Investigation of Two-Phase Flows in Piping Bends and Elbows

Final Report

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Abstract

An experimental investigation of the hydrodynamic characteristics of two-phase R-113 flow has been carried out. Straight tube pressure drop data, as a function of mass flow rate (mass flux) and flow quality has been obtained using the Two-Phase Flow Test Facility located in the Advanced Thermal Laboratories of the Crew and Thermal Systems Division at the Lyndon B. Johnson Space Center. Additionally, after successfully obtaining the straight tube pressure drop data, the test facility was modified in order to obtain pressure drop data for the flow of two-phase R-113 through 180° piping bends. Inherent instabilities of the test facility prevented the successful acquisition of pressure drop data through the piping bends.

The experimental straight tube data will be presented and compared with existing predictive correlations in an attempt to gain insight into the utility of such correlations as the basis for developing design criteria. A discussion of the instabilities which rendered successful acquisition of the piping bend data will be presented and suggestions will be made for eliminating these system tendencies. Finally, recommendations for future investigations, based on successful reconfiguration of the test facility, will be made.

Introduction

Power requirements for spacecraft and satellites continue to increase, necessitating similar increases in the effectiveness and efficiencies of spacecraft thermal management systems. Active two-phase cooling loops have been identified as systems which may satisfy the requirements of future spaceflight thermal control systems. However, archival literature documenting both experimental and analytical investigations of the pressure gradient characteristics of two-phase flow through piping bends and elbows, such as those which will be included in realistic system designs, is virtually non-existent. The current investigation will obtain baseline data for the two-phase flow test facility developed by the Crew and Thermal Systems Division. Additionally, the investigation will obtain data which will help characterize the pressure drop characteristics of two-phase flows through 180° piping bends. This investigation will compliment and support the TEEM flight experiment scheduled for launch in 1997.

During the summer period, an experimental investigation of the hydrodynamic characteristics of two-phase flows similar to those which would occur in the two-phase active thermal control systems (ATCS) of a space vehicle was undertaken. This investigation represents the first step of a long term effort which will develop mathematical models and experimental data for the prediction of the pressure drops which may be expected for two-phase flow through realistic systems which include piping elbows, expanding and contracting flow sections, and commonly utilized devices such as quick-disconnect fittings.

Experimental Investigation

Straight Tube Investigation

A schematic of the two-phase flow test facility utilized for the straight-tube flow characterization of the current investigation is illustrated in Fig. 1. The R-113 entered the positive displacement pump as single-phase liquid. The single-phase liquid was pumped through the evaporator section which consisted of a circulation heater where heat input could induce partial vaporization of the flowing R-113. The liquid or two-phase mixture which exited the evaporator section could be observed in the flow visualization section in order to characterize the nature of the two-phase or single-phase flow. Downstream of the visualization section, the fluid passed through the pressure drop test section. This pressure drop test section allowed the operator to choose either a low range (Baratron) or high range (Validyne) pressure transducer for the measurement of the pressure drop in the test section. The parameters which were directly varied in the experimental investigation were those of pump power input (controlling mass flow rate or mass flux) and evaporator input power (controlling flow quality). In this manner, the pressure drop in the straight-tube section was measured as a function of both mass flow rate (mass flux) and flow quality. The two-phase test facility was used in conjunction with a PC based data acquisition system for the recording and processing of each measured value obtained from system instrumentation.

