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AN EXAMINATION OF THE INFLUENCE OF SPACERS ON BURNOUT IN AN ANNULUS COOLED BY UPFLOW OF FREON-12

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ABSTRACT

To evaluate the spacer influence on burnout, tests were carried out in Freon-12 at 1.04 MPa (abs.) test section inlet pressure with an internally heated annulus 2743 mm long by 14.4 mm heater diameter, the outer tube (shroud) having a bore of 22.1 mm. The inner rod (heater) was located centrally to the shroud by spacers and their configuration was changed for each test.

Comparison of the results with those obtained with a test section having no spacers indicated that spacers can increase burnout power up to 75 per cent, decrease it, or show no effect at all, depending on the combination of the inlet temperature and mass velocity.

If the spacers were streamlined, removed from the upstream portion of the heater or relocated farther upstream from the downstream end of the heater, there was a considerably reduced effect on the test section performance.

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ANNULAR SPACE; BURNOUT; CRITICAL HEAT FLUX; FREONS; FUEL PINS; HEAT TRANSFER; REACTOR LATTICE PARAMETERS; SHROUDS; SPACERS

CONTENTS

(continued)

CONTENTS (continued)

1. INTRODUCTION

The functional purpose of spacers in single fuel-pin or simulated fuel-pin assemblies, is to centrally locate the fuel pin or heater rod with respect to the inner wall of the enclosed tube (shroud), so as to

(i) provide a uniform annular gap for the passage of coolant;

(ii) prevent contact between fuel pin or rod and shroud; and

(iii) inhibit fuel-pin or rod vibration.

When predicting a fuel pin heat transfer performance, the effect of spacers is not taken into account in burnout correlations, presumably because it has been thought that their presence favourably adds to the existing safety margin, thus reducing the need to know more about their effect, other than for pressure drop estimates.

After preliminary experiments in Freon-12 had shown that spacer influence could be significant for burnout performance, it was decided to make an extensive systematic investigation of the effect of spacers on burnout heat power. Because of the possible importance of the effect of spacers, especially in relation to burnout scaling experiments, the initial objective of these experiments was to provide qualitative information on any significant trends.

This report describes the effect of spacers on burnout performance of a simulated fuel pin, consisting of a uniformly heated inner rod 2743 mm long, and separated from the shroud by sets of three spacers whose pitch, number, location and geometry were varied.

2. EXPERIMENTAL APPARATUS AND DATA COLLECTION

2.1 Experimental Rig and Test Section

All tests were performed on the AAEC Freon-12 rig ACTOR, described in detail elsewhere (Ilic 1972). Test section and instrumentation details, as well as experimental method are described below.

The shroud and heater rod for the annulus test section were made of stainless steel. Power clamps were applied to copper tails attached to each end of the heater (Figure 1).

The complete test section specifications are:

heater material	stainless steel
heater diameter (mm)	14.4
heater wall thickness (mm)	1.63
heater length (mm)	2743
heater resistance at 20°C (ohm)	0.034
heater surface roughness (mm)	0.89×10^{-3}
shroud material	stainless steel
shroud bore (mm)	22.1
shroud bore surface roughness (mm)	1.14×10^{-3}

Initially, the entire heater section was kept concentric within the shroud by 3.2 mm diameter Tufnol rods mounted externally in sets of three (spaced at 120°), on and passing through the shroud at right angles to the flow. Three sets of pins having 920 mm axial pitch were used; they were equally spaced and sealed at the shroud periphery. For this experiment, the setting was referred to as the 'bare rod' configuration (*case 1* in data evaluation).

Other spacer configurations comprised 3.8 mm diameter by 12.7 mm long Tufnol cylinders located axially on the heater rod; they were attached to the rod by threading a length of 0.08 mm diameter Nichrome wire through each spacer and spot-welding the ends. All spacers were axially 'in line' and equally spaced in groups of three at either 152 mm pitch (*case* 3) or 305 mm pitch (*case* 2). The distance of the last downstream spacer from the end of the heated tube corresponded to the appropriate spacer pitch.

A summary of spacer configurations tested is tabulated below:

Case	Configuration
1	This was the control case in which annulus gap was maintained by pins at 920 mm pitch ('bare rod' in Figure 1).
2	Cylindrical spacers were used at a pitch of 305 mm.
3	Cylindrical spacers were used at a pitch of 152 mm.
4	All spacers were removed except the last four sets of spacers at 152 mm pitch; the last set of spacers was situated 152 mm from the downstream end of the heater.
5	All but one set of spacers were removed, leaving the last set at 152 mm from the downstream end of the heater.
6	The four sets of spacers (Case 4) were moved upstream so that the last set of spacers was situated 305 mm from the heater downstream end.
7	All but the downstream set of spacers were removed from the Case 6 configuration.
8	The upstream end of all spacers in the Case 3 configuration was streamlined.

