THERMAL-HYDRAULIC STUDIES OF THERMOSYPHON EVAPORATORS

A thesis submitted
in fulfilment of the requirements
for the degree of
DOCTOR OF PHILOSOPHY

BY

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April, 1989.

CERTIFICATE

This is to certify that the thesis entitled, "Thermal-Hydraulic Studies of Thermosyphon Evaporators" being submitted by Mr. D.P. Pande 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. D.P.Pande 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.

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ACKNOWLEDGEMENTS

It is with the sense of deep gratitude that the author wishes to thank Prof. R.S.Agarwal and Prof. P.L.Dhar for their fraternal guidance, keen interest and educational discussions.

The author also sincerely thanks Shri R.V.Amalraj, Head, Centralised Waste Management Facility, for the inspiration and guidance in steering this work to its completion. The author is grateful to Shri A.N.Prasad, Director, Reprocessing Group, for his keen interest and encouragement and to the BARC authorities for permitting registration for doctoral degree and providing opportunity to develop process engineering,instrumentation and other facilities for the research work at Centralised Waste Management Facility, Reprocessing Group, BARC, Kalpakkam.

It may not be possible to include the names of all the colleagues and friends who have been helpful in one way or the other. However special thanks are due to:

S/Shri J.Ahmed, K.B.Lal, P.K.Sinha, B.Paul, V.Dayalan and other friends for their goodwill and cooperation shown with regard to this work.

S/Shri S.Mathusoothanan, R.Muthiah, S.Palanilingam, A. Chokkalingam and other colleagues for the assistance in experimentation and various stages of this work.

S/Shri N. Govindarajan and Sushil Kumar for preparing the drawings. Mrs.S.Komalavalli for typing a part of the manuscript and S/Shri A.Etti and E.Krishnan for making Xerox Copies.

Finally the author is thankful to his near and dear ones, especially his wife Manjula, for the encouragement and support which have sustained him during the difficult periods. To his children Preeti and Biswabandu the author owes an apology for not being able to pay full attention to them during the period of this work.

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ABSTRACT

With the development of nuclear industry throughout the world, and growing concern about as low as reasonably achievable discharge to the environment, the treatment of radioactive waste is becoming increasingly important. The volume reduction of medium and high level liquid waste before leak tight containment aims to ensure zero leakage to the environment, but this is inherently a costly process because of its operational heat requirements and high standards of plant fabrication required to ensure reliability, and minimize maintenance when substantial amounts of radioactivity are involved. It is important therefore, when an evaporation system is to be used that all the parameters are carefully assessed to ensure that most economic solution is applied to meet the specific requirements. A comparison of technical, economic and safety aspects of various types of evaporator systems available for volume reduction, revealed the superiority of natural thermosyphon type of evaporator for concentrating radioactive effluents. An evaluation of operating performance of such natural thermosyphon evaporators revealed wide variation due to process and design parameters. In this work experimental investigations were carried out to find the effect of process and design parameters on the thermal hydraulic behavior in a natural thermosyphon

evaporator during boiling of liquid solutions which are similar to radioactive effluents generated in various processes of nuclear fuel cycle.

In a natural thermosyphon evaporator system the circulation of solution from the flash chamber to reboiler is caused by the difference between the hydrostatic head of liquid, and the two phase vapor liquid mixture in the reboiler. Since the weight fraction of vapor generated and the amount of heat transferred by the reboiler are functions of this circulation rate, an analysis of reboiler operation must simultaneously consider the hydrodynamic and thermal characteristics of the system. During boiling of radioactive solutions the exit vapor fraction from the reboiler have to be kept quite small to prevent deposition of salt and radionuclides on the tube surface and to keep the rate of scaling of tubes within reasonable limits. The boiling at greater vapor fraction produces slug flow in the reboiler tubes and prevents steady operation. The pulsating flow and collapse of vapor and liquid slugs increase the entrainment of liquid droplets with the vapor and reduces the decontamination efficiency of a radioactive effluent evaporator. Consequently process conditions suitable to generate low exit vapor quality with high recirculation rate are desirable during concentration of aqueous radio-chemical solutions.

A well instrumented experimental test rig was designed and fabricated to carry out the experiments with six different designs of the reboiler test sections. Two reboiler test sections had 52.5mm and 26.6mm diameter single vertical tubes, and four tube bundle reboiler test sections had tubes of 26.6mm, 20.91mm, 15mm and 12.5mm diameter respectively, while retaining same tube height for all test sections. Experiments were also done on a pilot scale reboiler which had 14 numbers, 20.93mm I.D, 2m long reboiler tubes. The experiments revealed that design parameters, as well as operating process conditions influenced the thermal hydraulics and performance of a thermosyphon evaporator. The first phase of experiments were done to find the effect of process variables such as liquid submergence in the reboiler tubes, temperature differential on the heat flux, vapor produced, recirculation flow rates and resultant heat transfer coefficients. The second phase included evaluation of thermo physical properties of aqueous solutions (containing Sodium Sulphate, Sodium Nitrate and Sodium Chloride) which are normally present in the radioactive effluents. This was followed by experiments on boiling of such aqueous solutions in the experimental thermosyphon reboilers. In addition, influence of physical parameters, diameter and height of the reboiler tubes on the system performance has also been investigated. The fouling resistance during boiling of these aqueous solutions was found to increase with time. The increase in tube diameter and velocity produced smaller vapor fraction during evaporation and rate of increase of fouling resistance was found smaller.

An analysis of the experimental results demonstrated that good recirculation flow and heat transfer is obtained when suitable hydrostatic level in flash chamber was maintained to produce 70 to 80 percent liquid submergence in the reboiler tubes. When liquid submergence in reboiler was smaller than 70 percent of the reboiler tube height, most of the solution vaporized by the time it reached the top of the tubes. This resulted in large exit vapor fraction and excessive scaling of the reboiler tubes. The recirculation flow was low with smaller diameter tubes. The vapor produced per unit area reduced for the reboilers of greater tube diameter. The recirculation flow also reduces when more than 90 percent liquid submergence is used.

The experimental data obtained from all the thermosyphon reboiler systems were analyzed and the results have been presented in graphical forms. A correlation have been developed for fouling resistance during boiling of such aqueous solutions as a function of recirculation flow rate and tube diameter. The measurements of liquid phase recirculation flow in the experiments have enabled accurate estimation of the actual vapor quality at the exit of the reboiler.

Based on the experimental results of the thermosyphon systems in the present work, a realistic design procedure has been evolved. Using the existing correlations available in literature for pressure drop, hold up and heat transfer, the operating performance has been theoretically predicted and compared with experimental data. The new design method and calculation procedure provides the basis for equipment design and predicting optimum operating conditions for any prescribed duty.

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