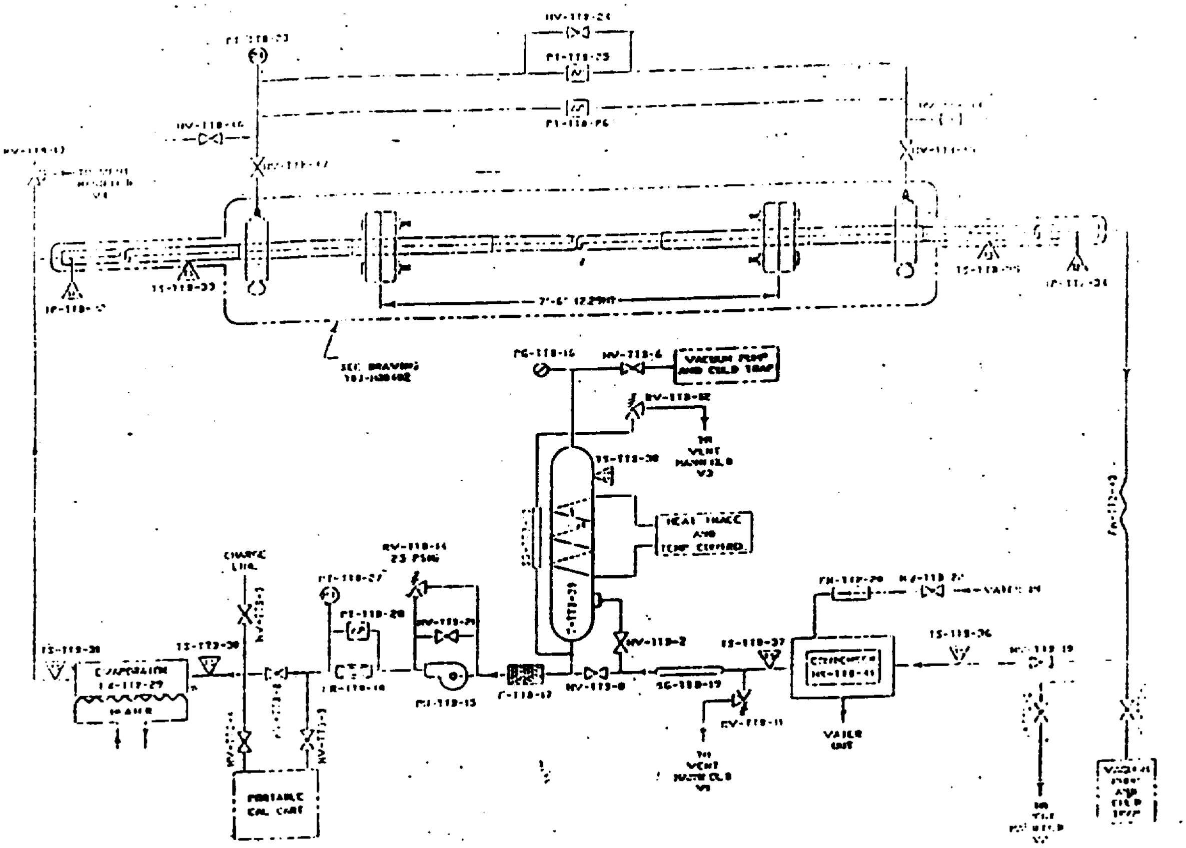

Fig. 1 Schematic of Test Facility

Figure 2 illustrates the measured pressure drop in the straight tube section for single phase R-113 liquid. While the measured values of pressure drop consistently exceed those which are predicted using the Blasius Solution[1], the trend exhibited was quite uniform, with the mean of the measure values exceeding the prediction by approximately 0.075 kPa for virtually the entire range