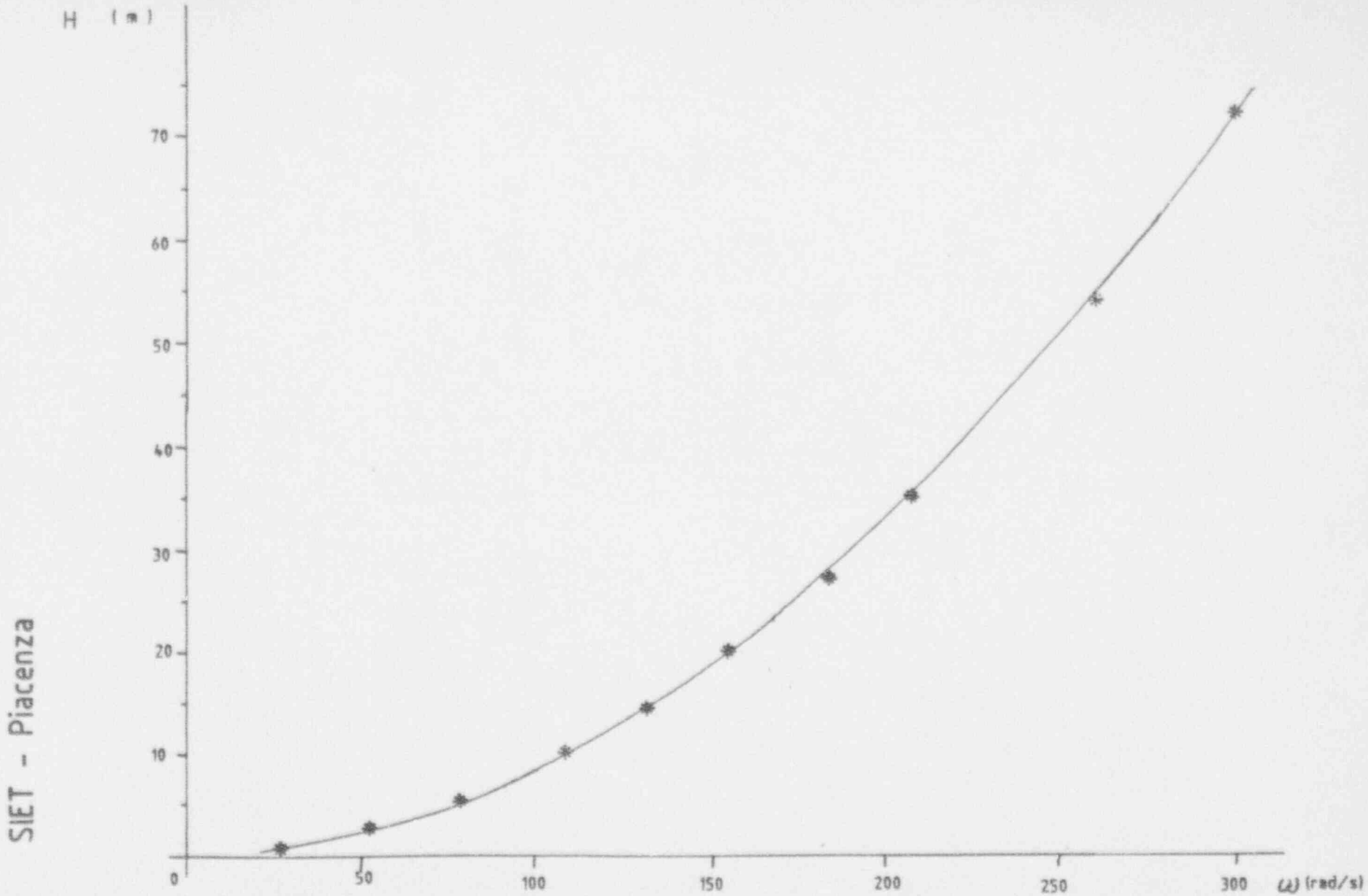
RP-1 Test flowsheet



- f i g . 1 -

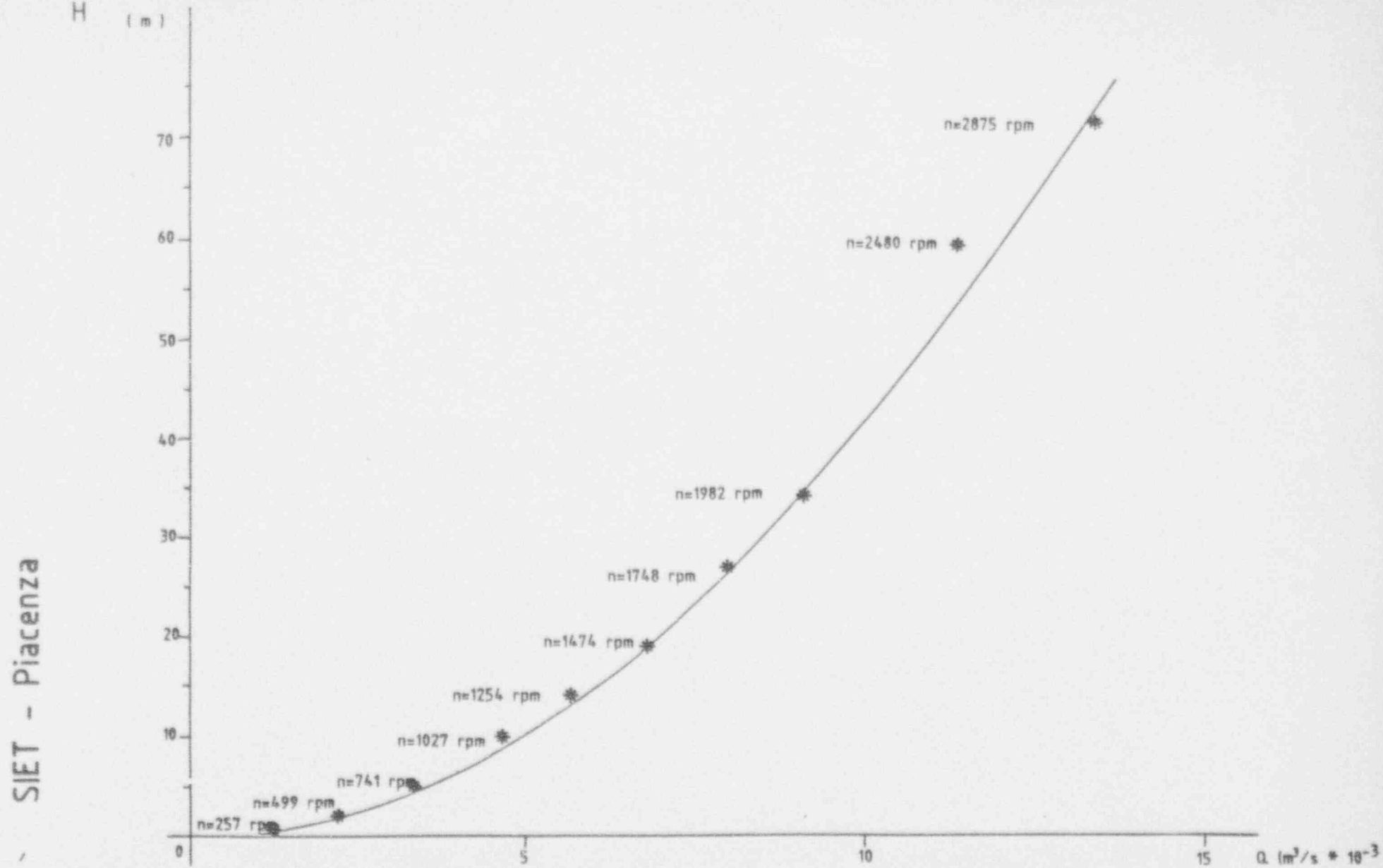

H (m)
70
60
50
40
30
20
10
0
5
10
15
n = 2728 rpm
SIET - Piacenza.
RP-1 PUMP CHARACTERIZATION - TEST A
Q (m³/s * 10⁻³)

