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Discussion

O. E. Dwyer.[6] The authors have gone a long way toward settling the question of whether or not the dynamical behavior of heavy metals in flow equipment is the same as that for ordinary fluids. Since degree of wetting was mentioned as a possible factor in distinguishing between the behavior of the two types of liquids, it would be desirable to have seen some discussion on this question, with reference to the experimental results. For example, to what extent, if any, did the Pb-Bi wet the pipe or the orifice edges? We at Brookhaven have found that, in the case of bismuth (about 200 ppm Zr and 100 ppm Mg) at 1000 F, high velocity is capable of effecting complete wetting on steels.

The authors state that when their apparatus was once running fairly constant results were obtained; but that from run to run duplicability was not nearly as good. We have observed the same phenomenon in a mercury loop at our laboratory; and the writer is of the opinion, in agreement with the authors' suspicion, that entrapped gas is mainly responsible; i.e., in the case of a nonwetting system. In this connection, it is significant to note that the friction-factor data for water scattered appreciably less than those for the Pb-Bi. It would have been interesting to determine the effect of wetting on duplicability from run to run, by adding an alkali or alkaline-earth metal to the Pb-Bi to induce wetting. The amounts needed would not have been enough to change the physical properties of the Pb-Bi.

R. R. Miller.[7] It is of interest that similar friction factors and orifice metering coefficients are found for the metals and water but, considering the properties of liquid metals in general, it is not surprising. The liquid metals are simpler in molecular structure and should be more ideal than the customary liquids. While we have done no work in connection with friction factors of flow and relatively little on viscosity, the most unusual phenomena are those attributed to the condition of nonwetting. This condition can be aggravated and perhaps extended by the occlusion of gases in liquids as found by Boarts, et al. (reference 8 of the paper), where decreases in density of mercury up to 12 per cent were found to be due to entrapped gases. It is not entirely clear from the present paper whether or not gases could be trapped during the operation of this apparatus. The entrapment of gases and nonwetting appear to be the only characteristics with which we are acquainted which could cause the variation in the friction factors. However, these would appear to cause variation only in one direction away from the water values and it does not appear to be a complete explanation of the effects found.

T. Trocki[8] and R. A. Edwards.[8] In this paper, the authors have contributed some significant experimental work and they are to be commended on it. The experimental program and the test equipment were quite adequate to meet their objectives.

One question which arises in our minds is why a simple permanent magnet, magnetic-type flowmeter was not investigated at the same time. For laboratory installation, a magnetic flowmeter should not be any more expensive than the orifice with its instrumentation. It would be valuable to have more calibrations of magnetic flowmeters by use of a metering tank.

Another question arises with regard to the control of temperature during these experiments. Some of the scatter may be accounted for by variation of temperature among different runs of the test.

Authors' Closure

The authors wish to express their appreciation to the discussers for bringing out some significant points which were not covered adequately in the paper. In answer to Dr. Dwyer's questions regarding wetting, visual inspection indicated that the lead-bismuth did not wet the pipe or orifice plates. No attempt was made to cause wetting by the use of additives, since after the pressure-drop tests it was planned to obtain heat-transfer data under nonwetting conditions. With regard to the question of entrapped gas raised by both Dwyer and Miller, it was pointed out in the paper that there were no indications of such a condition during the present tests. Several of the present authors had reported in 1951 (reference 4 of the paper) the severe effects of small amounts of entrapped gas on the heat-transfer performance of liquid metals and consequently extreme care was exercised to eliminate, or at least minimize, such effects during the present tests. However, it is possible that some small

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amounts of gas may have been in solution in the lead-bismuth and possibly these may come out of solution at the wall of the tube. If one postulates such an occlusion of gases to be responsible for the random behavior of the pipe-friction factors, it is difficult to understand why the orifice-metering coefficients were not influenced in a similar manner.

A magnetic-type flowmeter, as suggested by Messrs. Trocki and Edwards, was not tried in this Pb-Bi test loop since the authors had been advised early in the development of the meter, that its performance would be sensitive to a lack of wetting and the electrical output response poor for Pb-Bi, as compared with Na or Na-K. On the other hand, the authors certainly agree that calibrations of the magnetic flowmeter would have been worth while here since the metering-tank performance was quite satisfactory.

With reference to the suggestion that temperature variation may have contributed to the scatter, a review of the data reveals that 52 per cent, for test section 1, was observed in the temperature range 350 to 370 F; 10 per cent at 400 to 450 F; and for test section 2, 75 per cent at 370 to 390 F and 10 per cent at 400 to 415 F. The results for temperatures above 400 F showed the same scatter and could not be distinguished from the results for the temperature range 355 to 365 F. Although this indicates that temperature is probably not a cause for the excessive scatter, better temperature control is to be desired.