A NUCLEATE POOL BOILING STUDY OF REFRIGERANT 22-DIMETHYL FORMAMIDE MIXTURES

by

S. DORAIRAJ

A thesis submitted to the
Indian Institute of Technology, Delhi
for the award of the degree of

DOCTOR OF PHILOSOPHY

Department of Mechanical Engineering

INDIAN INSTITUTE OF TECHNOLOGY, DELHI

INDIA

October 1986

CERTIFICATE

This is to certify that the thesis entitled,"A NUCLEATE POOL BOILING STUDY OF REFRIGERANT-22 AND DIMETHYL FORMAMIDE MIXTURES" being submitted by Mr. S. Dorairaj to the Indian Institute of Technology, Delhi, for the award of Degree of 'Doctor of Philosophy' in the Mechanical Engineering, is a record of the candidate's own bonafide research work.

Mr. S. Dorairaj has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to our knowledge, has reached the requisite standard.

The results contained in this work have not been submitted in part or in full, to any other University or Institute for the award of any degree.

SKGupta

(Dr. S.K. Gupta)

Assistant Professor,

RSAgarwal

(Dr. R.S. Agarwal)

Professor,

Mechanical Engineering Department,

Indian Institute of Technology, Delhi

Hauz Khas, New Delhi-110016.

ACKNOWLEDGEMENTS

It is with great pleasure that the author wishes to express his profound gratitude and sincere regards to Professor R.S. Agarwal and Dr. S.K. Gupta for their fraternal guidance in steering this work to its completion.

The author feels highly indebted to Prof. R.S. Agarwal for his day-to-day discussions and help, which have been very stimulating and educational.

The author is extremely grateful to Professor J.W. Westwater, Department of Chemical Engineering, University of Illinois at Urbana-Champaign, Illinois, U.S.A., for his encouragement and help during the initial stage of the work.

Thanks are due to Messrs D.S. Saini, Mahimanand, and K.D. Khurana of the Refrigeration Laboratory and other technical staff of departmental Workshop who helped in fabrication and experimentation required in this work. The cooperation of the Computer Centre staff is also appreciated.

The author expresses his special thanks to Mr. S.M. Bin Gadhi, South Yemen, a friend and colleague for his assistance in experimentation.

Although the inspiration received from the friends will be remembered for the times to come, to name a few, the author is thankful to Messrs. S. Mohan, P. Sundaram, R. Ashokan, K. Karuppuswamy and R.P. Kapoor.

Thanks are also due to Mr. V.P. Gulati for typing of the manuscript and Mr. N.K. Choudhary for preparing the tracings.

The author owes a sense of apology to his parents, brothers, sister and sister-in-law, who patiently bore his neglect during this period.

October, 1986 S. DORAIRAJ

ABSTRACT

With growing emphasis on the use of low grade energy such as the solar, geothermal, waste process heat etc., the interest in vapour-absorption refrigeration systems has rejuvenated. This has also engendered the need to evolve better refrigerant-absorbent combinations. The replacement of conventional systems such as ammonia-water, water-lithium bromide, etc., by new combination especially with fluro-chloro-alkanes as refrigerant has been shown to be advantageous by a number of researchers. However, this suggestion has not yet been practically implemented by industry, mainly because of lack of reliable information on heat transfer performance of these mixtures during boiling in the generator. In the present work, an attempt has been made on one such combination, viz., monochloro difluromethane (R22)-dimethyl formamide (DMF) system, to provide reliable experimental data and to develop a correlation for prediction of heat transfer coefficient under nucleate pool boiling conditions.

An experimental set-up has been designed and fabricated to carryout heat transfer studies in nucleate pool boiling of R22, DMF and their mixtures. Thermophysical properties of these mixtures have been estimated by applying standard predictive methods for a wide range of pressure, temperature and concentration. The existing correlations have been analysed and suitable empirical correlations for predicting the heat transfer coefficient in nucleate pool boiling of the R22-DMF mixtures have been suggested.