of flow rates. Possible reasons for this steady state error are the presence of roughness in the tubes or a pressure drop due to the fittings present at each pressure tap and each end of the tube. This data indicated that for single phase flow, the measured values obtained from the test facility were acceptably accurate and repeatable.

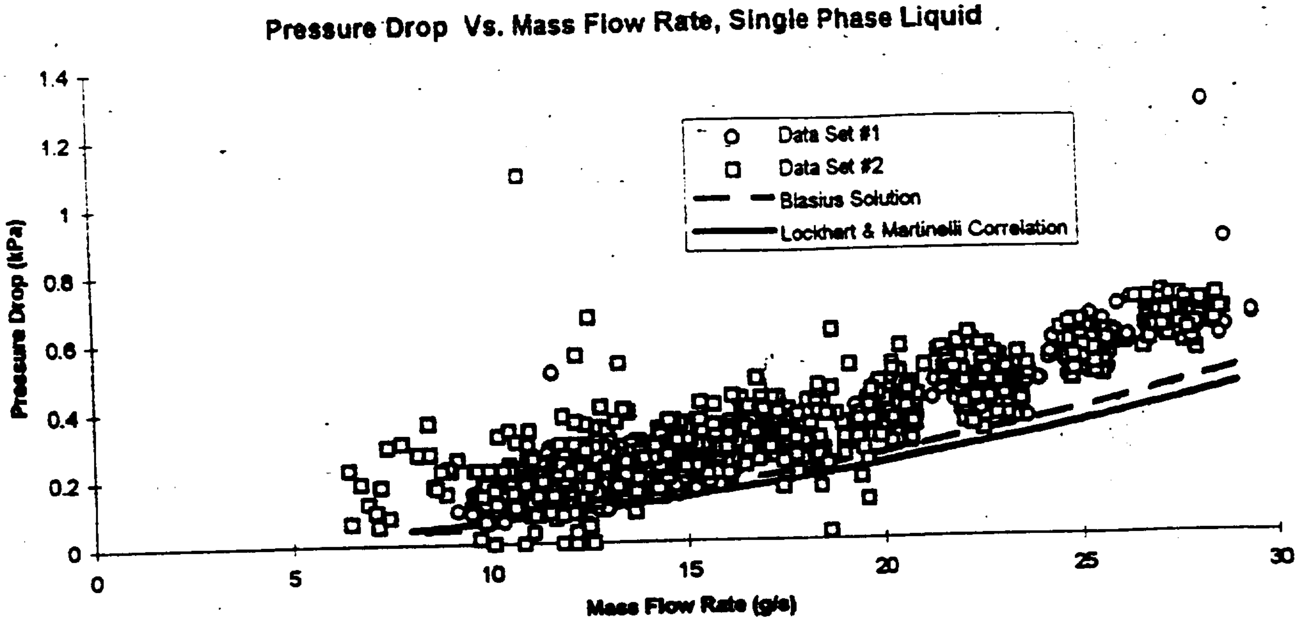

Fig. 2 Single Phase Straight Tube Pressure Drop, Data and Predictive Correlations

