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A Comparison of Experimental Results of Pressure Drop for Two Phase Steam/Water and Air/Water Mixtures in a Horizontal Pipe

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SUMMARY Steam/water measurements of pressure drop in a 10cm diameter horizontal pipe are presented using a void fraction correlation and the one dimensional separated flow model. The measurements are compared with experimental data from two smaller diameter air/water rigs and demonstrate the dependence of pressure drop on the void fraction correlation used and pipe surface roughness.

1 INTRODUCTION

The transmission of geothermal fluid from the well head to where it is utilised, for the generation of electricity or for use in an industrial process, has to be accomplished as efficiently as possible. Pipeline costs represent a significant part of the cost of the development of a geothermal resource. It has been the general practice for wet geothermal fields to separate the fluid at the well head into steam and water phases and carry these fluids in separate pipelines or as was the case in the early days at the Wairakei (NZ) Geothermal power station, to discharge the hot water to waste. Nowadays, at Wairakei, some of this hot water is flashed to steam releasing low pressure steam for additional power generation. In connection with the generation of electricity from a geothermal heat source, James (1968) and Takahasmiy et al (1970) showed that by using two phase transmission there were economic factors and an increase in power obtainable from (Wairakei and Otake) geothermal resources which promised a significant overall reduced cost per kilowatt over a comparable single phase system.

In order to design a safe and efficient pipe network for carrying a one component two phase mixture, data is needed describing the flow structure, the line pressure drop, quality change and the flow response to pertubations caused by various fittings and components. Demand for information for the design of nuclear power stations has been responsible for the great bulk of experimental work and associated correlations and models for steam water flow. However experience has shown that descriptions of flow through relatively small diameter boiler type tubes (up to 5 cm diameter) do not successfully predict the flow performance through the large diameter (up to 1 metre diameter) pipes that are encountered in geothermal applications. In addition much of the data is for a two component flow, mainly air/water. The Engineering Science Data Unit in a recently issued set of data items has used a data bank of 2210 measurements to provide a statistical method of selection from seven well used prediction methods, for use with a particular set of conditions. Of this data about 60% of the measurements were for two component fluid flow and 80% of the measurements were taken in pipe diameters in the 0.5 to 4.6 cm range.

An experimental facility comprising of a 10 cm diameter horizontal pipe loop was built by the author on the Wairakei geothermal field at Bore 207. Its object was to obtain pressure drop data for geothermal steam/water flow through straight pipe and common components such as right angled bends, bends in 'S' and 'U' configuration and 'Tee' fittings.

This paper presents some of this data as obtained for a horizontal straight pipe and makes a preliminary comparison with some measurements made on laboratory air/water rigs.

2 EXPERIMENTAL EQUIPMENT AND PROCEDURES

Freeston and Lee (1979) describe the rig and measurement techniques used and also present some preliminary measurements from the Wairakei experiment. To develop measurement techniques and to provide data for comparison with the Wairakei measurements an air/water loop was constructed of 8.4 cm diameter perspex pipe. This loop is described by Lee (1978). Pressure drop is one of the most important parameters in a two phase pipeline design study, its accurate measurement in an experiment is therefore essential.

Hewitt et al (1964) report a technique using liquid purging of the pressure lines so that the lines are always full of the liquid phase, gas filled lines having been found to be unsatisfactory. This method is suitable only for laboratory type experiments as it is considered to be too complicated and not practical for field experiments. The position of the measurement point on the pipe circumference was also thought to influence the measurement. Adler (1977) suggested that pressure taps be on the horizontal centreline to avoid error induced by gravity.

At Wairakei, Freeston and Lee (1979) used condensation pots on all tappings which were placed on the horizontal centre line. The lines were liquid filled and fed to water/mercury manometers. This system was developed from the air/water facility, pressure purging was used as a standard, and the pressure distribution on complimentary diameters around the pipe were compared at positions along the rig. These results showed that the techniques used at Wairakei could be expected to measure pressure with an accuracy better than 8% which was considered satisfactory for the field experiment.

3 RESULTS AND DISCUSSION

Initial test runs at Wairakei were done with dry steam and established that the pipes relative roughness of 0.001 to 0.002 was typical for a 10 cm diameter lightly rusted pipe (ESDU 6602), whilst the air/water rig with a perspex pipe was shown to be hydraulically smooth.

