SMiRT-12 / K. Kussmaul (Editor)



D10/4

# LABORATORY TESTS OF STRATIFIED FLOW IN HORIZONTAL PIPING

E. Jud, A. Crua and U.R. Blumer

Sulzer Winterthur, Switzerland

## 1. INTRODUCTION

Thermal stratification in horizontal piping of light water reactors is a phenomenon that has been investigated in a research project at Sulzer in Switzerland, partly funded by the Swiss Government. This phenomenon has become known over the last years in many nuclear plants through more extensive thermocouple installations and monitoring of piping. The project covered a laboratory part for the study of the fluid flow and an analytical part for the study of the thermomechanical behaviour of the pipe walls. This paper will present the part that dealt with the investigations into the fluid flow behaviour in the laboratories.

## 2. THE TEST INSTALLATION

Fig. 1 shows an overview of the test installation used. The basic configuration is the plexiglass model of the feedwater pipe inlet into a BWR reactor pressure vessel. The feedwater flow rises through a pump, a flow meter, a control valve and a shut-off valve in the vertical section and is guided through a pipe bend into the horizontal pipe. This pipe leads with a flow restriction device, which is similar in configuration and resistance to the BWR sparger ring, into a larger container. The restriction device could also be installed in various differing geometries, in order to study various end dam effects.

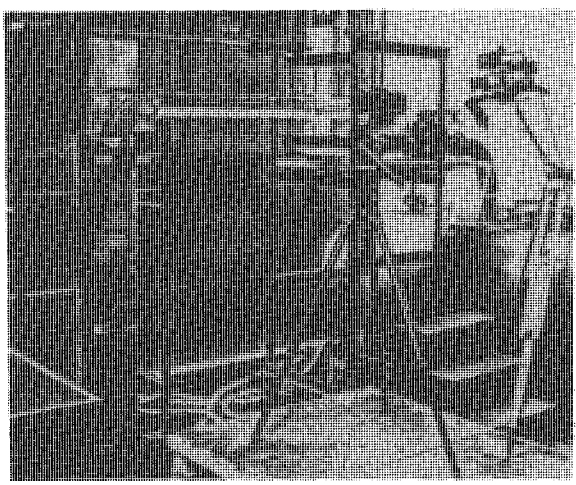

Fig. 1, Test Arrangement

The pipe above the valve and the container are filled initially with pure water. Below the valve, the whole system is filled with water, enriched with $CaCl_2$ salt and with Fluorescine-Sodium. The two ingredients were added in a mixing tank up to the required concentration. The mixing tank has enough capacity to allow a few minutes testing at the highest flow rate of interest. With this salt, a density ratio of 1.3 was obtainable, thereby simulating relatively large temperature differences in the water. The fluorescine was added in order to visualize the flow by laser beam light, as described in the next chapter.

For each test, the shut-off valve was opened, and a pre-set constant flow of heavier water entered the horizontal pipe. At the appropriate flow rates, this lead to stratification in the horizontal piping section. The starting wave and the evolution of a stationary flow were recorded by video tape and photography. Parameters like stratification height, layer slope, and surface wave formation was registered.

## 3. THE FLOW VISUALIZATION TECHNIQUE

The flow in the horizontal plexiglass pipe was made visible by a special laser beam technique. The arrangement is shown in fig.2. The heavier water in the lower portion of the pipe was coloured with fluorescine. If this water is penetrated by laser light, the light beam shines up strongly luminously. In order to get the illumination of a whole axial section through the pipe, the laser beam was sweeped repeatedly by reflection on a rotating mirror wheel mounted on top of the test section.

Fig. 3 shows a photograph of such a longitudinal light section through the pipe. The registration on video tape allowed a later evaluation for stratification level height, wave formation and wave frequency.

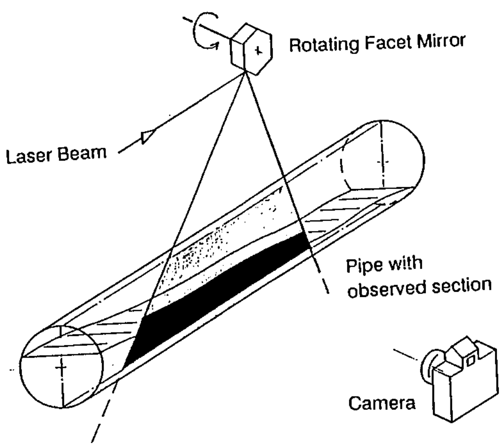


Fig. 2, Visualization Principle

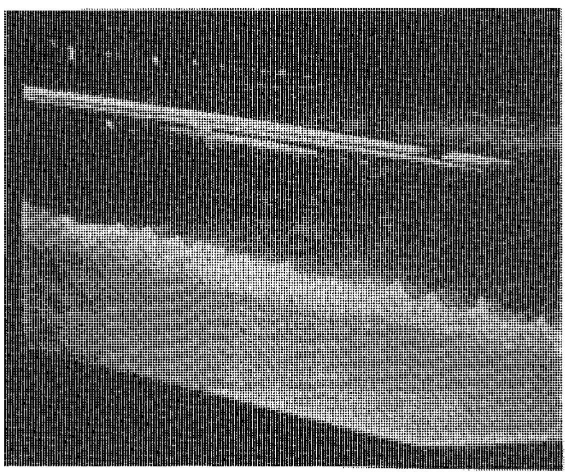

Fig. 3, Boundary with waves

## 4. DEFINITION OF LOCAL AND GLOBAL FROUDE NUMBERS

The phenomena encountered have shown many qualitative results. Among them is e.g. the fact, that the separation boundary transition was very sharp in practically all tests. Even when there were stong waves with high flow rate, the transition was sharply recognisable.