Figure 3 illustrates the measured pressure drop in the straight tube section for two-phase R-113 flow subjected to evaporator input levels which produced a flow quality of 20%. The data was compared with four predictive correlations, each of these empirically developed. The first of these was that of Lockhart and Martinelli[2], utilizing the friction factor associated with the Blasius Solution[1]. Secondly, the prediction of Lockhart and Martinelli[2] was used with their recommended friction factor. The third predictive correlation utilized for comparison was that of Troniewski and Ulbrich[3]. Finally, the predictive correlation of Barozcy[4] was utilized. While the trend of the observed data was consistent with those of the predictive correlations throughout the range of mass flow rates, each of the three correlations predicted pressure drop values which were greater than those which were measured.

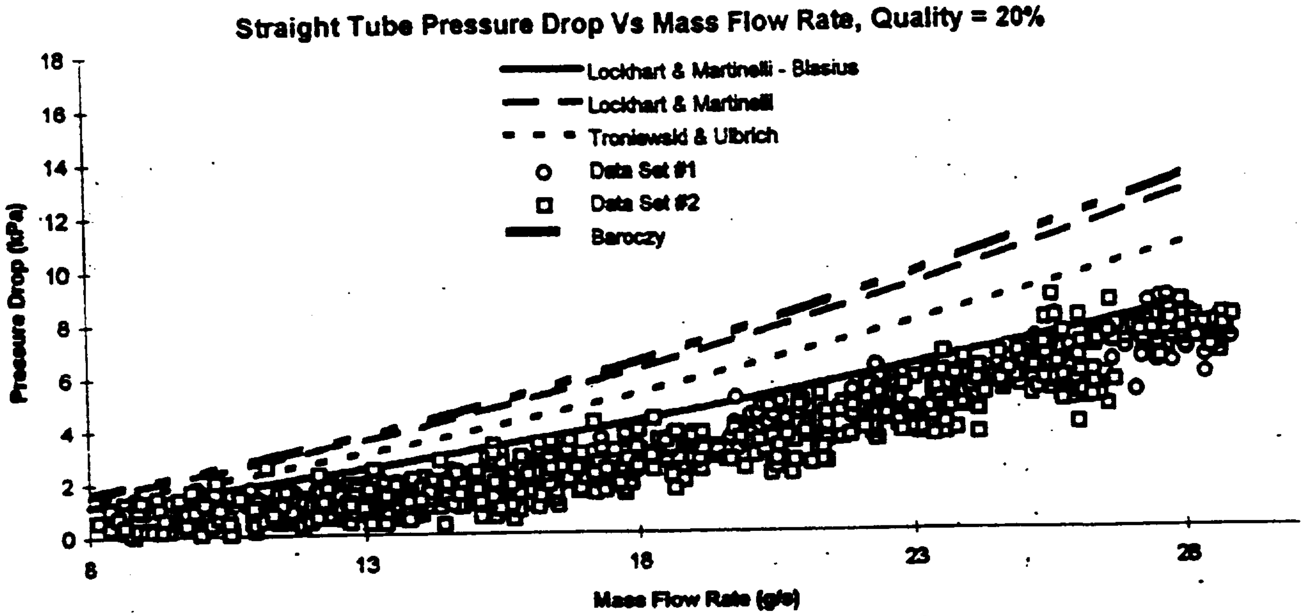

Fig. 3 Straight Tube Pressure Drop Vs. Mass Flow Rate, Quality = 20%

Figure 4 illustrates the measured pressure drop in the straight tube section for two-phase R-113 flow subjected to evaporator input levels which produced a flow quality of 30% as well as the corresponding predictive correlations. As observed in Fig. 3, each of the correlations produced a prediction of pressure drop which was greater than that observed experimentally. The most significant difference between Fig. 4 and Fig. 3 is that the predictive correlation which utilized the Blasius Solution[1] friction factor with the prediction of Lockhart and Martinelli[2] demonstrated a significant "jump" at the transition to turbulent flow of the R-113 liquid in the two-phase flow. The predictive correlation of Troniewski and Ulbrich[3] yielded the closest agreement with the measured values

Figure 5 illustrates the measured and predicted pressure drop values for two-phase flow having a quality of 40%. While two of the correlations, that of Troniewski and Ulbrich[3] and that of Lockhart and Martinelli[2] match both the trends and values of the measured data, this may have been simply because it is at this quality value that the fluctuation in measured mass flow rate became quite significant. At this quality value, fluctuations in the measured value of the mass flow rate were as great as ± 15%. While this fluctuation occurred in the measured value, the trends of the data displayed in Fig. 4 indicate that there was little effect on the measured pressure drop values lying within the "high end" of the range of data. However, for the measured pressure drop values lying within the low end of the data (< 8 kPa), the uncertain fluctuation in mass flow rate appeared to be accompanied by an uncertain fluctuation in the measured pressure drop value.