2.2 Instrumentation

The mass flowrate was measured by a multi-orifice system especially designed for operation on the Freon-12 rig in conjunction with a pressure cell. The fluid temperatures near the orifice meter and at the inlet to the test section were measured by two separate platinum resistance thermometers.

The power to the test section was obtained from separate measurements of the voltage drop between the heater power clamps and evaluation of the current through the test section. The latter was obtained by measuring the voltage drop across a calibrated precision resistance in the power supply line.

The test section pressure drop was measured by means of a differential transmitter. The test section inlet static pressure signal was generated by a pressure transmitter and, together with the other signals, was recorded onto a 5-channel paper tape, *via* an instrument scanner. The indication of burnout was provided on a pen recorder by means of a bridge detector, similar to the one described by Salt & Wintle (1964).

2.3 Method of Data Collection

The first experiments were done with the bare heater rod; subsequent tests were made in the sequence:

case 2, 3, 5, 4, 6, 7 and *8*.

In each case, the required flow conditions were initially established and a trial burnout was obtained through a rapid succession of test section power increments. The power was then reduced to about 0.5 V below the burnout value, and the system was allowed to settle again. The burnout was then approached at small rates of power increase, until the pen recorder registered a substantial deviation in the burnout signal.

A complete set of data was logged at zero power and at 0.5 V below burnout. After the latter reading, the data scanning speed on the scanner was increased from 0.5 s per channel to 0.25 s per channel, and a tape record was made of the test section current, voltage, flowrate and pressure drop only. The scan was terminated once burnout was reached.

2.4 Estimate of Experimental Errors

The estimate of random errors associated with each measurement, is given below:

Mass flowrate	± 1.4%
Inlet pressure	± 14 kPa
Inlet temperature	± 1°C
Heater power	± 3.3%
Heater area	± 0.8%
Pressure drop	± 4%

3. RESULTS AND DISCUSSION

3.1 Parameter Range

The comparison of the effect of spacers on the burnout heat flux was carried out over the following ranges of parameters at 1.04 MPa (abs.) test section inlet pressure:

inlet temperature	16 – 40°C;
mass velocity	0.5 – 3.0 Mg m^{-2} s^{-1}.

Experimental results are given in Tables 1 to 8. Data have been graphically represented in Figures 2 to 12 and show the relative change in burnout performance with mass velocity for four values of inlet temperature. The curve corresponding to the inlet temperature of 44°C was obtained by extrapolation and was included because it corresponds to the highest (*i.e.* saturation) inlet temperature at which the incoming coolant can remain liquid.

3.2 The Effect of Presence of Spacers on Burnout Heat Flux

The presence of spacers in the annulus test section considerably affected the heat transfer rate at burnout in several ways, depending on the inlet temperature, mass velocity, spacer pitch and location, and the geometry of a spacer (Figures 2, 3, 7 and 11). Ilic & Lawther (1973) have reported briefly on the effect of the first three parameters.

The effect on burnout power of the presence of spacers in the annulus gap is shown in Figure 2 for the spacer pitch of 152 mm. At 305 mm spacer pitch, the variation of relative burnout power with mass velocity is shown in Figure 3.

From these figures it is apparent that the presence of spacers considerably affects the burnout power, since the extent of spacer influence depends on inlet temperature, mass velocity and spacer pitch. It is possible to increase burnout power by about 75 per cent at high inlet temperature (44 °C) and mass velocity (approximately 2.5 Mg m^{-2} s^{-1}) ; on the other hand, perhaps it may decrease it relative to the values obtained with the bare rod at inlet temperatures less than 20 °C (Figure 3).

The exact physical mechanism to explain how the presence of spacers affects the variation in burnout performance is not clear. Simple visualisation tests with air/water and Freon-113 have indicated that dryout may occur either at the front of a spacer, because of flow stagnation and thinning of the liquid film (in the case of annular flow) owing to the flow deceleration with increase in local static pressure, or immediately behind a spacer at higher mass velocities because of the preferential formation of vapour in the relatively stagnant liquid in this region.

3.3 The Effect of Change of Spacer Pitch on Burnout Heat Flux

For a given test section length, increasing the spacer pitch will also reduce the number of sets of spacers, therefore the effect on burnout is a combination of these two factors. The effect of doubling the spacer pitch from 152 to 305 mm is shown in Figure 4. Irrespective of the inlet temperature, the increased spacer pitch decreases the burnout power relative to the narrow pitch. The magnitude of this relative decrease in burnout power varies with mass velocity, reaching a maximum of about 25 per cent at approximately 2.2 Mg m^{-2} s^{-1} .

