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Project Summary

Heat Transfer Evaluation of HFC-236ea with High Performance Enhanced Tubes in Condensation and Evaporation

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This research evaluated the heat transfer performance of pure hydrofluorocarbon (HFC)-236ea for high performance enhanced tubes which had not been previously used in Navy shipboard chillers. Shell-side heat transfer coefficient data are presented for condensation on a Turbo-CII tube, pool boiling on Turbo-B and -BII tubes, and spray evaporation on Turbo-B and -CII tubes and a 1575-fpm (1575-fins-per-meter) tube. These tubes have nominal outside diameters of 19.1 mm (3/4-in.), and they were evaluated at a saturation temperature of 2%C (35.6%F) in evaporation and 40%C (104%F) in condensation.

The condensation and pool boiling results for the high performance enhanced tubes in this study were compared with the results for a plain tube and two integral finned tubes (1024- and 1575-fpm tubes), which were evaluated in an earlier study. The comparison shows that the high performance enhanced tubes are able to promote heat transfer processes better than the plain tube, and especially better than the integral finned tubes that are currently being used with chlorofluorocarbon (CFC)-114 in Navy shipboard chillers. It was found that the Turbo-CII, -BII, and -B tubes performed best in condensation, pool boiling, and spray evaporation, respectively. The condensation heat transfer coefficients for the Turbo-CII tube were approximately 2 times those for the two integral finned tubes and 5 to 10 times those for the plain tube. During pool boiling, the Turbo-BII tube provided 1.2 to 1.7 times the heat transfer coefficients of the Turbo-B tube, 1.7 times the values of the 1024-fpm tube, 1.9 to 2.4 times the values of the 1575-fpm tube, and 3 times the values of the plain tube. During spray evaporation, the Turbo-B tube provided 1.2 times and 1.7 times the heat transfer coefficients of the Turbo-CII and the 1575-fpm tubes, respectively.

The comparative heat transfer performance of spray evaporation with pool boiling was made by using Turbo-B and 1575-fpm tubes. For the range of liquid refrigerant feed rates evaluated, the superiority of spray evaporation over pool boiling was found to exist only at low heat loads.

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This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This research evaluated the heat transfer performance of pure HFC-236ea during condensation, pool boiling, and spray evaporation on the outside of high performance enhanced tubes that had not previously been installed in Navy shipboard heat exchangers. Specifically, shell-and-tube heat exchangers in Navy shipboard chillers currently use integral finned tubes (1024- and 1575-fpm tubes) and CFC-114 as the working refrigerant.

Since HFC-236ea is free of stratospheric ozone depleting substances and considered as a prospective substitute for replacing CFC-114 that is harmful to the ozone layer, an investigation was initiated to determine the heat transfer performance of HFC-236ea. In a previous study, Phase I, the comparative heat transfer performance of CFC-114 and HFC-236ea was determined for a plain tube and two types of conventional finned (1024- and 1575-fpm) tubes.

The high performance enhanced tubes evaluated in this research included Turbo-CII, -B, and -BII tubes. The Turbo-CII tube is commercially designed to enhance shell-side condensation, while the Turbo-B and -BII tubes are commercially suggested for use in nucleate boiling. None of these tubes had been previously installed in shipboard heat exchangers. The heat transfer coefficients of HFC-236ea were measured for condensation, pool boiling, and spray evaporation occurring on the outside of a single horizontal tube with a nominal outside diameter of 19.1 mm.

Objectives and Scope

The objective of this study was to determine the optimum tube types for shell-side heat transfer of HFC-236ea during condensation, pool boiling, and spray evaporation. An additional objective was to compare the heat transfer performance for evaporation of HFC-236ea during pool boiling and spray evaporation.

Three types of high performance enhanced tubes that had not been previously installed in shipboard chillers were investigated: (1) a Turbo-CII tube in condensation testing as well as in spray evaporation testing, (2) a Turbo-BII tube in pool boiling tests, and (3) a Turbo-B tube tested for both pool boiling and spray evaporation. In addition to these high performance enhanced tubes, a 1575-fpm tube was also tested for spray evaporation.

The results for the high performance enhanced tubes in the study reported here (Phase II) were compared with those for the conventional finned tubes tested earlier (Phase I). The comparative heat transfer performance of HFC-236ea for spray evaporation with pool boiling was also made by using Turbo-B and 1575-fpm tubes.

Measurements were conducted on a single-tube setup at a refrigerant saturation temperature of 2%C for both pool boiling and spray evaporation and at 40%C for condensation. The tested range of heat fluxes was from 15 to 40 kW/m^2 for condensation and pool boiling, and 10 to 30 kW/m^2 for spray evaporation.