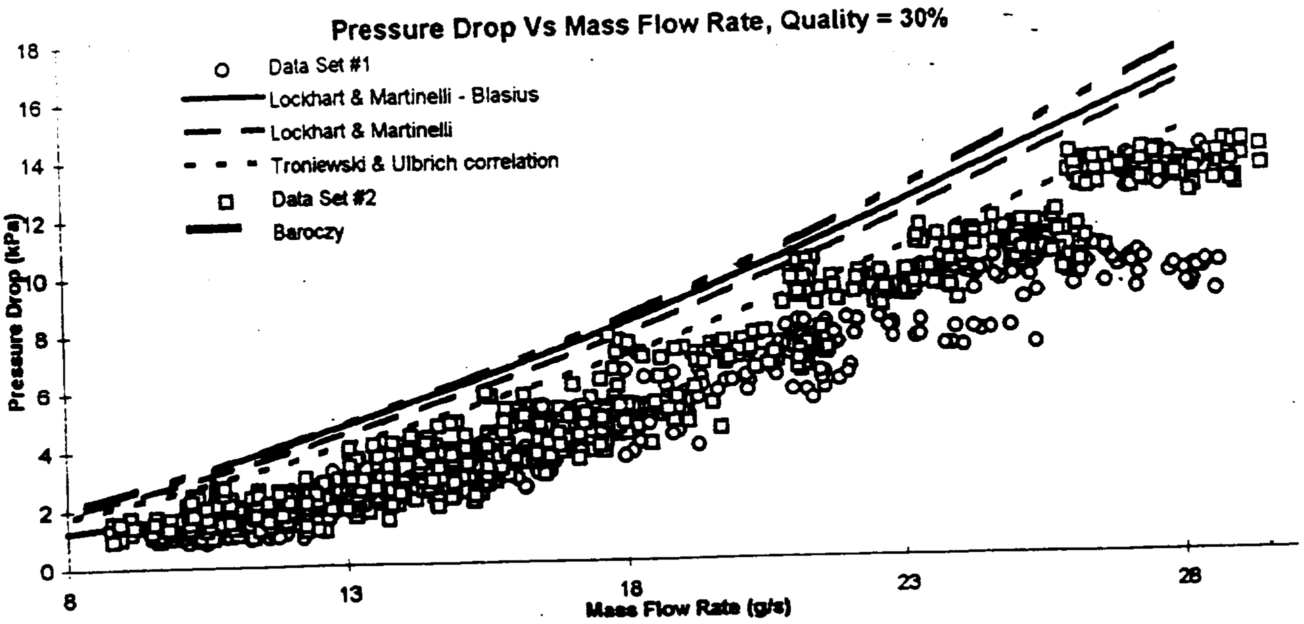

Fig. 4 Straight Tube Pressure Drop Vs. Mass Flow Rate, Quality = 30%

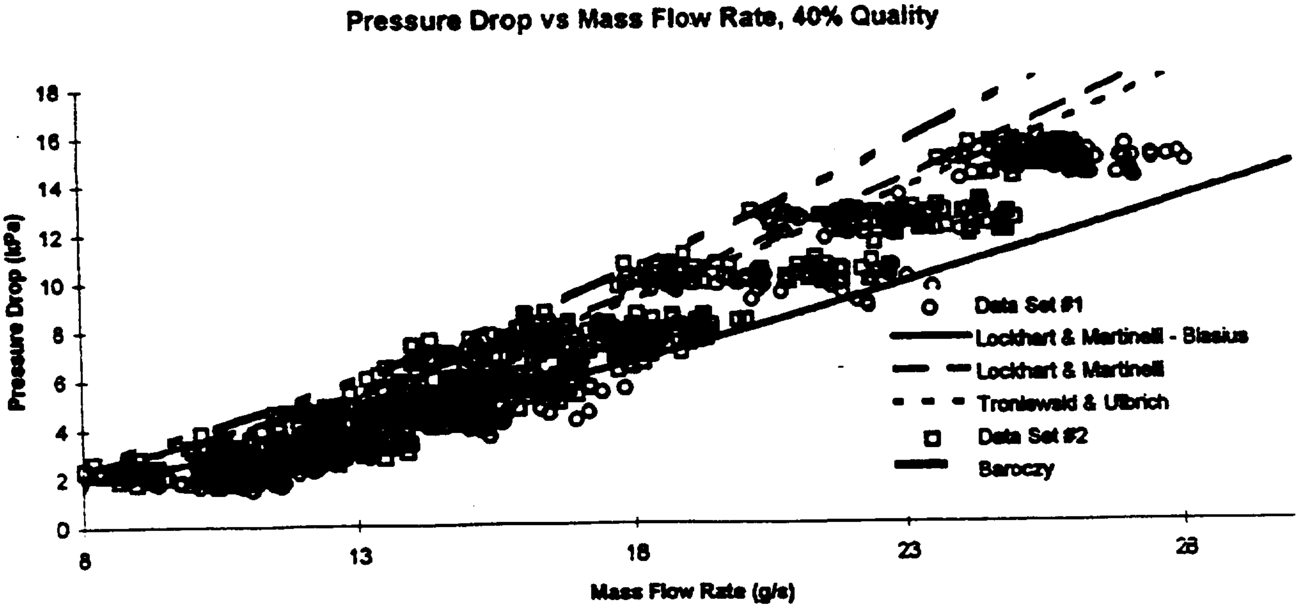

Fig. 5 Straight Tube Pressure Drop Vs. Mass Flow Rate, Quality = 40%

Figures 6 - 9 illustrate the measured and predicted pressure drop values for two-phase flows having qualities of 50%, 60%, 70%, and 80%, respectively. In general, it appears that as flow quality increased, each of the correlations began to predict pressure drop values which were significantly less than those measured experimentally. Experimental trends made it difficult to draw worthwhile conclusions from the data. Unfortunately, with this increase in quality, came a great increase in the uncertain fluctuation of the measured mass flow rate value. This large uncertain fluctuation made the process of obtaining useful information from the experiments quite difficult. Only the most general trend could be observed, which was that of the predictive correlations yielding pressure drop values less than those measured experimentally.

