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Possible HRE-3 Configurations
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SUMMARY

Dye hold-up time studies were completed for three 1/16-scale lucite models of possible configurations of HRE-3. The models studied had a spherical (#MF-2) and a cylindrical (#MF-1) core with flat heads on the pressure vessels. Model MF-2 was also run with a "dished" head on the pressure vessel (#MF-2D). Results for these models indicate a change from laminar to turbulent flow when the equivalent Reynolds number was within a range of 900 to 1,500. Better mixing was found in model MF-1 than in model MF-2, but the difference was small beyond the transition point. Addition of a dished head to model MF-2 caused the dye hold-up times to decrease at Reynolds numbers less than 2,500.

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INTRODUCTION

The configuration of a slurry blanket system is dependent upon such factors as the possibilities of boiling at the core-blanket interface, of slurry settling in the bottom of the blanket region or on top of the core, and of the presence of relatively stagnant regions in the blanket. Exploratory runs in the slurry blanket test facility⁴ have shown that a blanket configuration such as the one in the Homogeneous Reactor Test will require modification before being suitable for operation with slurry.

The dye hold-up time study is one method being developed to give information on the flow conditions present in some reactor concepts and on how these flow conditions change with a change in geometry. Tests in possible HRE-3 concepts were made to provide quantitative data on retention times which would serve as a means of comparison of the various configurations tested. It is hoped that this will prove a simple method of screening the different concepts while still at a small scale.

The experimental work covered by this report gives results from dye retention time tests on models number MF-1 (Fig. 2), MF-2 (Fig. 3), and MF-2D (Fig. 4). The range of Reynolds numbers, calculated at the equator of the blanket region, used in the tests ran from 250 to 3,000.

DESCRIPTION OF APPARATUS

The flow diagram for the dye retention tests is shown in Fig. 1. The two models on which dye retention tests have been completed are shown in Figs. 2 and 3. In each model water flowed up between the core and shroud and down in the outer blanket region. Water left through the annulus at the bottom of the model. Five- and ten-gpm Fisher and Porter rotameters connected in parallel were to measure the water flow rate. A water leg on the model outlet line was necessary to prevent losses when the model was being filled with dye. Static pressure inside the model was indicated by the 0-30 psi gauge on the vent line and was controlled by the globe valve on the model outlet line. The 10-psig air supply was used to facilitate drainage of the outer blanket region of the model. Dye retention was timed with a Standard electric timer which had 0.1 second graduations.

A dye concentrate was made by mixing together 3060 ml water, 13.6 grams bromthymol blue indicator, and 10,180 ml of 0.1 normal sodium hydroxide. The dye solution used was then prepared by adding 87.2 ml of concentrate for each gallon of dye solution desired and diluting with water to the desired volume.

OPERATING PROCEDURE

To begin a run, the model was first filled with water (vent and water outlet valves open). The model was filled slowly to keep the formation of air bubbles to a minimum and to sweep those bubbles that did form up to the vent line. When the model was completely filled, the vent valve was closed and the water flow rate was adjusted to the desired value. By adjusting the water outlet valve, the desired static pressure in the model was obtained.

After both the desired flow rate and static pressure had been set, the three-way cock was turned so that the water flow went to drain. The vent valve was opened and a short burst of air from the ten-pound air supply was used to start a siphoning action which drained the outer blanket region of the model. With the region inside the shroud full of water, the outer blanket region was filled with dye from a dye tank above the model. When the model was completely full, the vent valve was closed, the three-way cock was turned so that water (at a preset rate) flowed through the model and, at the same instant, an electric timer was started. The electric timer was stopped when the last trace of dye was gone, as determined by visual observation. Four trials were made at each setting of flow rate and pressure. Another trial was run if there was any doubt about the accuracy of one of the first four. Runs were made at 0, 5, 10, and 15 psig static pressures using various flow rates between 0.5 and 13.0 gpm.

EXPERIMENTAL RESULTS

The data are presented in plots (Figs. 4, 5, and 6) with the minimum Reynolds number throughout the blanket of the models as the abscissa. The Reynolds number in each case was calculated for the annular region of the blanket at the equator. Figures 4 and 5 are for models MF-1 and MF-2, respectively.