3.4 The Effect of Removing Upstream Spacers on Burnout Heat Flux

To ascertain the extent of the effect of upstream turbulence on the test section performance, upstream spacers were removed in two stages. In the first instance, fourteen (of the total eighteen) sets of spacers were removed from the upstream portion of the test section with the *case* 3 configuration. This left four sets of spacers at 152 mm pitch, the last set being 152 mm from the downstream end of the heater. Burnout performance of this rod with respect to the bare rod is shown in Figure 5. Compared to the results in Figure 2, the magnitude of the increase in performance was considerably reduced for mass velocities greater than 1 Mg m^{-2} s^{-1} (the maximum increase was reduced from about 75 per cent to about 43 per cent). Figure 6 shows that removal of all but the last set of spacers greatly reduced the effect to the extent that the maximum increase in burnout heat flux was about 8 per cent.

This demonstrates that the turbulence caused by the presence of upstream spacers significantly affects the burnout performance of the test section. The comparative effects for five spacer configurations at the inlet temperature of 39 °C are shown in Figure 7.

3.5 The Effect of Spacer Location on Burnout Heat Flux

The single set of spacers was initially placed 152 mm from the heater end. To determine the effect of increasing its distance from the heater end, the set was moved 152 mm upstream so that its distance from the heater end was then 305 mm. The burnout performance was expressed relative to the bare rod and plotted against mass velocity (Figure 8). About 18 per cent increase in burnout performance for an inlet temperature of 44 °C appears possible, while at the least inlet temperature (20 °C) a decrease in burnout performance by about 6 per cent occurred at 2 Mg m^{-2} s^{-1} . As Figure 9 indicates, increasing the distance of a set of spacers upstream from the downstream end of the heater increased the burnout performance compared to the performance for a spacer set at 152 mm from the heater end for the inlet temperature of 39 °C. The increase in burnout performance is probably the result of a greater flow turbulence in the region where burnout usually occurs.

The burnout tests having four sets of spacers at 152 mm pitch and downstream distance of 152 mm were repeated at 305 mm from the downstream end of the heater. A comparison of the performance with respect to the bare rod at the inlet temperature of 39 °C is shown in Figure 10. It is apparent that the burnout performance is significantly higher the closer the spacers are to the end of each heater.

3.6 The Effect of Streamlining Spacers on Burnout Heat Flux

Each spacer was machined so that the centre of the upstream end was the apex of a cone extending to half the length of spacer. Burnout data relative to the results obtained with the bare test section are shown in Figure 11 for four different inlet temperatures.

Burnout performance was increased in all cases, although the maximum increase was considerably less than with cylindrical spacers. It is significant that no decrease in performance occurred when compared with that of the bare rod. However, with respect to the case with cylindrical spacers, a reduction in performance caused by streamlining occurred at all mass velocities tested, the extent depending on the specific inlet temperature and mass velocity (Figure 12).

4. CONCLUSIONS

(a) The presence of spacers can considerably influence the burnout performance of a test section. Increases in burnout heat flux by up to 75 per cent are possible although no effect upon, or reduction in the performance can occur in some cases, depending on the mass velocity and inlet temperature.

(b) Changing the spacer pitch for a given heater length is also an important factor influencing the test section performance. In general, increasing the spacer pitch reduced the burnout heat flux except at a low mass velocity (0.7 Mg m^{-2} s^{-1}), where the effect was relatively unchanged.

(c) The number of upstream sets of spacers and their location with respect to the downstream end of the heater have a significant influence on the test section burnout performance: for a group of four spacer sets at 152 mm pitch, the performance was reduced by removing upstream spacers or increasing the separation between the last downstream set of spacers and the downstream end of the heater.

(d) Streamlining the spacers reduced the burnout power of a test section.

5. RECOMMENDATIONS

(i) A more extensive small scale experimental program is required to explain the behaviour observed in these tests.

(ii) A study should be made of the possibility of quantitatively formulating the effect of spacers on burnout by comparing the data with predictions using a correlation (*e.g.* CISE) based on data which were not influenced by spacers or grids.

6. ACKNOWLEDGEMENTS

The author is grateful to Dr. K. R. Lawther, Head, Heat Transfer Section for his help with the project. The author also acknowledges the able technical assistance of H. N. Harvey, C. Evans, A. Ozolins, A. Beard and, in particular, J. R. Stevens.

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Salt, K J. & Wintle, C A (1964) - Design and Operations of a Transistorised Bridge Type Detector for Burnout in Boiling Heat Transfer Experiments. AEEW R330.

