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ANNUAL TECHNICAL PROGRESS REPORT
LMFBR TASK 25, TRANSIT TIME FLOWMETER
GFY 1970

AEC Research and Development Report

Atomics International
North American Rockwell

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Program:	LMFBR Component Development	
AEC Task:	25, Transit Time Flowmeter	
Project Manager:	C. W. Wheelock	
Reporting Period:	Government Fiscal Year 1970	
General Order:	7757	Subaccount: 53100
		AEC Category: 04-40-03-01.1

I. PROJECT OBJECTIVES

The objective of the program is the development and demonstration of a flowmeter using noise-analysis techniques which will be suitable for use as a flow-measurement standard in large liquid-metal systems at temperatures to 1200°F or higher. A secondary objective is the development and testing of a small flowmeter for use in measuring flowrate from individual fuel assemblies in liquid-metal-cooled reactors such as the FFTF.

Operation of the Transit Time Flowmeter (TTF) depends upon the detection of small temperature variations (thermal eddies) at two points a known distance apart in a flowstream. The two signals are cross-correlated with a variable delay time. The delay time which gives maximum correlation is the transit time of the fluid between the sensors, which time is inversely proportional to the fluid velocity.

Part 1 of the development program completed in GFY 1969 determined through water-loop tests of a TTF that the system was feasible and would perform satisfactorily, and analytical studies showed that it also would function similarly in sodium at flowrates above 1 ft/sec.

Objectives of the second part of the program, completed in January 1970, were to: (1) demonstrate the Transit Time Flowmeter technique for flow measurement in sodium at temperatures up to 1200°F, (2) obtain comparative performance data of a 2-in.-diam TTF of fixed design in sodium and water, and (3) investigate the effects on potential accuracy of the TTF variables, such as the number and configuration of in-stream sensors, amount and type of heat injection, operating conditions, and measurement techniques.

The Part 3 program, February 1970 through January 1971, has three objectives as follows: (1) design and assembly of a 6-in.-diam TTF and testing of this in water and sodium at flow velocities to 30 ft/sec and temperatures to 1050°F, (2) development and testing of an electronics system to provide a direct-reading flow-signal from the transit-time detectors, and (3) development and testing of a transit-time thermal flowmeter which has potential application in the FFTF and other reactors for measuring flowrate from individual fuel assemblies.

II. TECHNICAL PROGRESS DURING FISCAL YEAR 1970

A 2-in.diam Transit Time Flowmeter was completed, operated, and tested in water at flow velocities to 15 ft/sec and in sodium at operating temperatures to 1200°F. A topical report* describing the test results was prepared.

Under the Part 3 program, a 6-in.diam transit-time flowmeter to be tested at the Sodium Components Test Installation (SCTI) in 1050°F sodium at flowrates to 30 ft/sec, was designed, materials were procured, and fabrication of components was started. For TTF electronic-system development, commercially available components were investigated and the requirements were discussed with potential suppliers. Work on the fuel-assembly transit-time thermal flowmeter was limited to preliminary investigations of the effects of changing design features on heating requirements, signal strength, and response time.

A. TESTS AND CALIBRATION OF 2-in.-diam TRANSIT TIME FLOWMETER

The tests of the 2-in.diam Transit Time Flowmeter were completed. The water-loop tests were made at flow velocities up to 15 ft/sec to check the accuracy of the TTF flow measurements for various sensor configurations against volumetric/time measurements. The results of these tests are summarized in Table 1.

Sodium-loop tests were made at 500, 900, and 1200°F and flow velocities up to 10 ft/sec. The test-loop configuration was that shown in Figures 1 and 2.

*R. L. Randall, "Transit Time Flowmeters Employing Noise Analysis Techniques, Part 2 - 2-in. Sodium-Loop Tests," AI-AEC-12941 (to be published)

TABLE 1
MEASURED/AVERAGE FLOW RATIOS FOR WATER-LOOP TESTS

Run No.	Average Flow* (ft/sec)	Axial Average of Measured/Average Flow	Axial Average of Measured/Average Flow With Correction for End Effects
208	14.67	0.967	1.002
202	10.29	0.981	1.001
204	5.96	0.996	1.001
205	4.09	0.999	1.001
206	2.45	1.022	1.022
207	1.41	1.015	1.015

*Average flow was determined from volume/time calibration measurements.