- fig. 2 -



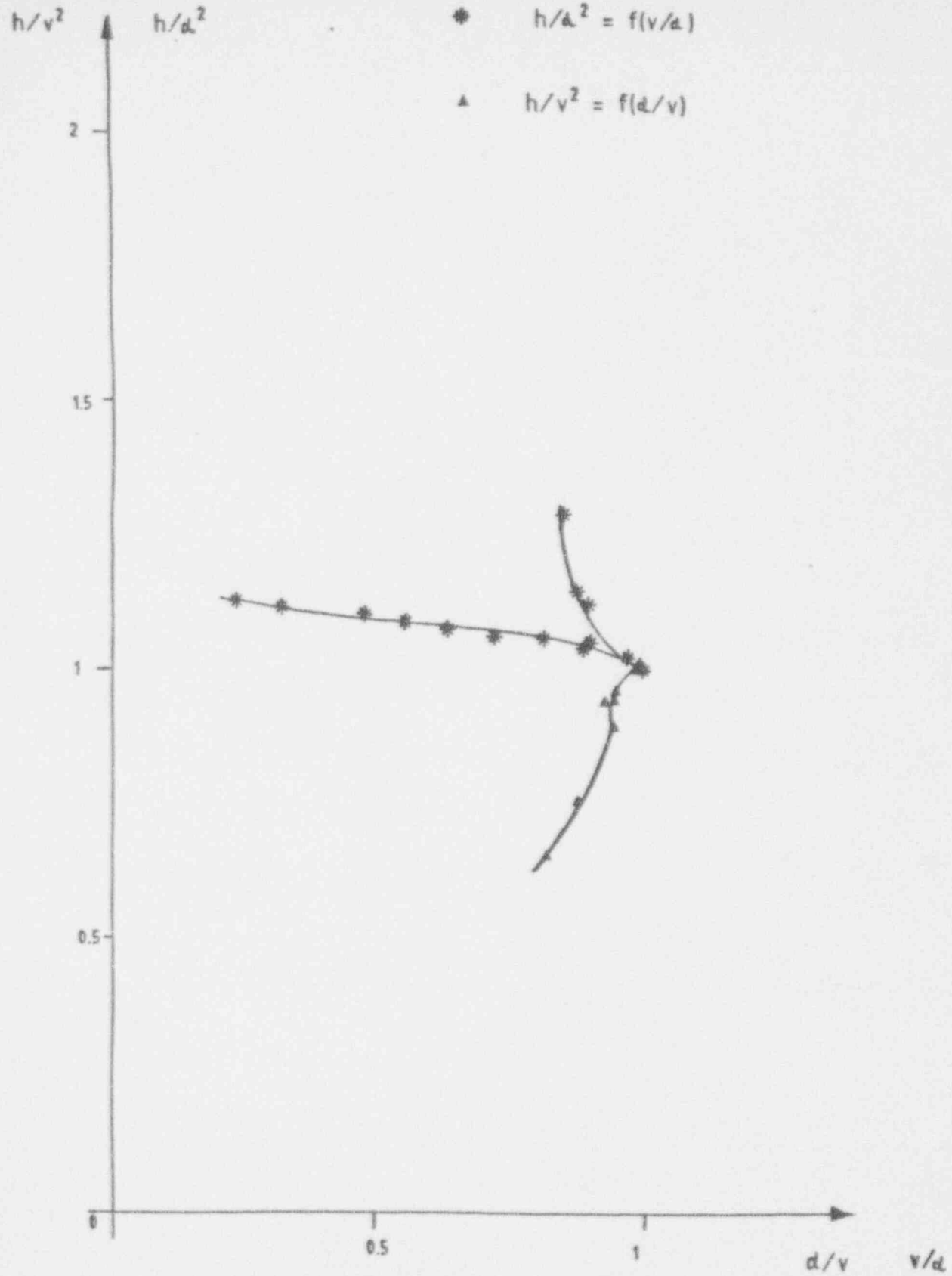
RP-1 PUMP CHARACTERIZATION - TEST B

- fig. 3 -



RP-1 PUMP CHARACTERIZATION - TEST B

- Fig. 4 -