TABLE 1

EXPERIMENTAL DATA FOR BARE ANNULUS

Run Number	Mass Velocity ($Mg\ m^{-2}\ s^{-1}$)	Inlet Subcooling ($kJ\ kg^{-1}$)	Power (kW)	Exit Quality*	Pressure Drop (kPa)
29057002	2.85	23.8	19.9	0.074	40
29057003		5.4	12.2	0.122	39
27057007		14.1	15.9	0.100	38
29057004		4.4	12.3	0.132	39
10067007	0.70	24.0	10.4	0.354	36
10067010		14.0	8.9	0.354	36
11067002		5.8	7.6	0.351	36
11067001		3.4	7.5	0.367	36
29057006	1.27	24.5	14.5	0.239	37
10067001		5.0	9.2	0.235	37
29057008		14.3	11.7	0.229	37
20067005	4.00	19.5	20.7	0.044	40
20067002		4.8	14.1	0.102	43
10067003		23.2	22.1	0.026	39
10067005		14.3	18.8	0.065	41
20067004		10.0	16.5	0.079	42

TABLE 2

EXPERIMENTAL DATA FOR THE HEATER ROD WITH SPACERS AT 305 mm PITCH

Run Number	Mass Velocity ($Mg\ m^{-2}\ s^{-1}$)	Inlet Subcooling ($kJ\ kg^{-1}$)	Power (kW)	Exit Quality*	Pressure Drop (kPa)
6107104	0.50	22.5	8.9	0.461	30
6107122		15.4	8.1	0.462	29
6107126		4.7	7.2	0.482	26
7107105	0.99	23.2	13.2	0.302	46
7107114		14.0	12.1	0.336	45
7107122		4.1	10.5	0.356	45
8107104	2.01	23.9	17.0	0.135	63
8107106		13.5	15.1	0.184	72
11107108		4.8	12.8	0.220	80
12107105	2.96	24.8	20.8	0.086	85
12107110		14.6	18.7	0.145	110
12107115		3.7	15.8	0.208	148

* *estimate from heat balance equation*

TABLE 3

EXPERIMENTAL DATA FOR THE HEATER ROD WITH SPACERS AT 152 mm PITCH

Run Number	Mass Velocity (Mg $\mathrm{m^{-2}\,s^{-1}}$)	Inlet Subcooling (kJ $\mathrm{kg^{-1}}$)	Power (kW)	Exit Quality*	Pressure Drop (kPa)
11117103	0.50	24.0	10.0	0.534	31
11117106		14.7	7.6	0.434	29
11117108		4.1	6.3	0.424	27
12117105	0.99	4.8	11.2	0.379	53
15117103		23.8	15.5	0.381	49
15117105		15.1	13.7	0.387	50
15117109	2.01	25.4	21.4	0.203	77
16117103		14.5	18.7	0.241	89
16117104		4.4	16.8	0.293	108
16117108	2.92	24.6	26.0	0.167	118
16117110		13.4	23.5	0.225	148
17117102		5.1	19.7	0.264	213

TABLE 4

EXPERIMENTAL DATA FOR THE HEATER ROD WITH FOUR SETS OF SPACERS AT 152 mm PITCH 152 mm FROM THE HEATER DOWNSTREAM END

Run Number	Mass Velocity (Mg $\mathrm{m^{-2}\,s^{-1}}$)	Inlet Subcooling (kJ $\mathrm{kg^{-1}}$)	Power (kW)	Exit Quality*	Pressure Drop (kPa)
13067205	0.50	7.4	7.8	0.510	31
13067204		15.7	8.7	0.504	31
13067203		25.4	9.6	0.497	31
9067205	0.98	4.2	11.2	0.390	45
9067203		23.1	14.5	0.359	43
14067204	2.01	6.5	14.6	0.232	79
14067203		16.2	17.4	0.204	72
14067205		24.9	20.3	0.186	67
14067208	2.89	4.9	15.5	0.192	132
14067207		13.8	19.3	0.166	113
14067206		25.4	23.7	0.129	91

* *estimate from heat balance equation*

TABLE 5

EXPERIMENTAL DATA FOR THE HEATER ROD WITH ONE SET OF SPACERS 152 mm FROM THE HEATER DOWNSTREAM END

Run Number	Mass Velocity (Mg $\mathrm{m^{-2}\,s^{-1}}$)	Inlet Subcooling (kJ $\mathrm{kg^{-1}}$)	Power (kW)	Exit Quality*	Pressure Drop (kPa)
25057205	0.50	7.5	7.3	0.476	25
26057204		14.6	8.1	0.476	26
26057203		23.3	8.9	0.462	28
25057204	0.98	5.8	9.2	0.300	40
25057203		15.2	11.0	0.293	40
25057202		22.2	12.5	0.292	40
24057203	2.00	6.8	11.5	0.173	64
24057202		15.7	14.8	0.157	62
23057202		23.4	17.7	0.154	59
24057204	2.94	6.7	13.4	0.143	100
24057205		13.2	16.5	0.125	92
24057206		23.8	21.5	0.101	81