Experimental Apparatus

The experimental arrangements required for testing condensation, pool boiling, and spray evaporation are illustrated in Figures 1 through 3, respectively. The main components of the test facility include the test section, tubes under test, closed water loop, closed refrigerant loop, glycol/water chiller, and data acquisition system.

The heat transfer experiments were performed in a cylindrical, stainless steel chamber. On the top of the test section, there are two ports which are passageways for vapor and five threaded ports where spray nozzles could be installed with compression fittings for testing spray evaporation. The test section also has the two other ports which serve as liquid paths on the bottom.

The closed water loop consists mainly of a storage tank, two triplex diaphragm

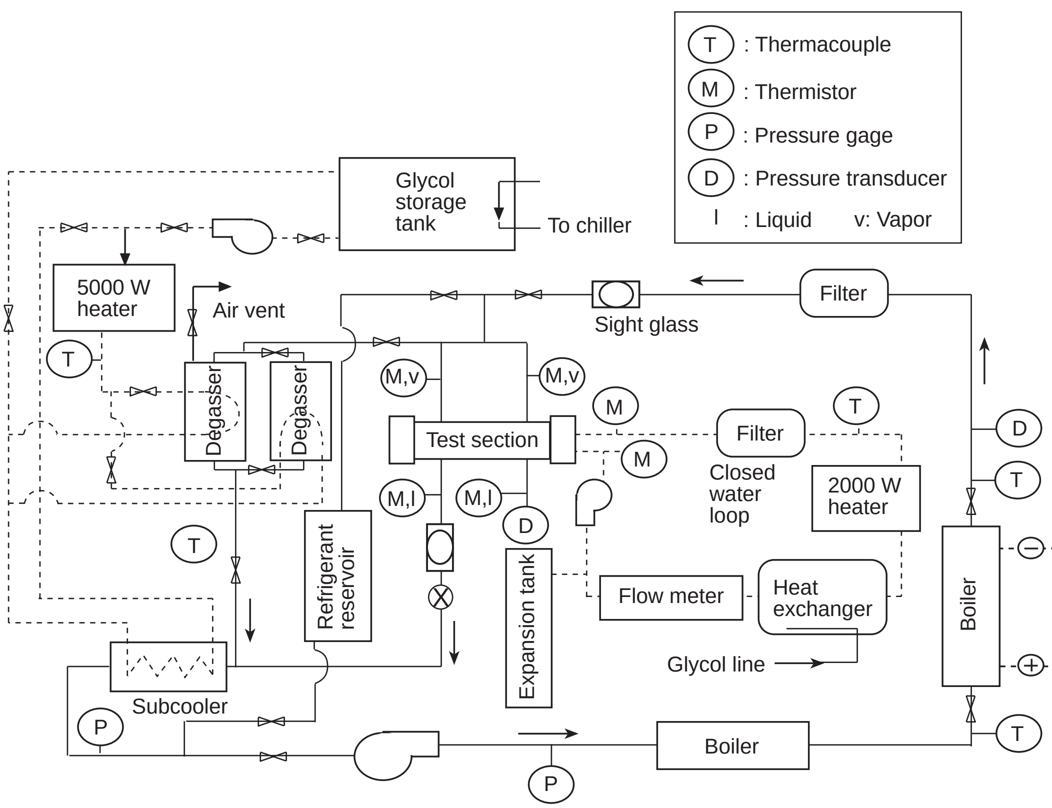

Figure 1. Schematic of test facility for condensation tests.