In Fig. 6 the ratio of sweep-out time to hold-up time was plotted versus Reynolds number for all three models. Sweep-out time was defined as the volume of the model divided by the flow rate; i.e., it was the time required to sweep the dye out of the model if perfect slug flow existed. Data taken when the static pressure was less than 10 psig have been omitted from Fig. 6 for clarity.

Experimental data from which Figs. 4, 5, and 6 were plotted are tabulated in Tables I, II, and III for models MF-1, MF-2, and MF-2D, respectively.

In all cases the last visible trace of dye was in the form of thin filaments or a film which clung to the outside of the shroud. In model MF-2, dye was last seen on the bottom half of the shroud. Runs at increased flow rates caused the location of the last filaments of dye to progress downward.

In model MF-2D, dye was last seen on the bottom half of the shroud at an angle of approximately 50° below the equator and at the top half of the shroud at an angle of approximately 45° above the equator. In model MF-1, the last trace of dye was seen in the curved portion just below the top of the shroud.

DISCUSSION OF RESULTS

Figures 4 and 5 are presented to show the effect that static pressure within the models had on the amount of air bubbles in the models and therefore on hold-up times. It was impossible to keep air bubbles out of the system with zero psig pressure in the models, but for a pressure of 10 psig the model was usually clear of air bubbles. For model MF-1 (Fig. 4) the presence of air bubbles (0 psig) increased the dye hold-up time by 11 to 17 per cent and only a small amount of pressure (as little as 2 psig) was required to reduce the air bubbles to a negligible quantity.

For model MF-2 (Fig. 5) the data for 5, 10, and 15 psig all fell on the same line, indicating that the amount of static pressure was not critical above 5 psig. The data for a static pressure of zero psig, however, showed that the hold-up times were between 20 and 60 per cent less when air bubbles were present in the model. Visual observation of dye tests, together with the obvious difference in the effect that air bubbles have on the hold-up times of the two

models, indicate that the flow patterns in model MF-1 are apparently different in nature to those of model MF-2. Photographic techniques and visual observation of a circulating suspension of phosphorescent particles^{1, 5} have been used to determine the flow patterns present in model MF-1 below a Reynolds number of 1200.² It is planned to use these same methods to determine the shape of the flow patterns in models MF-2 and MF-2D.

It is believed that the knowledge of the flow patterns present in the models together with the dye hold-up time data will indicate more clearly the cause of the variation of hold-up times as a function of static pressure. A knowledge of how the flow patterns change as the flow rate passes the transition point in the curves is also expected to be useful in explaining the change in the curves at flow rates above the transition point.

The curves (Figs. 4, 5, and 6) indicate a change of flow regime at a Reynolds number of 1500 for models MF-1 and MF-2D and between 900 and 1200 for model MF-2. The appearance of a possible flow transition below the usual 2100 Reynolds number may result from not using the proper characteristic length in computing the Reynolds number and/or the promotion of turbulence prematurely as the liquid breaks over the top of the shroud.

The plot shown in Fig. 6 is the one used for comparison of the flow characteristics of the various models. Only the data taken with a static pressure of 10 psig or more were plotted.

The dye retention time studies completed show that the addition of the dished head to model MF-2 improved the flow distribution for Reynolds numbers less than 2500. Even though comparatively stagnant areas were seen in two places in model MF-2D, the amount of dye held in the stagnant regions (on the shroud surface) and the over-all hold-up times were less than those for model MF-2. Above a Reynolds number of 2500 the stagnant area in model MF-2 had

moved to the lower portion of the shroud, the amount of dye remaining decreased, and the hold-up times were less than for model MF-2D.

This preliminary information indicates better flow distribution in model MF-1 than in model MF-2. Beyond the flow transition point (where the full scale HRE-3 would operate), there appears to be little difference. Using a dished head definitely improves the flow pattern in model MF-2 below the transition point. The almost constant value of the ratio of sweep-out time to hold-up time (Fig. 6) for model MF-2D above the transition point indicates perfect mixing if it is assumed that the percentage of dye at the limit of visibility is the same for all flow rates. The validity of this assumption has not yet been determined.

Despite the use of visual observation for taking the dye hold-up time data, the scatter of individual hold-up time measurements about their mean was small. The range of the probable error of the mean³ of duplicate runs was 0.7 to 3% at 0 psig and 0.6 - 5.8% at pressures greater than zero for model MF-1; 0.4 to 12% at 0 psig and 0.6 - 6.0% at pressures greater than zero for MF-2; and 0.4 to 4.8% for model MF-2D.