TABLE 6

EXPERIMENTAL DATA FOR THE HEATER ROD WITH FOUR SETS OF SPACERS AT 152 mm PITCH 305 mm FROM THE HEATER DOWNSTREAM END

Run Number	Mass Velocity (Mg $\mathrm{m^{-2}\,s^{-1}}$)	Inlet Subcooling (kJ $\mathrm{kg^{-1}}$)	Power (kW)	Exit Quality*	Pressure Drop (kPa)
28067207	0.50	5.9	7.6	0.512	26
28067208		13.3	8.4	0.507	27
28067209		24.1	9.4	0.493	29
28067206	0.99	8.3	11.0	0.347	45
28067204		15.5	12.2	0.331	44
28067203		25.1	13.5	0.303	44
27067204	2.01	7.5	13.3	0.200	76
27067203		15.6	14.9	0.163	68
27067202		25.6	17.2	0.122	60
27067205	2.97	7.0	15.4	0.169	117
27067206		13.9	17.1	0.130	105
27067297		25.0	20.3	0.074	82

* *estimate from heat balance equation*

TABLE 7

EXPERIMENTAL DATA FOR THE HEATER ROD WITH ONE SET OF SPACERS 305 mm FROM THE HEATER DOWNSTREAM END

Run Number	Mass Velocity ($Mg\ m^{-2}\ s^{-1}$)	Inlet Subcooling ($kJ\ kg^{-1}$)	Power (kW)	Exit Quality*	Pressure Drop (kPa)
11077204	0.49	6.1	7.2	0.506	24
11077203		13.9	7.8	0.464	28
11077202		26.0	9.0	0.456	29
10077205	0.99	4.6	9.5	0.317	42
10077206		12.9	11.0	0.304	42
10077207		24.3	13.2	0.295	42
12077203	2.01	5.8	12.0	0.189	70
12077202		12.8	13.7	0.163	64
12077204	2.95	6.6	14.2	0.154	106
12077206		16.5	17.6	0.112	89

TABLE 8

EXPERIMENTAL DATA FOR THE HEATER ROD WITH STREAMLINED SPACERS AT 152 mm PITCH

Run Number	Mass Velocity ($Mg\ m^{-2}\ s^{-1}$)	Inlet Subcooling ($kJ\ kg^{-1}$)	Power (kW)	Exit Quality*	Pressure Drop (kPa)
19077203	2.00	25.1	18.1	0.143	60
19077205		15.0	15.2	0.174	70
19077207		4.6	12.3	0.208	80
19077209	2.96	6.3	16.0	0.186	136
19077211		14.3	18.9	0.151	113
19077213		25.1	23.1	0.111	95
20077203	0.99	27.0	14.1	0.304	44
20077205		17.9	12.1	0.306	45
2077207	0.50	7.0	7.5	0.489	27
2077209		14.9	8.1	0.473	28
21077203		24.9	9.1	0.459	30