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Figure 1. Transit Time Flowmeter Sodium-Loop Schematic

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Figure 2. Transit Time Flowmeter 2-in. Sodium-Loop Installation

Results of sodium tests at 500 and 900°F did not differ significantly from the 1200°F tests or from the water-loop tests; therefore, the major emphasis on analysis and evaluation was given to data from the 1200°F tests, and comparisons with water-test results. Average flow velocities were determined by summing individual velocity measurements (velocity profiles) determined from pairs of individual thermocouples (TC's) and by summing the signals from groups of TC's on the sensors. This was done with a variable number of TC's, 2 to 14 per sensor, as the sources of the flow-velocity signals. The results of these tests are given in Table 2.

Results from water tests show that velocity measurements made with the two sets of "reference" sensors and the axial average of all sensor combinations are consistent within 1% with the average flow determined using the volume/time method for flowrates above 2.5 ft/sec. Results from the sodium tests show that the velocity measurements made with the two sets of reference sensors are consistent within 1% with the axial average of all sensor combinations for all temperature conditions, all flow conditions above 2.5 ft/sec, and all combinations (2, 4, 6, 8, 10, 12, or 14) of TC's on each sensor.

Studies of the propagation and decay of temperature patterns in sodium show results strikingly similar to those from the water tests. Empirical models were developed which relate amplitude, bandwidth, and measurement velocity of temperature patterns in water and sodium to injection temperature, geometrical factors, sensor position, and flow conditions. Measurements mapping the acceleration of temperature patterns to average stream velocity were used to compute second-order correction factors relating measured transit times to average flowrate for the various sensor configurations.

Sodium-velocity measurements by the transit-time method were compared with velocity indications from two EM flowmeters. These results show the expected linear proportionality relationship; however, 15 to 17.5% discrepancies were observed between the two electromagnetic (EM) flowmeters in the loop. The measured velocities using the transit-time method were consistent within 5% with the computed flow velocities measured by one of the EM flowmeters. The computed flow velocities from this EM flowmeter were based on post-test room-temperature measurements of the field strength of the permanent magnet.

TABLE 2
COMPARISON OF FLOW MEASUREMENTS USING SUMMATION AND
VELOCITY-PROFILE INTEGRATION METHODS

Reference Flow Measurement (ft/sec)	Number of Radial Samples per Sensor	Flow Measurements Between 1st and 2nd Sensor Position		Flow Measurements Between 2nd and 4th Sensor Position	
		Velocity Profile Integration Method (ft/sec)	Summation Method (ft/sec)	Velocity Profile Integration Method (ft/sec)	Summation Method (ft/sec)
10.30 ± 0.05 (Water) Run 202	14	9.61 ± 0.33	9.79 ± 0.05	10.13 ± 0.09	10.19 ± 0.04
	12	9.55 ± 0.39	-	10.17 ± 0.08	-
	10	9.69 ± 0.38	-	10.14 ± 0.12	-
	8	9.56 ± 0.47	-	10.10 ± 0.11	-
	6	9.59 ± 0.50	-	10.04 ± 0.16	-
	4	9.41 ± 0.77	-	10.12 ± 0.14	-
	2	9.95 ± 0.23	-	9.88 ± 0.48	-
7.80 ± 0.03 (1200°F Sodium) Runs 1208 to 1215	14	7.79 ± 0.20	7.37 ± 0.07	7.77 ± 0.06	7.78 ± 0.04
	12	7.74 ± 0.23	7.36 ± 0.05	7.79 ± 0.06	7.72 ± 0.05
	10	7.81 ± 0.25	7.25 ± 0.07	7.75 ± 0.07	7.78 ± 0.04
	8	7.95 ± 0.31	7.27 ± 0.06	7.77 ± 0.08	7.73 ± 0.04
	6	7.86 ± 0.27	7.45 ± 0.06	7.77 ± 0.09	7.76 ± 0.03
	4	7.75 ± 0.39	7.42 ± 0.05	7.82 ± 0.11	7.78 ± 0.04
	2	8.09 ± 0.39	7.70 ± 0.05	7.68 ± 0.19	7.78 ± 0.04

The prediction of actual field strength at temperature is expected to be within 5% of the values predicted from the measurements at room temperature. Post-test flux measurements were not obtained for the second EM flowmeter.

B. LARGE-DIAMETER TRANSIT TIME FLOWMETER

Work on the Part 3 program began with preparations for testing a 6-in.-diam Transit Time Flowmeter in sodium in the SCTI at temperatures to 1050°F and flowrates to 30 ft/sec.