RP-1 PUMP CHARACTERIZATION - HOMOLOGOUS CURVES

- fig. 5 -

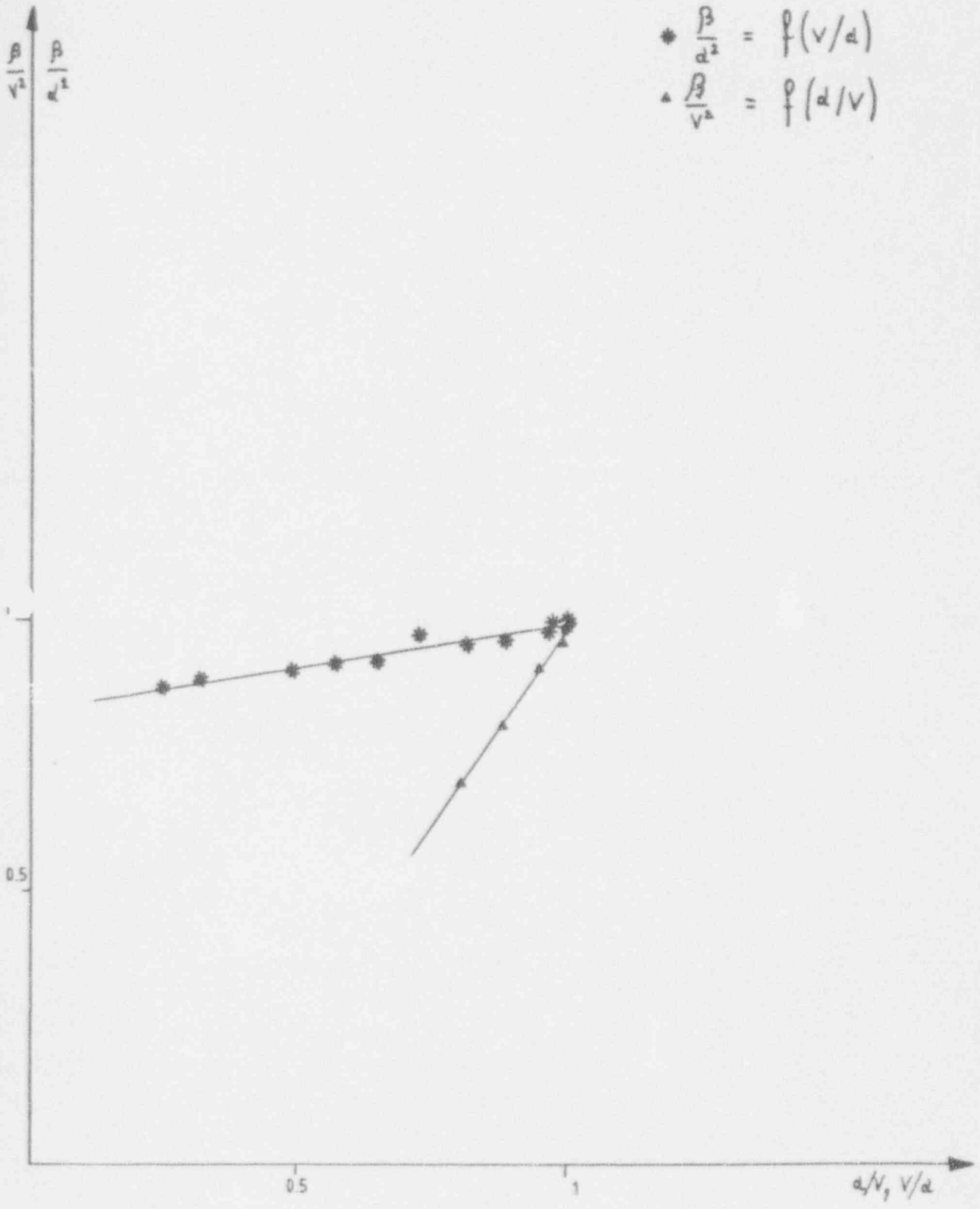


Fig. 6

RP-1 PUMP CHARACTERIZATION - HOMOLOGOUS CURVES