An experimental rig consisting of a boiler, a condenser and a chilling unit was carefully designed and fabricated to obtain nucleate pool boiling data of R22, DMF and their mixtures. A cylindrical boiler of size 150 mm outer diameter and 300 mm long, housed the heating surface. The heating surface was a horizontally oriented copper tube of 31.65 mm outside diameter and 200 mm long with an effective surface area of 0.0199 sq.m. The surface roughness of this heating surface was of the order of 0.3 μm (centre line average). This test section was internally heated by an electric heater.

The vapour formed due to heating in the boiler was condensed in the water cooled condenser and the condensate was returned back to the boiler. A chilling unit, with high precision temperature controller, controlled the inflow water temperature of the condenser and thus enabledin maintaining the system at various desired pressures.

The calibrated Fe-K thermocouples were used to measure the temperature of the heating surface, vapour and liquid return lines. The temperatures of water at inlet and outlet of the condenser were also measured. A special platinum-resistance thermometer probe was used to measure the bulk liquid temperature. The calibrated pressure gauge was used to measure the pressure of the boiling liquid. A provision was made in the experimental set-up to draw the liquid sample for measuring its concentration. The concentration of the boiling binary liquid mixtures was determined by drawing the liquid sample and measuring its vapour pressure and comparing it with the existing data [Bapat, 1981]. The liquid concentration was checked at several intervals of time during a given test run for a mixture of specified composition.

Extensive experiments were carried out to study the nucleate pool boiling of R22, DMF and their mixtures. The concentrations studied were 10.39%, 20.30%, 30.26%, 40.79%, 50.49% and 70.43% by weight of R22 in DMF. The heat flux ranged from 9,500 W/m^2 to 19,300 W/m^2 and the system pressure was varied from 0.8 MPa to 1.6 MPa at an interval of 0.1 MPa. In all the series of test runs, the desired system pressure was approached progressively, starting from a lower value at a constant heat flux.

The heat transfer coefficients obtained vary with heat flux, pressure and concentration of the R22 in the pool of mixture. In all the experiments conducted with pure components and their binary mixtures, the heating surface showed a distribution of temperature around its circumference. It was least at the top and maximum at the bottom.

An analysis of the experimental data of mixtures demonstrated rather significant compositional effect which amounted to the existence of a maximum superheat (ΔT), when the equilibrium composition difference between the vapour and liquid was maximum. This behaviour was seen at all the boiling pressures.

The experimental data obtained have been analysed and the results have been presented in suitable tabular and graphical forms. The empirical correlations have been developed for heat transfer coefficient as a function of pressure and heat flux for every composition as well as for whole range of concentration with the additional exponential function of concentration term.

In the second phase of the present work, various thermophysical properties, viz., thermal conductivity, viscosity surface tension, thermal diffusivity, specific heat, liquid density, vapour density and latent heat of vaporization of the mixtures have been estimated, using suitably selected estimation methods for the entire range of pressures, temperatures and concentrations expected to be encountered in a vapour absorption refrigeration system. Suitable empirical correlations have been developed to express each of the property as a function of composition and temperature. The results have also been presented in the suitable graphical form.

In the final phase of the present work, to augment the utility of the experimental data, the quantitative analysis has been carried out and suitable correlations have been proposed. The correlations proposed by Kruzhilin [1948], McNelly [1953], Kutateladze [1963] and Borishanskiy-Minchenko [1969] for predicting the heat transfer coefficients in nucleate pool boiling of pure fluids have been examined. Suitable dimensionless correlations for mixtures have been obtained by including the dimensionless concentration parameter of Tolubinskiy and Ostrovskiy [1969] as a multiplier in each of the above pure fluid correlations. These modified equations predict the nucleate pool boiling heat transfer coefficient for the R22-DMF mixtures quite reasonably. The deviations between the predicted and experimentally measured heat transfer cofficients are found to be less than the estimated experimental errors. Of the above modified correlations developed, that of Kutateladze [1963] appears to be the best.

CONTENTS

Page

Page