The format for presentation of results for the Wairakei results is based on the separated flow model discussed by Harrison (1975) and further developed by Harrison (1977). The basis of the method is a void fraction correlation due to Butterworth (1975) to which data from a 20 cm diameter pipe was fitted to determine the indices in the relationship (see Appendix). The correlation of data with the separated flow model of Harrison is shown on Fig. 1. The data was tested against other correlations but did not give a satisfactory result. The measured pressure gradient is compared with that calculated and Fig 2 shows the data presented with an abscissa of liquid phase velocity (V_f) divided by pipe diameter.

Data for two air/water experiments are plotted to the same base on Fig. 3. One set is obtained from the experiments previously described with an 84 mm diameter pipe using the steam/water correlation of Harrison (1975) for void fraction. The second set which covers the complete range of $Vf/_D$ tested at Wairakei are reported by Chen and Spedding (1979). They used a 45.5mm diameter perspex pipe test section and measured hold up with quick action valves over a range of flow patterns. The data plotted on Fig. 3. is chosen for flow patterns which were clearly identified as Annular, the experimental values of holdup were used.

Clearly the separated model correlates the data, however the air/water measurements under predict the steam/water pressure gradient at value of $Vf/_D$ greater than about 25. In figure 4 the experimental hold up data converted to void fraction, of Chen and Spedding (1979) is compared to the void fraction correlation of Harrison (1975) and shows divergance from the experimental data, the lower values of void fraction generally corresponding to low quality indicating larger quantities of water with increasing wall film thickness with subsequent changes in flow structure at the interface. The effect of using the calculated value of void fraction for the air/water results is to collapse the pressure drop data, that is reducing the range of $Vf/_D$ and bringing the measurements more in line with the steam/water curve.

The steam/water results were obtained for a rough pipe of relative roughness about 0.001 at fully turbulent liquid Reynolds numbers giving a friction factor from the Moody chart of about 0.022. The air/water data was obtained for a smooth pipe with a friction factor of about 0.009 over the liquid Reynolds number range tested. The separated flow model shows pressure gradient to be proportional to friction factor, ignoring the acceleration component for a given set of flow conditions. It could therefore be expected that the smooth pipe gradient for a given $Vf/_D$ would be increased in the ratio 0.022/0.009 = 2.4. This results in bringing the air/water data above the steam/water curve. However more data needs to be studied before detailed conclusions can be drawn.

4 CONCLUSIONS

Steam/water pressure drop measurements on a horizontal 10 cm diameter rough pipe have been correlated using a separated flow model and a void fraction correlation. Air/water data from two sources are presented which, although showing similar trends, gives absolute values of pressure drop below those of the steam/water data. It is tentatively suggested that surface roughness could be a major factor in accounting for the discrepancies between the two curves. However further study is necessary before detailed conclusions can be drawn.

5 ACKNOWLEDGEMENTS

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APPENDIX

Notation:-

p	pressure N/m^2
z	length m
$\bar{V}$	average water velocity m/s
W	total mass flow kg/s
x	steam quality
ψ	void fraction
v	specific volume m^3/kg
ρ	mass density kg/m^3
A	pipe cross sectional area m^2

D		pipe diameter
AC		acceleration component
τ		shear stress N/m^2
suffix g		saturated steam
f		saturated water

From Harrison (1977) correlation

$$\frac{dp}{dz} = \frac{4\tau_w}{D(1-AC)}$$

and $\tau = \frac{1}{2}\rho_f V_f^2 \times$ friction factor

with the friction factor determined from the Moody diagram using a Reynolds number based on the mean liquid quantities.

$$V_f = \frac{(1-x)W}{(1-\psi)\rho_f A}$$

The void fraction correlation used due to Butterworth (1975) with the indices determined by fitting data from tests on a 20 cm pipeline.

$$\psi = \frac{1}{1 + \left(\frac{(1-x)}{x}\right)^{0.8} \left(\frac{\rho g}{\rho f}\right)^{0.515}}$$

AC is acceleration component defined as

$$AC = \frac{W^2 x^2 v_g}{\psi A^2 p}$$

For these tests AC is small.

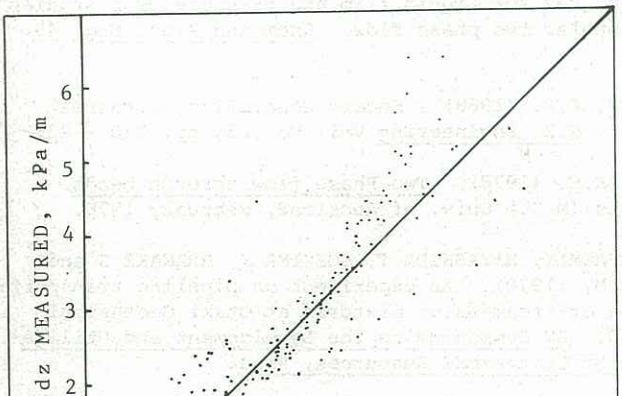

Figure 1 Measured pressure gradient versus pressure gradient predicted by Harrison correlation omitting water flow greater than 10 kg/s.