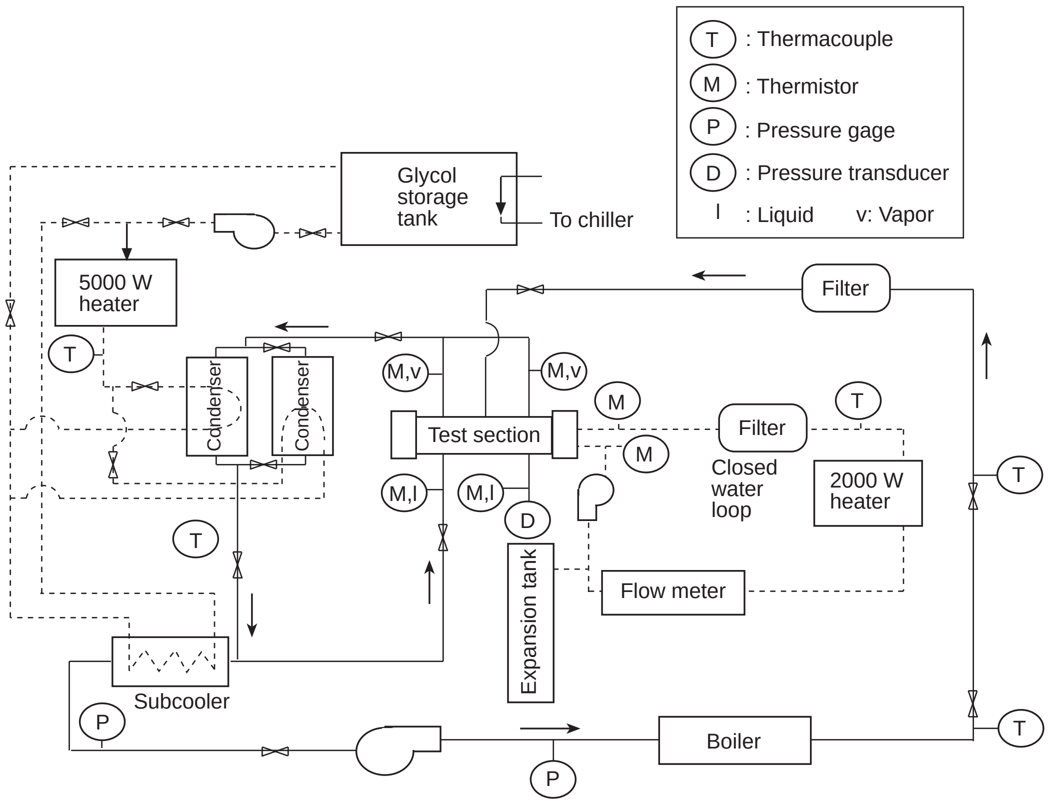

Figure 2. Schematic of test facility for pool boiling tests.

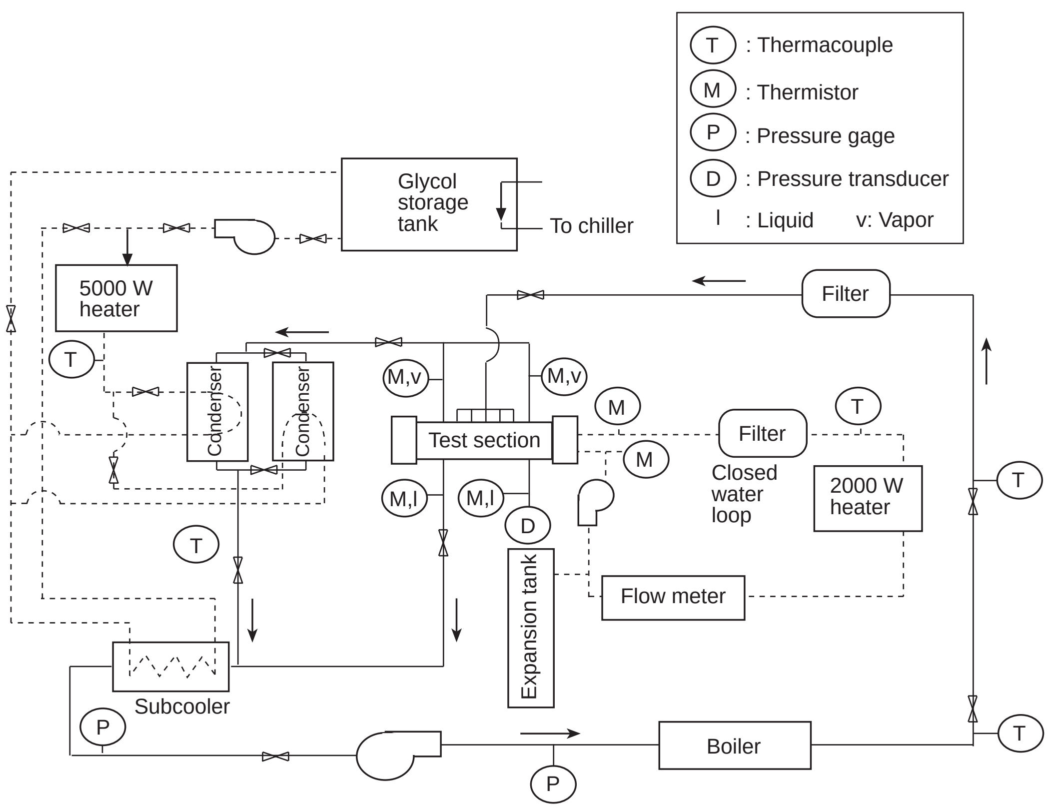

Figure 3. Schematic of test facility for spray evaporation tests.

pumps, a flow meter, an immersion heater, and a dual-tube heat exchanger. The heater and heat exchanger were used to control the water temperature.