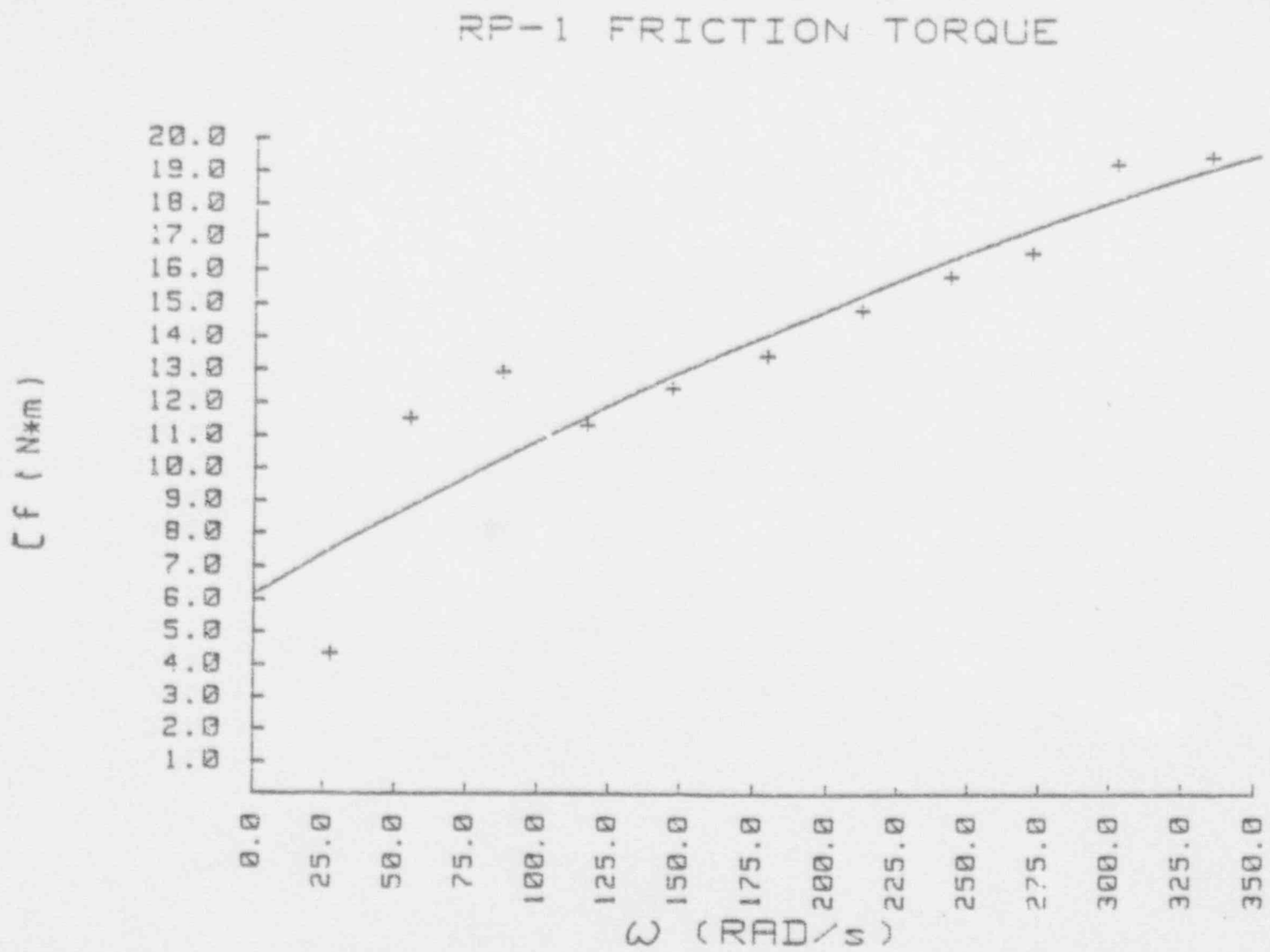

RP-1 FRICTION TORQUE
Cf (N*m)
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
225.0
250.0
275.0
300.0
325.0
350.0
ω (RAD/s)