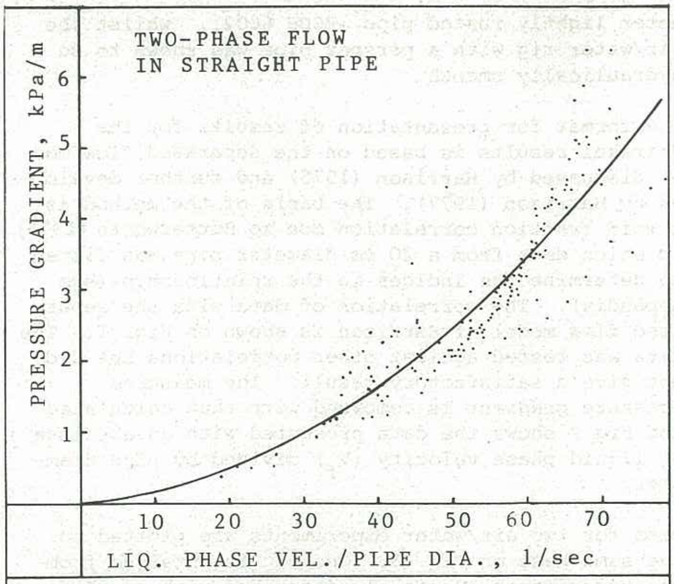

Figure 2 Measured pressure gradient versus liquid phase velocity/pipe diameter omitting water flow greater than 10 kg/s.

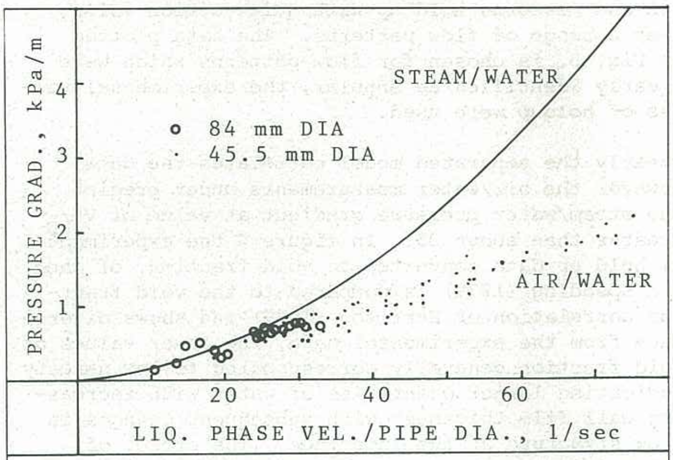

Figure 3 Comparison of steam/water and air/water pressure gradient.

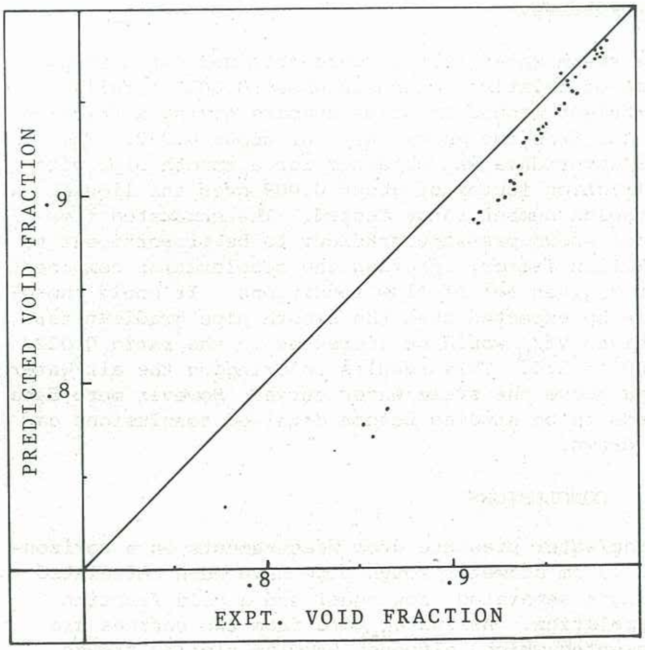

Figure 4 Comparison of predicted and experimental void fraction--Air/water experiment.