* *estimate from heat balance equation*

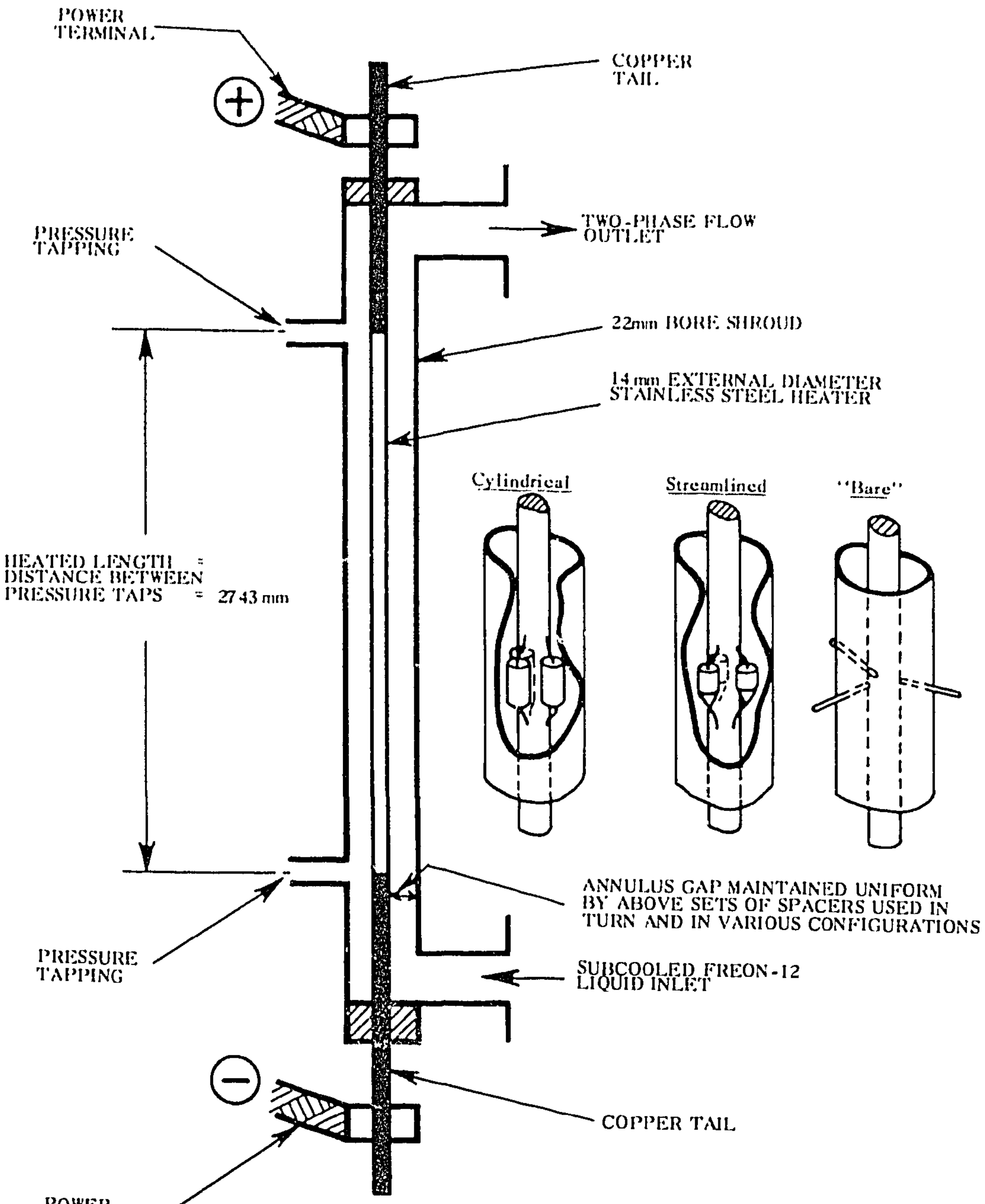

FIGURE 1 TEST SECTION ARRANGEMENT

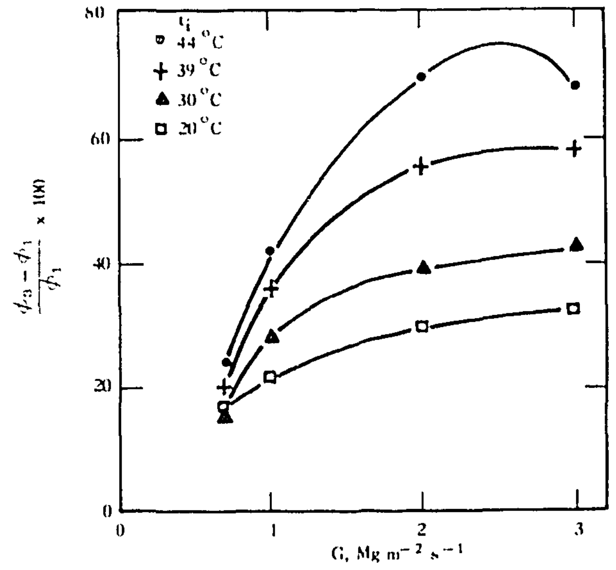

FIGURE 2 PERCENTAGE CHANGE IN BURNOUT POWER RELATIVE TO BARE ROD AT 152 mm SPACER PITCH

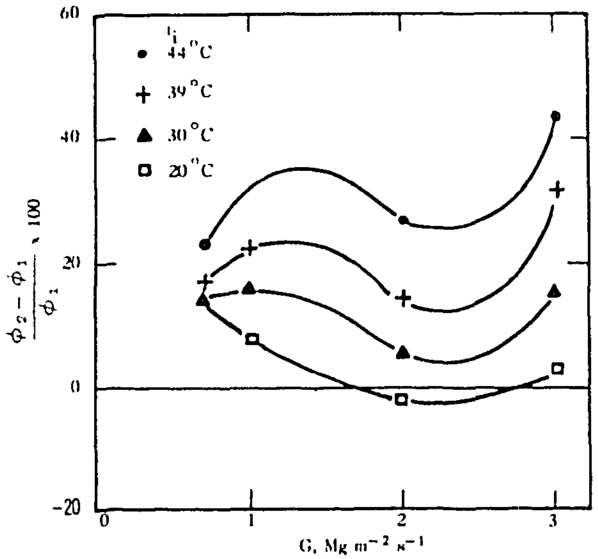

FIGURE 3 PERCENTAGE CHANGE IN BURNOUT POWER RELATIVE TO BARE ROD AT 305 mm SPACER PITCH

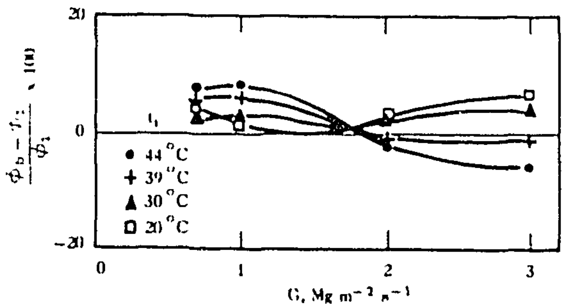

FIGURE 6 PERCENTAGE CHANGE IN BURNOUT POWER RELATIVE TO BARE ROD CAUSED BY A SINGLE SET OF SPACERS 152 mm FROM THE HEATER END