The quantitative results are only of interest if they can be presented in more general form. This can be accomplished with the help of dimensionless numbers. Two of these were defined as follows:

Global Froude Number :

$$FR_{global} = \frac{c^2 * Ro}{9.81 * D * DRo}$$

where

c fluid velocity in the vertical, wholly salt water filled pipe

D inner pipe diameter, used also for computing c

Ro density of the lighter fluid (pure water)

DRo density difference between the fluids

Local Froude Number :

$$FR_{local} = \frac{c_A^2 * Ro}{9.81 * D_{ho} * DRo}$$

$c_A$ average fluid velocity in the lower fluid layer

$D_{ho}$ hydraulic diameter of the upper layer

5. PARAMETRIC RESULTS FOR STRATIFIED FLOW BEHAVIOUR

Fig. 4 shows the layer transition height as a function of the global Froude Number as it was measured for different end configurations. It can be seen that the density change is well represented by the curves. It can also be seen that the change in end configuration has a marked influence on the height.

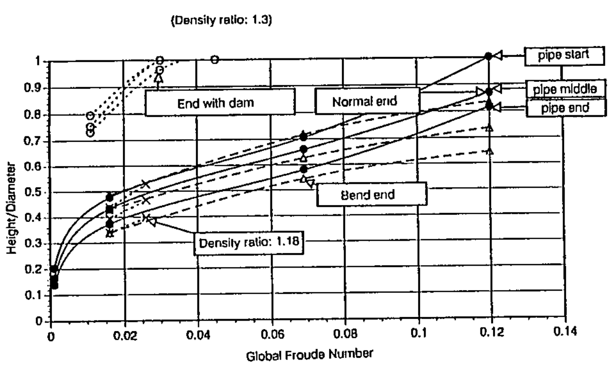


Fig. 4, Layer Boundary height as a function of global Froude Number

Fig. 5 shows the layer transition height inclination as a function of the local Froude Number. It can be seen that the data points can be correlated quite well by the use of this local Froude Number, for all end configurations.

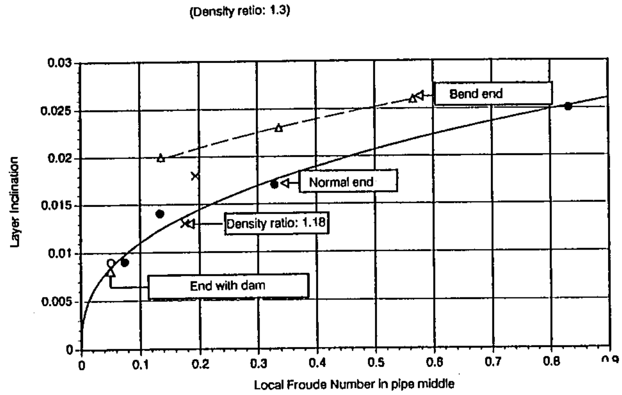


Fig. 5, Layer Boundary inclination as a function of local Froude Number

Fig. 6 shows the normalized transition layer wave height as a function of the local Froude Number. The values have been measured by evaluating the video pictures. It can be seen that below a threshold value there are no waves forming. It also becomes apparent that the wave height tends to saturate at a value of about 8 percent of the pipe diameter. The wave travel velocity was about half the lower layer fluid velocity.

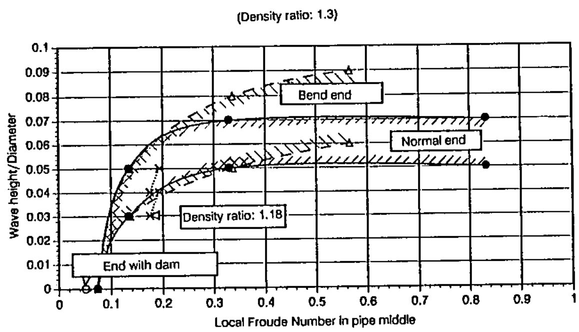


Fig. 6, Wave height as a function of local Froude Number

## 6. CONCLUSIONS

The visualization of the stratificatied flow of two fluids with different densities could be made visible very distinctly by a laser beam reflected on a rotating mirror. The flow evolution and the steady-state condition could be observed and fixed with photograph and video tape.

It has been shown that two definitions of Froude Numbers allowed to give parametric descriptions for layer boundary height, its axial inclination and the wave formation.

## 7. ABSTRACT

Laboratory tests have been performed to study the behaviour of stratified fluid flow in horizontal piping. The parametrically varied phenomena could be observed through the plexiglass piping by means of a longitudinal laser beam section through the flow.

Quantitative correlations of the phenomena have been established by the definition and use of two dimensionless Froude Numbers.