Fig. 7

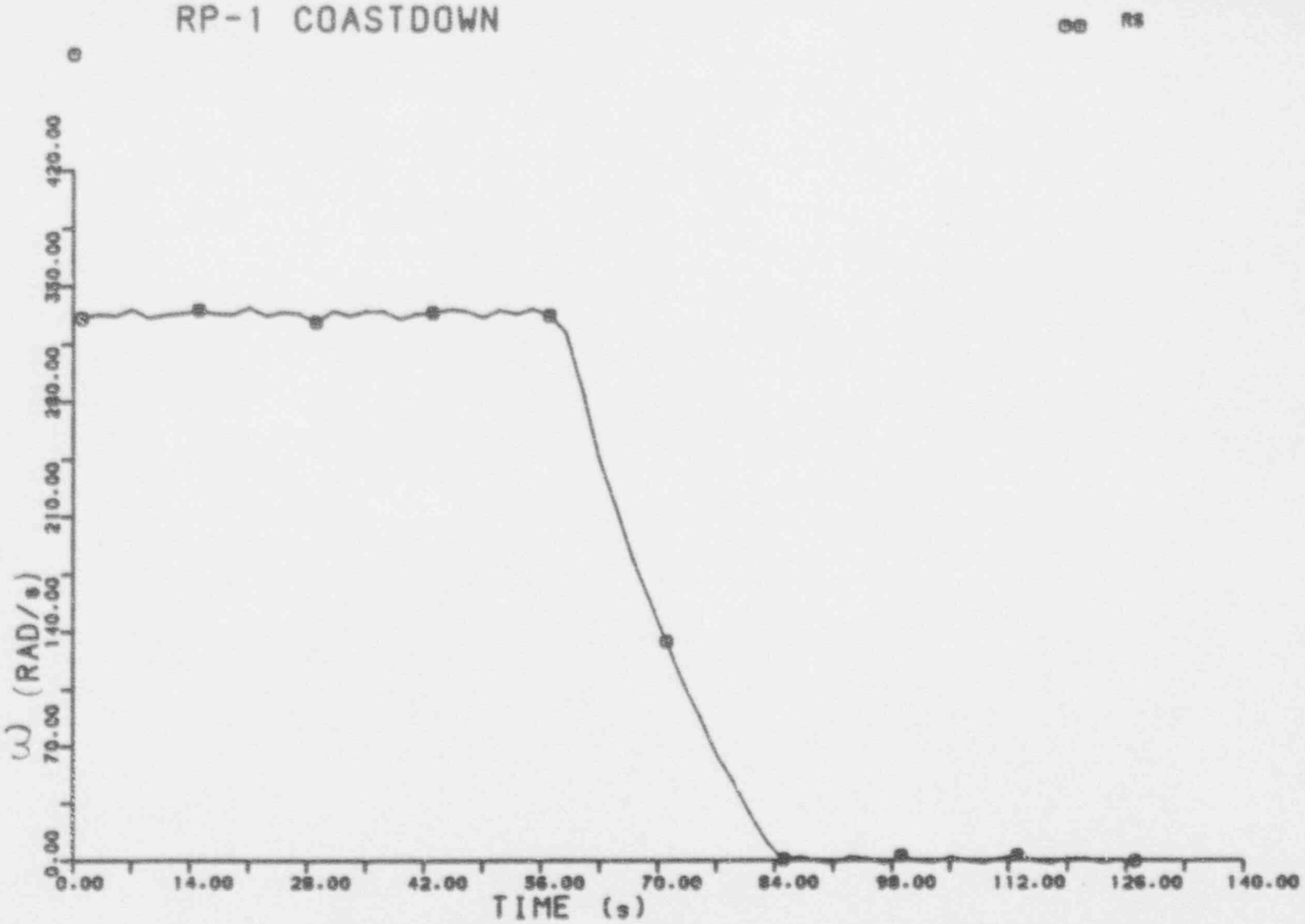

RP-1 COASTDOWN
ω (RAD/s)
0.00
70.00
140.00
210.00
280.00
350.00
420.00
0.00
14.00
28.00
42.00
56.00
70.00
84.00
98.00
112.00
126.00
140.00
TIME (s)

FIG. 8