CHAPTER II

LITERATURE REVIEW

Two-phase flow has been studied extensively over the past sixty years. The usual approach is an empirical one, since a theoretical analysis is extremely complex. Some theoretical studies have been made assuming a homogeneous fluid. The advent of the space age has focused attention on the problems of single component two-phase flow of cryogenic fluids. This has been particularly true in the transfer of large quantities of cryogenic propellant where the pressure drop has been observed to be much greater than that predicted by the normal single component incompressible fluid flow analysis.

Martinelli et al. (1944) followed by Lockhart and Martinelli (1949) developed correlations based on work done in a narrow range of temperature (70-85°F) and pressure (16-52 psia), with a limited number of liquid-vapor systems. Attempts to use these correlations for systems operating at pressure much greater than 52 psia can lead to serious errors.

Several methods have been presented in the literature to calculate the pressure drop under flow boiling conditions. The Martinelli-Nelson method (1948) is based on a slip-flow, which was originally developed for the annular flow regime. The method proposed by Levy (1960) is based on a momentum-exchange model between liquid and vapor. The homogeneous model is based on the assumption that vapor and liquid flow at the same velocity so that the two-phases may be treated as a single fluid with mixture properties. The two-phase pressure drop relations based on these models involve differential expressions that were integrated to exit conditions. One important result of the large number of data required in developing empirical or semi-empirical correlations is that it was necessary in developing what is regarded as one of the best correlations of two-phase flow that of Baroczy (1966) to use data for both horizontal and vertical flow without account of their different attitudes in the final correlation.

The best agreement of A. de La Harpe, S. Lehongre, J. Mollard and C. Johannès (1969) is obtained with the homogeneous model, although the pressure drop values predicted are consistently on the low side. The momentum-exchange model of Levy agrees equally well with the data up to vapor qualities of 70%, but the predicted values are consistently on the high side.

R. P. Sugden, K. D. Timmerhaus, and D. K. Edmonds (1969) suggested the possibility of correlating the vapor quality of a homogeneous vapor-liquid mixture with a modified friction factor as a function of the Reynolds number based on the average properties of the fluid. Such a proposed correlation would help to simplify the pressure drop calculation for a two-phase flow transfer system if the average vapor quality of the fluid being transferred were known or could reasonably be estimated. It may be quite difficult to obtain. However, careful heat balances should be able to provide workable estimates.

Michael A. Grolmes and Hans K. Fauske (1971) suggested that a choice of the likely two-phase flow pattern in a given situation should be made in order to select an appropriate two-phase pressure drop model. The helium data of A. de La Harpe et al. would likely be characterized by a homogeneous flow pattern because of the relative good agreement with the homogeneous pressure drop relation. This is all that can be said for lack of knowledge of other experimental conditions that would permit an independent assessment of the flow regime. The original pressure drop correlation of Martinelli and Lockhart has recently been shown to be in agreement with theoretical considerations of pressure drop for annular flow by G. B. Wallis (1969). However, designers have often used the Martinelli correlation as modified by Martinelli and Nelson for pressures higher than one atmosphere without consideration of flow pattern. The nature of the Martinelli-Nelson pressure drop correlation is such that as the critical pressure is approached, the correlation effectively becomes a homogeneous model.

Flow pattern regions in two-phase flow are defined by O. Baker (1958) in terms of mass velocity of gas phase and ratio of liquid and mass velocities. The boundaries of the various regions are based on work done by several investigators with the air-water system at atmospheric pressure.

Data of flow patterns are often represented in terms of flow pattern maps in which the region of operation of each of flow patterns is indicated. Taitel and Dukler (1976) have made significant progress in developing theoretical procedures for predicting the flow pattern in horizontal flow. They identify three basic patterns from the fingerprint of the power spectral densities of wall pressure fluctuations. For vertical upflow according to Govier and Aziz (1972) and vertical downflow based on the work of Golan and Stenning (1969), the flow patterns and maps are developed.

Information on inclined tube flow patterns is reviewed by Hewitt (1982). The transition that is most sensitive to tube inclination is that between stratified and intermittent flows. Work by Barnea et al. (1980) shows that even small tube inclinations can dramatically affect this transition. For this particular transition, the effects of tube inclination are reasonably well predicted by the Taitel and Dukler analysis, but this analysis does not predict the relative insensitivity to tube inclination of some of the other transitions. A generalized flow pattern map for tubes of any inclination is discussed by Barnea (1987).

The basic programme PDROP has been developed by P. Sjoberg of CIG Process R & D Group in 1986 to calculate pressure drop in horizontal piping systems on DOS. It handles both single phase and single component two-phase flow situations. The two-phase calculation is based on a modified Lockhart-Martinelli method. The Fanning friction factor is calculated with the explicit Chen equation. The pipe calculations can be segmented to enhance accuracy. PDROP also gives the possibility to calculate pipe diameter or pipe length if the pressure drop is given.

Cryodata Inc.'s GASPAK programme was available in either a DOS or a windows version. The first GASPAK application provided properties for 12 gases, this number has grown steadily for the past few years until today the most recent version of GASPAK 3.2 provides properties for 32 gases. All of the properties of fluids obtained from GASPAK are calculated using a mathematical model of the equation of state of the fluid in question. All of the models used have been carefully chosen to provide the best properties for that fluid. In some cases more than one choice is given for a particular fluid, this is because a newer and probably a slightly more accurate equation of state has recently become available for a fluid where an older equation of state has been widely used for several years. Providing both surfaces offers the user a choice and a means of comparing properties from the newer equation with properties that may have used in the past from the older equation. Some of the fluids include transport properties. GASPAK are constantly being modified by adding new properties and new fluids, as they become available.

GTC Data of British Oxygen Company Process Plants (BOCPP) is available as version 6.0 and may be run on either VAX main frame or PC and it has been linked with Lotus 123. This Fortran programme provides the following calculation options such as dew point temperature and pressure, bubble point temperature and pressure, temperature from enthalpy, temperature from entropy, etc. that are based on rigorous equations of state. GTC Data is still being developed to include additional calculations and estimations of transport properties. The limitation of this software is that it is only suitable for use with three fluids, oxygen, nitrogen and argon.