Since the ultimate use of the configurations tested will be for a slurry blanket reactor, a comparison of slurry hold-up times to the already determined dye hold-up times will be necessary before the value of dye hold-up time studies is proved.

FIGURE 1 - SCHEMATIC DIAGRAM FOR DYE RETENTION TIME STUDIES.

FIGURE 2 - SKETCH OF LUCITE MODEL NUMBER MF-1.

FIGURE 3 - SKETCH OF LUCITE MODEL NUMBER MF-2 AND MF-2D.

FIGURE 4 - HOLD-UP TIME VERSUS REYNOLDS NUMBER AT THE BLANKET EQUATOR FOR MODEL MF-1.

FIGURE 5 - HOLD-UP TIME VERSUS REYNOLDS NUMBER AT THE BLANKET EQUATOR FOR MODELS MF-2 AND MF-2D.

FIGURE 6 - RATIO OF SWEEP-OUT TIME TO HOLD-UP TIME VERSUS REYNOLDS NUMBER AT THE EQUATOR OF THE BLANKET.

Table I. Data from Dye Hold-up Time Studies for Model MF-1

Run	Water Flow Rate, gpm	Reynolds Number	Average Dye Hold-up Time, sec.	Sweep- out Time, sec.	<u>Sweep-out Time</u> Avg. Hold-up Time	Static Pressure in Model, psig
MF1-4	0.96	250	252.6	25.5	0.101	0
	1.45	378	127.6	16.9	0.132	0
	1.90	496	94.5	12.9	0.136	0
	2.35	613	71.0	10.4	0.147	0
	2.85	743	58.2	8.60	0.148	0
	3.30	861	51.3	7.42	0.145	0
	3.75	978	39.2	6.54	0.167	2.0
	4.20	1069	28.8	5.83	0.202	3.5
	4.75	1209	28.4	5.16	0.182	4.6
	5.20	1323	25.2	4.71	0.188	6.0
	5.70	1451	25.4	4.29	0.169	5.9
	6.20	1578	22.1	3.96	0.174	9.5
	9.00	2092	14.0	2.73	0.195	3.6
	9.60	2231	13.4	2.55	0.190	4.0
MF1-5	10.45	2429	10.7	2.34	0.218	5.0
	10.50	2440	10.6	2.34	0.220	5.0
	11.1	2580	10.2	2.21	0.216	6.0
MF1-4	0.96	250	178.7	25.5	0.142	10.0
	1.45	378	124.2	16.9	0.136	10.0
	1.90	496	89.4	12.9	0.144	10.0
	2.35	613	64.8	10.4	0.161	10.0
	2.85	743	55.0	8.60	0.156	10.0
	3.30	861	45.5	7.42	0.163	10.0
	3.75	954	38.8	6.54	0.168	10.0
	4.30	1094	29.0	5.70	0.198	10.0
	4.75	1209	26.7	5.16	0.194	10.0
	5.20	1323	30.0	4.71	0.156	10.0
	5.70	1451	23.4	4.29	0.183	10.0
	6.70	1705	18.4	3.66	0.199	11.0
	7.18	1762	15.8	3.42	0.216	13.0
	7.70	1890	14.9	3.18	0.214	14.5
	8.12	1993	12.8	3.02	0.236	17.25
	8.40	2061	12.6	2.92	0.232	18.75
	8.85	2172	11.3	2.76	0.245	13.0
MF1-6	1.10	258	145.0	22.3	0.154	10.0
	1.60	375	103.0	15.3	0.149	10.0
	1.35	316	127.1	18.2	0.143	10.0
	2.10	492	75.7	11.7	0.154	10.0
	3.20	749	49.3	7.66	0.156	10.0
	4.60	1077	31.2	5.33	0.170	10.0