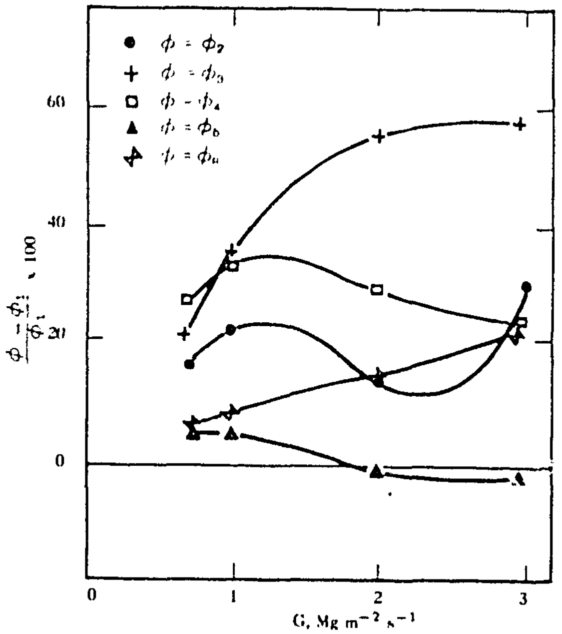

FIGURE 7 COMPARISON OF RELATIVE CHANGES IN BURNOUT POWER FOR FIVE SPACER CONFIGURATIONS AT 39 °C INLET TEMPERATURE

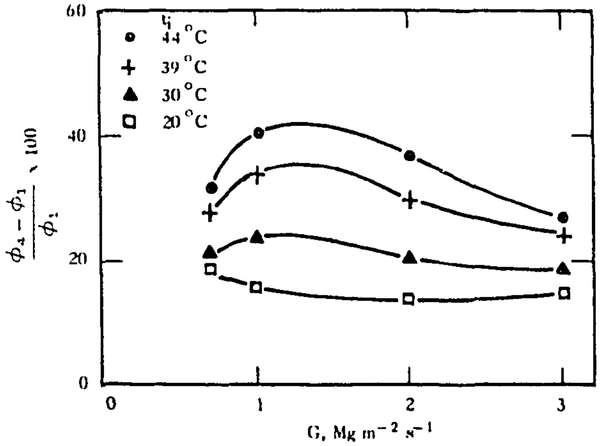

FIGURE 5 PERCENTAGE CHANGE IN BURNOUT POWER RELATIVE TO BARE ROD WITH 14 SETS OF UPSTREAM SPACERS REMOVED AT 152 mm PITCH

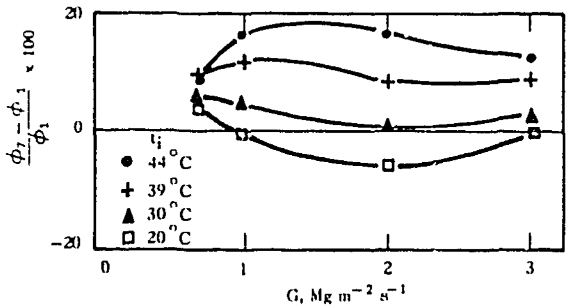

FIGURE 8 PERCENTAGE CHANGE IN BURNOUT POWER RELATIVE TO BARE ROD CAUSED BY A SINGLE SET OF SPACERS 305 mm FROM THE HEATER END