The glycol/water mixture was pumped through a chiller with a 105-kW (30-ton) cooling capacity, and then supplied through manifolds to the dual-tube heat exchanger, two condensers, and a subcooler.

During condensation tests, a stainless steel boiler was used to vaporize refrigerant before it reached the test section. For evaporation tests, a subcooler and two condensers were utilized to condense refrigerant after it was boiled in the test section.

Results

The heat transfer performance of HFC-236ea for high performance enhanced tubes during condensation, pool boiling, and spray evaporation was evaluated and documented. Since these tube types have not been employed in the Navy shipboard chillers, the results obtained in this study can be applied to the design of new chillers. Using the results for integral finned tubes reported previously (Phase I), the heat transfer performance of high performance tubes was also compared with that of integral finned tubes.

For condensation of HFC-236ea at 40%C, the high performance tube, Turbo-CII, performed better than the plain tube and the integral finned tubes which were tested earlier (Phase I). The heat transfer coefficients for the Turbo-CII tube were approximately 2 times those for the integral finned tubes and 5 to 10 times those for the plain tube.

For pool boiling of HFC-236ea at 2%C, the pair of high performance tubes, the Turbo-BII and -B tubes, provided higher heat transfer performance than the plain tube and integral finned tubes, which were tested earlier (Phase I). The Turbo-BII tube outperformed the other tube types tested and provided 1.2 to 1.7 times the heat transfer coefficients of the Turbo-B tube. In turn, the Turbo-B tube yielded 1.1 to 1.3 times the heat transfer coefficients than the 1024-fpm tube, 1.4 to 1.5 times the values of the 1575-fpm tube, and 1.8 to 2.2 times the values of the plain tube.

For spray evaporation of HFC-236ea at 2%C, the Turbo-B tube performed better than the 1575-fpm and Turbo-CII tubes. The Turbo-B tube provided heat transfer coefficients 1.1 to 1.2 times those of the Turbo-CII tube, and 1.6 to 1.8 times the values of the 1575-fpm tube. With increasing heat flux, the heat transfer coefficient in spray evaporation increased until the heat flux reached around 15 kW/m^2 and then decreased with increasing heat flux to 30 kW/m^2.

Pool boiling and spray evaporation of HFC-236ea were compared for 1575- fpm and Turbo-B tubes. Generally, spray evaporation provided higher heat transfer below the heat flux of 30 kW/m^2 compared with pool boiling. At a heat flux of 15 kW/m^2, the heat transfer coefficients provided by the Turbo-B and 1575-fpm tubes in spray evaporation were 2.3 times and 1.2 times, respectively, the values in pool boiling. At a heat flux of 30 kW/m^2, both of these tube types provided similar heat transfer performance in these two different heat transfer forms.

Summary

The results of the comparisons reported here demonstrate that substantial increases in heat transfer can be obtained with the use of the high performance enhanced tubes compared to the plain tube and conventional finned tubes (1024- and 1575-fpm tubes) that are presently used with CFC-114 in Navy shipboard chillers.

The high performance Turbo-CII tube outperformed the two integral finned tubes during condensation testing; the heat transfer coefficients for the Turbo-CII tube were around twice those for the two integral finned tubes.

The high performance Turbo-BII and -B tubes outperformed the two integral finned tubes during pool boiling. In particular, the Turbo-BII tube outperformed the other tubes tested and provided heat transfer coefficients 1.2 to 1.7 times those of the Turbo-B tube. In turn, the Turbo-B tube yielded 1.1 to 1.3 times the heat transfer coefficients of the 1024-fpm tube and 1.4 to 1.5 times the values of the 1575-fpm tube.

During spray evaporation testing, the Turbo-B tube provided higher heat transfer coefficients than both the 1575-fpm and Turbo-CII tubes. Specifically, the Turbo-B tube gave 1.1 to 1.2 times the heat transfer coefficients of the Turbo-CII tube and 1.6 to 1.8 times the values of the 1575-fpm tube.

The comparative heat transfer performance of spray evaporation with pool boiling shows that the heat transfer superiority of HFC-236ea for spray evaporation over pool boiling exists only at heat fluxes below about 30 kW/m^2.

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***Theodore G. Brna** is the EPA Project Officer (see below).*
The complete report, entitled "Heat Transfer Evaluation of HFC-236ea with High Performance Enhanced Tubes in Condensation and Evaporation," (Order No. PB98-137177; Cost: $29.50, subject to change) will be available only from:
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