Table II. Data from Dye Hold-up Time Studies for Model MF-2

Run	Water Flow Rate, gpm	Reynolds Number	Average Dye Hold-up Time, sec.	Sweep- out Time, sec.	Sweep-out Time Avg. Hold-up Time	Static Pressure in Model, psig
MF2-3	1.00	252	266.8	27.4	0.103	0
	4.25	1070	41.9	6.46	.154	0
	3.80	957	51.7	7.22	.140	0
	3.30	831	43.9	8.32	.189	0
	2.85	718	54.2	9.62	.178	0
	2.40	604	71.8	11.4	.159	0
	1.90	478	118.9	14.5	.122	0
	4.75	1196	26.8	5.77	.215	0
	5.20	1309	23.0	5.27	.229	0
	5.70	1435	21.2	4.81	.227	0
	4.25	1007	38.8	6.45	.166	0
	1.92	455	180.6	14.4	.081	0
	3.84	910	49.0	7.23	.148	0
	6.60	1540	22.0	4.20	.187	10.0
MF2-4	5.70	1351	27.6	4.82	.175	10.0
	4.72	1119	42.9	5.82	.136	10.0
	3.80	901	58.6	7.23	.124	10.0
	2.90	687	121.1	9.49	.078	10.0
	1.90	450	269.6	14.5	.054	10.0
	2.35	557	201.7	11.7	.058	10.0
	3.30	782	110.3	8.32	.076	10.0
	4.30	1019	72.0	6.40	.089	10.0
	5.19	1230	59.0	5.30	.090	10.0
	5.10	1185	50.7	5.30	.105	5.0
MF2-5	3.75	889	71.5	7.32	.102	5.0
	2.90	687	134.3	9.50	.070	
	2.35	557	203.7	11.3	.056	
	7.93	1879	16.6	3.45	.208	15.0
MF2-6	5.20	1232	44.8	5.30	.118	16.4
	3.30	782	110.2	8.32	.076	15.0
	9.40	2228	13.2	2.92	.220	10.0
MF2-7	2.35	557	157.5	11.5	.073	0
	2.35	557	190.9	11.7	.061	10.0
	3.30	782	94.7	8.32	.088	10.0
MF2-8	4.00	948	77.7	6.88	.088	10.0
	5.50	1304	36.0	5.05	.140	10.0
	6.00	1422	33.0	4.58	.142	10.0
	6.58	1559	24.7	4.18	.170	10.0

Table II. Data from Dye Hold-up Time Studies for Model MF-1 (Cont'd)

Run	Water Flow Rate, gpm	Reynolds Number	Average Dye Hold-up Time, sec.	Sweep- out Time, sec.	Sweep-out Time Avg. Hold-up Time	Static Pressure in Model, psig
MF2-9	7.70	1812	14.6	3.56	0.245	0
	8.65	2035	13.3	3.17	.238	0
	13.20	3106	9.0	2.08	.230	10.0
	12.30	2894	9.0	2.24	.247	10.0
	11.92	2805	8.7	2.31	.265	10.0
	11.60	2729	8.1	2.37	.294	10.0
	11.10	2612	8.6	2.48	.290	10.0
	10.60	2494	10.1	2.59	.256	10.0
	10.10	2377	11.2	2.72	.244	10.0
	12.50	2941	8.7	2.20	.253	10.0
MF2-10	11.85	2788	9.0	2.32	.290	10.0
	10.88	2560	9.8	2.52	.257	10.0
	9.80	2306	10.3	2.81	.272	10.0

Table III. Data from Dye Hold-up Time Studies for Model MF-2D

Run	Water Flow Rate, gpm	Reynolds Number	Average Dye Hold-up Time, sec.	Sweep- out Time, sec.	Sweep-out Time Avg. Hold-up Time	Static Pressure in Model, psig
MF2D-2	1.92	516	213.3	14.3	0.067	10.0
	2.88	774	87.9	9.52	.109	10.0
	3.85	1034	44.2	7.13	.161	10.0
	4.80	1289	23.7	5.72	.241	10.0
	5.75	1544	17.5	4.78	.273	10.0
	6.72	1805	16.1	4.09	.254	10.0
	7.70	2068	14.3	3.56	.249	10.0
	8.65	2323	12.4	3.17	.256	10.0
	9.60	2579	11.4	2.86	.252	10.0
	5.00	3250	9.04	2.25	.249	10.0
	2.40	645	125.5	11.4	.091	10.0
	3.36	902	59.7	8.17	.137	10.0
	4.32	1160	35.3	6.36	.180	10.0
	4.05	1088	39.0	6.78	.174	10.0
	3.55	954	48.7	7.74	.159	10.0

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