The test section to be installed in the SCTI is 6-in. in diameter and approximately 20-ft long as shown in Figure 3. Eight TTF sensors and an EM flowmeter will be located on this test section. This arrangement will provide accurate EM flowmeter data for comparison to the TTF results and the eight widely spaced TTF sensors will increase the capability of the test setup for studying diffusion of thermal patterns. Designs for the flow section, sensors, and thermal-source assembly have been completed and a System Design Description was drafted.

The thermal source shown in Figure 4 was devised in the form of a fin-shaped eductor-injector about 0.9-in.-wide by 6-in.-long which extends vertically from above into the 6-in.-diam flow section. About 5% of the sodium stream is diverted through an air cooler (a 4-in.-diam pipe with fins, about 5-ft-long) where it is cooled before it returns to the flowstream. The flowrate through this unit is a constant fraction of the flow, approximately dependent upon the sodium temperature and relatively independent of the velocity of the flowstream. By use of this type of thermal source, separate piping connections to the SCTI sodium system are avoided. The thermal and hydraulic analyses of this heat source were completed.

Analyses of the 0.3- by 1.3-in. airfoil-shaped sensors (Figure 5) have indicated that these dimensions would provide an adequate margin of safety for both strength and vibration resistance for a fin designed as a cantilever long enough to extend across the 6-in.-diam pipe. The fins were made from a 7/8-in.-diam hollow tubing with a 0.035-in.-wall thickness formed into an airfoil shape with integral transition to the round cross-section. Each sensor has eight 0.040-in. (sheath OD) and two 1/16-in. thermocouples arranged by the method of Chebyshev to minimize error when the signals from them are summed.

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Figure 3. 6-in.- diam Transit Time Flowmeter Installation in the Sodium Components Test Installation Primary Loop

Figure 4.
Thermal Source for 6-in.
Transit Time
Flowmeter

Figure 5.
Cantilevered Thermocouple
Sensor in 6-in. Transit
Time Flowmeter

III. EVALUATION OF EFFORT DURING FISCAL YEAR 1970

The sodium tests of the 2-in. TTF demonstrated that inherent or induced temperature patterns are readily detectable at two or more axially spaced in-stream sensors and that these signals are suitable for measuring flow velocity. Random-temperature patterns generated by injection of a thermal tracer were detected at all four in-stream sensor positions, and transit-time measurements were obtained relating the six sensor pair combinations for all flow and temperature conditions. Typical signal levels ranged from 0.01 to 1.0°F peak-to-peak, depending on heater power, flowrate, and sensor position. Tests results for flow velocities from ~1.4 to 10 ft/sec indicated that temperature patterns decay at approximately the same rates in sodium and water. This is in agreement with earlier studies^{*} which indicated that hydrodynamic effects, not thermal diffusion, dominate the deterioration of temperature patterns. However, because of the lower density and heat capacity of sodium, temperature patterns of detectable magnitude are more readily generated in sodium than in water. Of particular interest for future applications are the results of the 1200°F 2-in. loop tests which show that inherent temperature fluctuations created by heat loss at the first in-stream sensor provide temperature signals for flow measurements between the second sensor 12-in. downstream and the other sensors farther downstream. Results without heat injection appear to be within 1% of those with.

The TTF sensors and flow section were successfully operated over the temperature range from room temperature (water tests) to 1200°F (sodium tests), which demonstrated one of the unique advantages of the Transit Time Flowmeter over other methods; i e, the useful temperature range is limited only by the temperature limitations of the sensor materials and TC's. Except for changes in the distance between sensors by thermal expansion (on the order of a few tenths of a percent), flow-velocity measurements by the transit-time method are unaffected by temperature. These inherent characteristics and the test results to date continue to indicate that the Transit Time Flowmeter will be valuable for use in calibration measurements of flow velocity in large sodium loops where volume/time calibration methods are not practical.

*R. L. Randall, "Transit Time Flowmeter Employing Noise Analysis Techniques, Part 1 - Water Loop Tests," AI-AEC-12802 (1969)

Discussions with suppliers of electronic systems indicate that commercially available cross-correlation equipment is being improved and reduced in cost and that correlation systems which required several racks of equipment a few years ago now require a single-rack module. By the time LMFBR's are placed in operation the electronics package for a Transit Time Flowmeter with 0.1% accuracy should require no more than three or four circuit cards. Simpler versions with 1% accuracy are also foreseen for use as in-core flowmeters.

The cantilever design for the 6-in.-diam TTF being developed for tests in the SCTI will provide the bases for evaluation of the capabilities of this type of flowmeter as well as the basic components required. The eductor-injector thermal source is applicable to any size piped system, and the cantilevered sensors can be installed in any larger-size pipe at two or more angular positions in planes normal to the pipe axis.