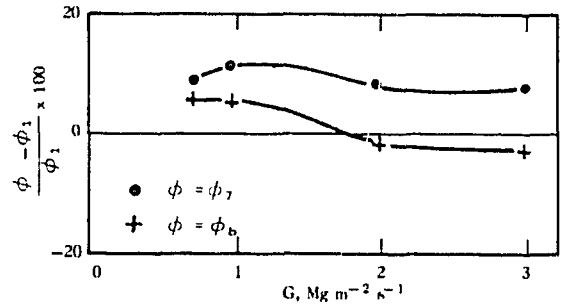

FIGURE 9 COMPARISON OF PERCENTAGE CHANGE IN BURNOUT POWER RELATIVE TO BARE ROD CAUSED BY DISPLACEMENT OF A SINGLE SET OF SPACERS FROM 152 mm TO 305 mm BELOW HEATER END AT 39 °C INLET TEMPERATURE

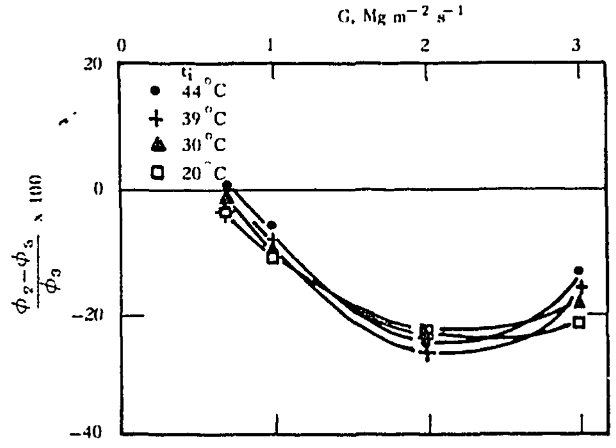

FIGURE 4 PERCENTAGE CHANGE IN BURNOUT POWER AT 305 mm SPACER PITCH RELATIVE TO 152 mm SPACER PITCH

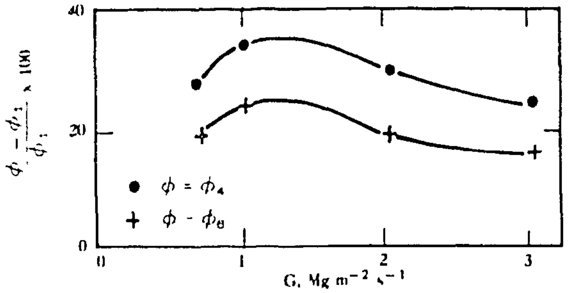

FIGURE 10 COMPARISON OF RELATIVE EFFECT OF CHANGING THE DISTANCE OF THE LAST SET OF SPACERS (AT 152 mm PITCH) FROM 152 mm TO 305 mm FROM HEATER END FOR FOUR SETS OF SPACERS

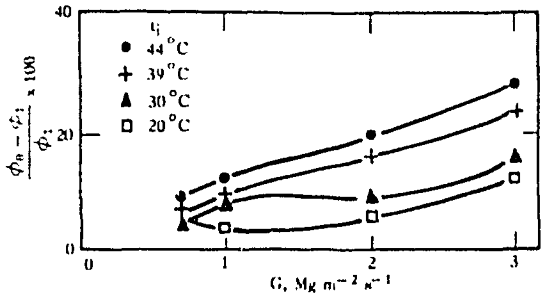

FIGURE 11 PERCENTAGE CHANGE IN BURNOUT POWER RELATIVE TO BARE ROD FOR STREAMLINED SPACERS AT 152 mm PITCH

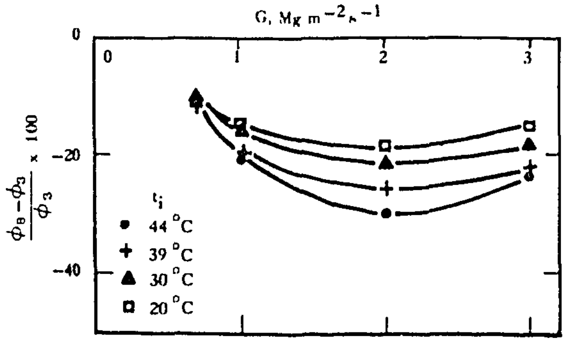

FIGURE 12 PERCENTAGE CHANGE IN BURNOUT POWER FOR TEST SECTION WITH STREAMLINED SPACERS RELATIVE TO THAT WITH CYLINDRICAL SPACERS AT 152 mm PITCH

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