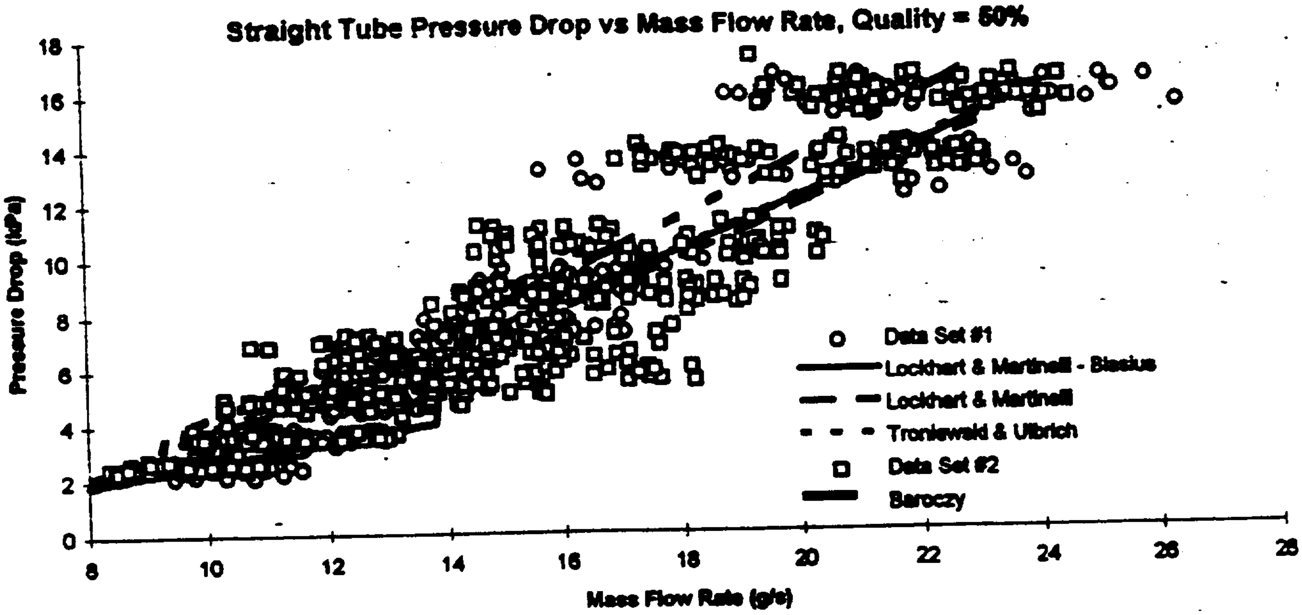

Fig. 6 Straight Tube Pressure Drop Vs. Mass Flow Rate, Quality = 50%

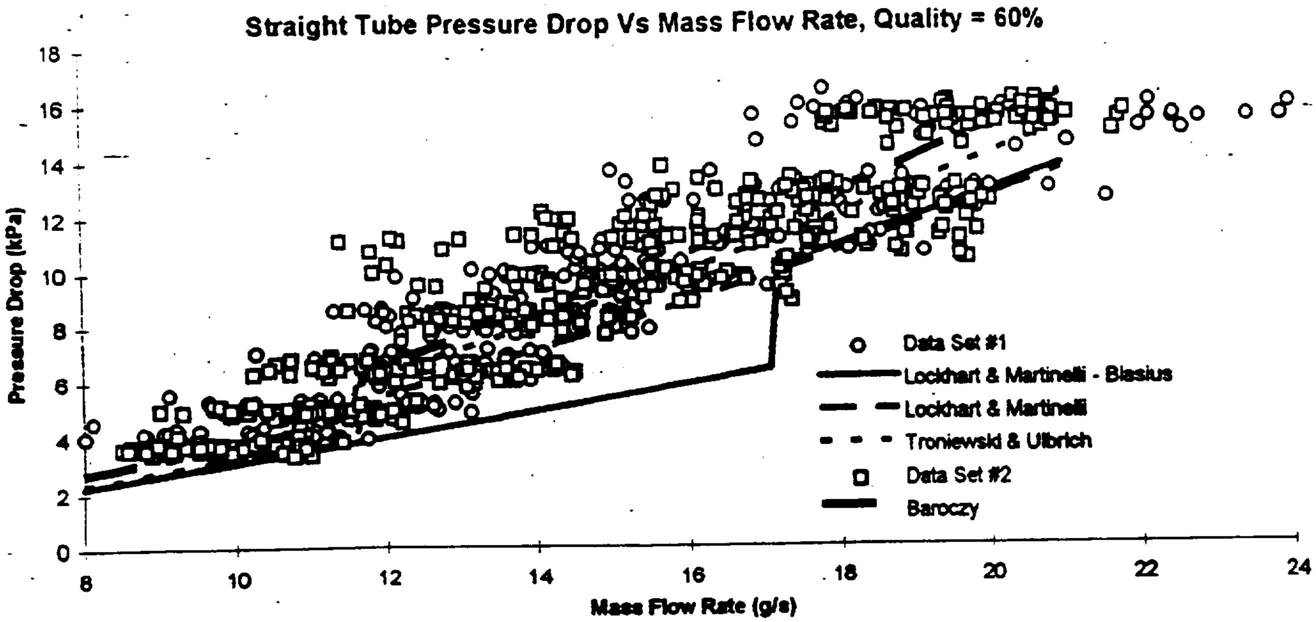

Fig. 7 Straight Tube Pressure Drop Vs. Mass Flow Rate, Quality = 60%

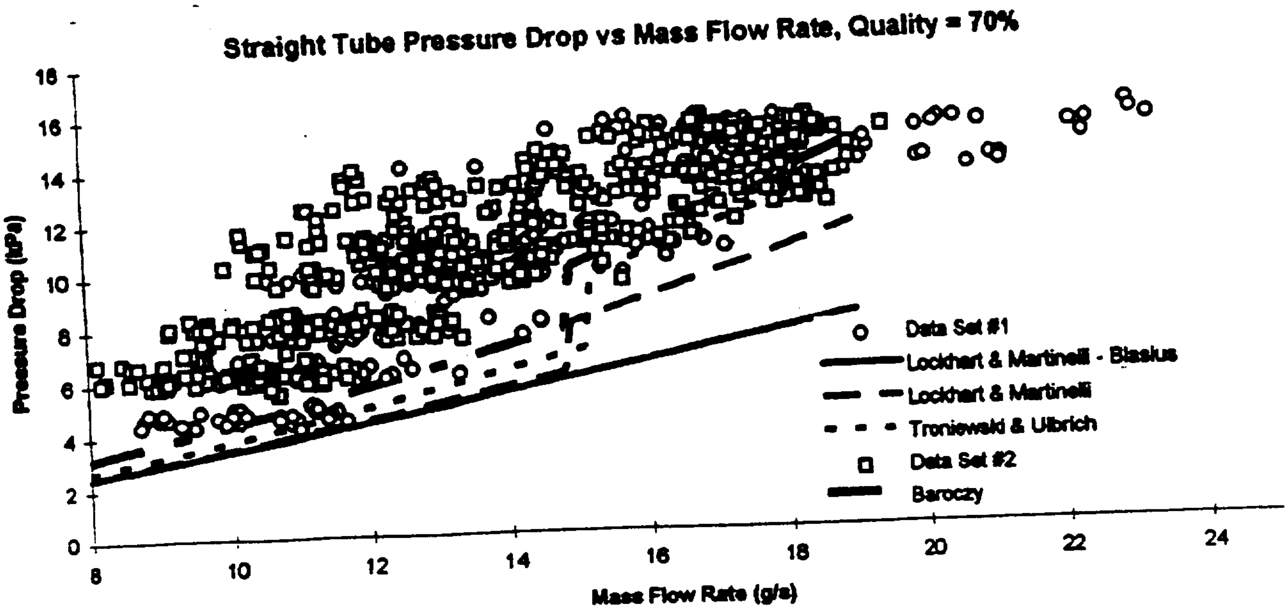

Fig. 8 Straight Tube Pressure Drop Vs. Mass Flow Rate, Quality = 70%

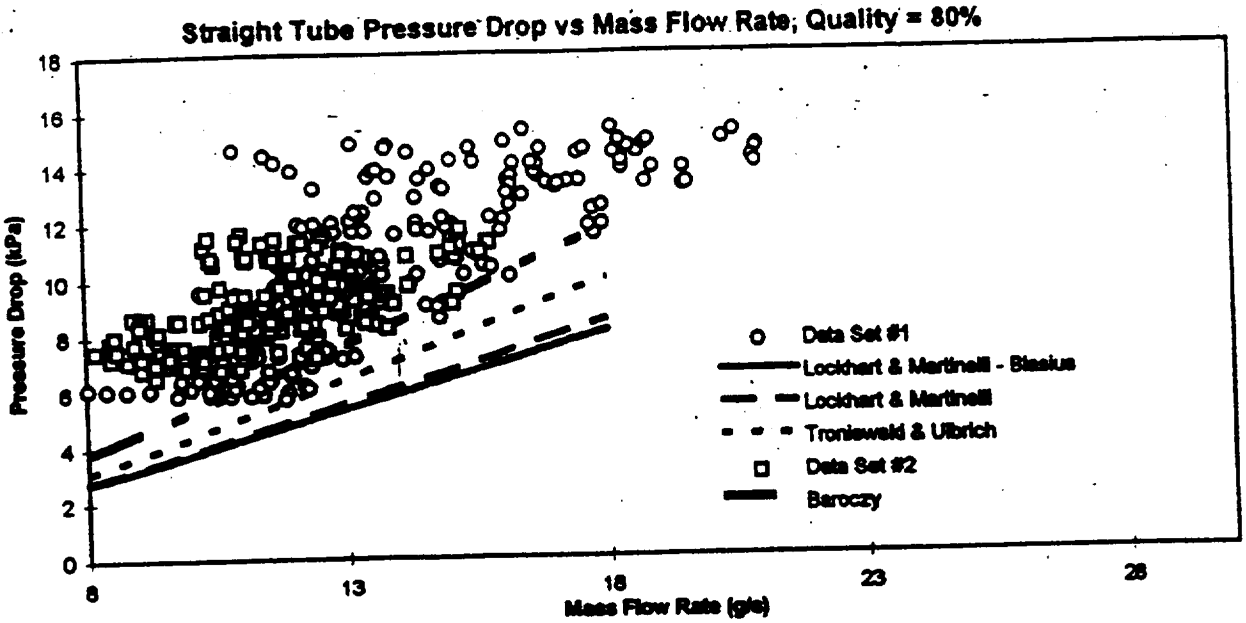

Fig. 9 Straight Tube Pressure Drop Vs. Mass Flow Rate, Quality = 80%

Investigation of Two-Phase Flow Through Piping Bends

The test facility was modified in an attempt to obtain pressure drop information for flow through 180° bends, as illustrated in Fig. 10. Unfortunately, this attempt was not successful. The lack of success is primarily due to two different system design characteristics. First, it was concluded that fluctuations mass flow (and therefore quality) due to percolation in the evaporator section produced random changes in system pressure which were greater in magnitude than those measured across the tubing bend. Second, the configuration of pressure transducers prescribed for the system did not allow for accurately and repeatably obtaining pressure drop data across the tubing bend.

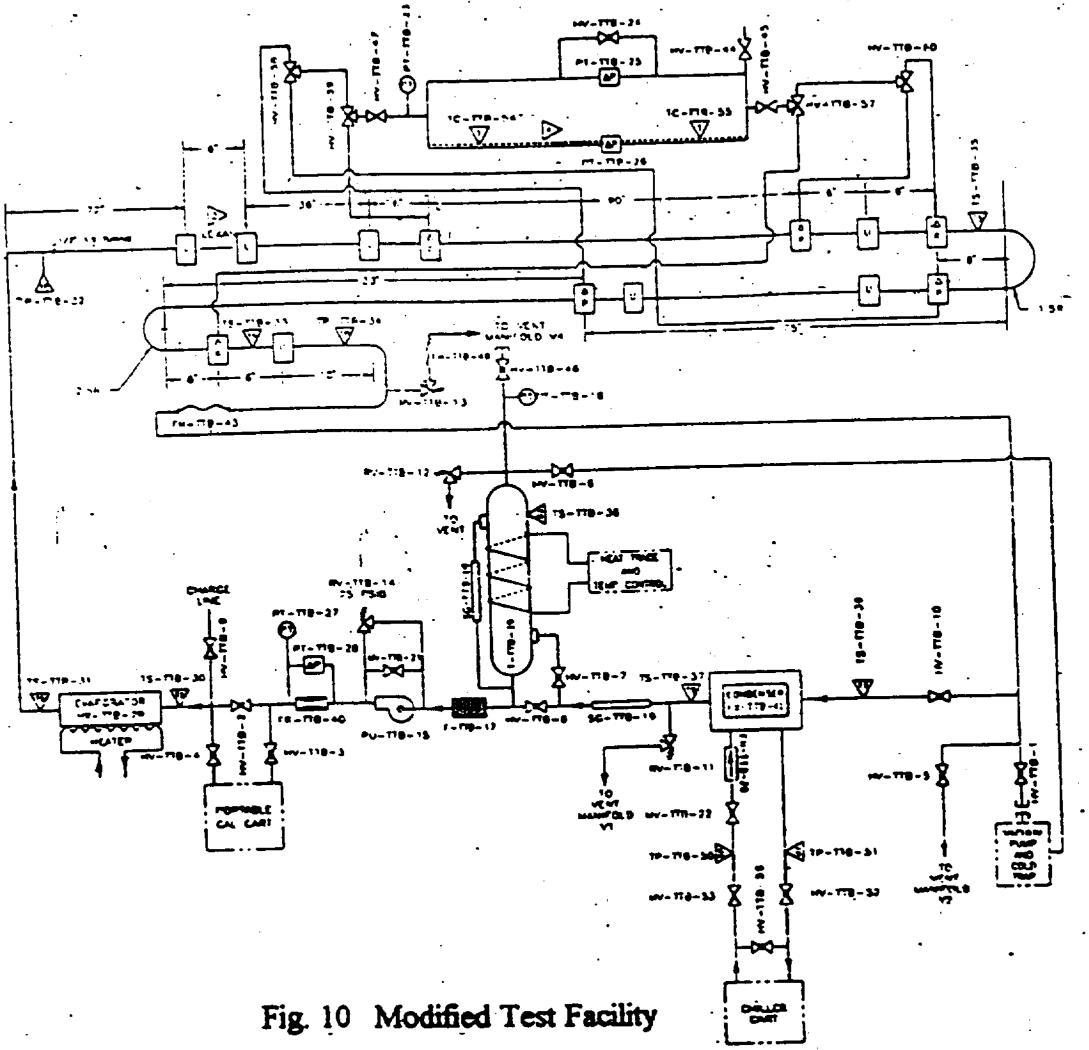

Fig. 10 Modified Test Facility

Conclusions and Recommendations for Future Research Efforts

Data has been obtained for two-phase flow of R-113 through $\frac{1}{2}$" diameter straight tubing and tubing bends. The pressure drop data obtained for flow through straight tubing sections demonstrated trends which agreed with those of the predictive models. Each of the three models utilized demonstrated reasonable agreement with the data within a limited range of quality, though none of the three models agreed with the data throughout the entire range of qualities observed (0% - 80%).

The measurements of pressure drop through the tubing bends illustrated unacceptable levels of uncertainty. This was due to uncertain random fluctuations occurring in the mass flow rate in the test facility. Based on the observation of high speed video films of the flow, this fluctuation in the mass flow rate was due to a percolating pressure gradient which was produced in the vertical evaporator section. This fluctuation adversely affected the measurement of pressure drop in the tubing bend due to the fact that the magnitude of the pressure drop through the bend was less than the magnitude of the random pressure fluctuation induced by the percolation.

Future efforts should initially be directed at eliminating the fluctuation in the mass flow rate associated with the two-phase test facility. Replacing the vertical evaporator section with a horizontal section having significantly greater effective tubing length and lower heat flux values should eliminate the occurrence of percolation. Additionally, replacing the current flat plate orifice flow meter with a rotor-type flow meter may reduce the noise level associated with the signal delivered to the data acquisition system.

Beyond reconfiguration efforts for the two-phase test facility, several investigations should be undertaken. Certainly, the first of these should be to complete a comprehensive investigation of the pressure drop characteristics of two-phase flows through the 180° bends of the modified facility. Investigations utilizing various refrigerants, mass flux values, and tubing diameters should be undertaken. Additionally, investigations of the pressure drops measured through quick-disconnects and other fittings, as well as tubing expansions, contractions, and manifolds should follow. Each of this experimental investigations should be coupled with rigorous analysis of the observed phenomena.

References

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