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EPA **Project Summary**

Heat Transfer Evaluation of HFC-236fa In Condensation and Evaporation

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The shell-side heat transfer performance of hydrofluorocarbon (HFC)-236fa, which is considered to be a potential substitute for chlorofluorocarbon (CFC)-114 in Navy shipboard chillers, was evaluated in this study for both conventional finned [1024- and 1575-fpm (fins-per-meter)] tubes and high performance enhanced (Turbo-CII, -B, and -BII) tubes.

Condensation of oil-free HFC-236fa was conducted on 1024- and 1575-fpm, and Turbo-CII tubes. Pool boiling on four tube types (1024- and 1575-fpm, and Turbo-B and -BII) was tested not only for pure HFC-236fa but also for HFC-236fa mixed with 1 and 3% lubricant by weight. The polyolester lubricant used has a viscosity 340 SSU at 37.8°C (100°F) and the trade name of Castrol Icematic SW-68. The above tubes, which have nominal outside diameters of 19.1 mm (3/4-in.), were evaluated at a saturation temperature of 40°C for condensation and 2°C for pool boiling over the heat flux range of 15 to 40 kW/m^2.

Heat transfer was improved for HFC-236fa by using the high performance enhanced tubes. Specifically, the Turbo-CII tube performed better than the two conventional finned tubes in condensation testing, while the performance of the Turbo-B and -BII tubes was superior to the two conventional finned tubes in pool boiling testing.

The maximum increase in heat transfer coefficient for the Turbo-CII tube was 80% relative to the 1024-fpm tube and 70% relative to the 1575-fpm tube, while for the Turbo-B tube, it was 0.7 and 1.2 times greater than for the 1024- and 1575-fpm tubes, respectively. In addition, the Turbo-BII tube gave boiling heat transfer coefficients up to 80% larger than those of the Turbo-B tube.

The heat transfer performance of HFC-236fa was compared with the CFC-114 and HFC-236ea data obtained in earlier studies using the same test facility. For all tube types tested, except the Turbo-CII tube, the heat transfer results showed that HFC-236fa performed better than CFC-114 and HFC-236ea during both shell-side condensation and pool boiling. The heat transfer coefficients for HFC-236fa during condensation were up to 40% larger than those for CFC-114 and up to 30% larger than those for HFC-236ea, while the pool boiling coefficients were up to 80% higher for HFC-236fa compared with CFC-114 and up to 70% higher compared with HFC-236ea. The condensation heat transfer coefficients for the Turbo-CII tube were similar for both HFC-236fa and -236ea; the deviation was within 10%. The effects of compressor oil on heat transfer performance during pool boiling were investigated. The presence of up to 3% oil (by weight) in HFC-236fa affected the boiling performance by less than a 10% deviation from the pure HFC-236fa results for all but one of the tubes tested. The Turbo-BII tube, the only exception, showed an increase in boiling coefficients of up to 30% over the pure-refrigerant values for the testing with 1% oil and up to 15% with 3% oil.

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Introduction

This research evaluated the heat transfer coefficients for HFC-236fa during condensation and pool boiling on the outside of a single horizontal tube with a nominal outside diameter of 19.1 mm (3/4-in.). Two types of integral finned (1024- and 1575-fpm) tubes and three types of high performance enhanced (Turbo-CII, -B, and -BII) tubes were tested for the heat transfer performance of HFC-236fa. Integral finned tubes tested are presently used in Navy shipboard heat exchangers to enhance heat transfer, while three high performance enhanced tubes, which were produced by advanced manufacturing techniques, were tested to evaluate their potential for improving the heat transfer performance of chillers but have not yet been used in shipboard chillers.

Saturated pool boiling was also investigated for HFC-236fa mixed with 1 and 3% oil by weight. A miscible polyolester oil with a viscosity of 340 SSU at 37.8°C was added to HFC-236fa, in order to assess the effects of the oil's presence on the boiling heat transfer performance.

In addition, the comparative heat transfer performance of HFC-236fa and -236ea, and CFC-114 was made in order to evaluate the possibility of replacing CFC-114 with HFC-236fa. The first two refrigerants are non-ozone depleting alternatives for CFC-114. Both CFC-114 and HFC-236ea were tested earlier in the current test facility.

Objectives and Scope

This study not only evaluated the shell-side heat transfer coefficients of an environmentally safe refrigerant, HFC-236fa, during condensation and pool boiling for two integral finned (1024- and 1575-fpm) tubes and three high performance enhanced (Turbo-CII, -B, and -BII) tubes but also compared the heat transfer performance of the tubes tested with HFC-236fa. In addition, the comparison of the heat transfer coefficients for HFC-236fa and -236ea and CFC-114 was also an important objective, where HFC-236fa and HFC-236ea are potential alternative refrigerants for CFC-114.

Using the same test facility which allows analysis of condensation and pool boiling, measurements were conducted on a single-tube configuration at a saturation temperature of 2°C for pool boiling and at 40°C for condensation over the heat flux range of 15 to 40 kW/m^2.

Two integral finned (1024- and 1575-fpm) tubes were tested for both shell-side condensation and pool boiling. In addition, the Turbo-CII tube, designed to enhance condensation, was tested during shell-side condensation while the enhanced boiling Turbo-B and -BII tubes were tested in pool boiling.

The comparative heat transfer performance of the high performance enhanced tubes with the conventional finned tubes was made for HFC-236fa in this study. Heat transfer results for CFC-114 and HFC-236ea and -236fa were also compared with each other. CFC-114 and HFC-236ea were tested previously in the same test facility. In addition, the effects of oil in the refrigerant on the heat transfer performance during pool boiling were assessed for HFC-236fa in this research.

The heat transfer coefficients for the integral finned tubes were used as a baseline for comparing the heat transfer performance of the high performance enhanced tubes. All the tubes compared had the same tube outside diameter of 19.1 mm (3/4-in.).

Experimental Apparatus

Even though the same test rig was used in all the experiments, different experimental arrangements were required for testing condensation and pool boiling. The main components of the test facility included 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 are two ports which are passageways for vapor. The test section also has two other ports on the bottom to serve as liquid paths.

The closed water loop consists mainly of a storage tank, two triplex diaphragm pumps, a flowmeter, 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 could be 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.

Condensation Results

Heat transfer coefficients were obtained for condensation of HFC-236fa on three tube types— 1024- and 1575-fpm, and Turbo-CII tubes. A comparison of results for these tubes with the previously obtained results of CFC-114 and HFC-236ea was made.

The best heat transfer performance with HFC-236fa was provided by the high performance Turbo-CII tube, indicating an increase in heat transfer coefficients of around 20 to 80% with respect to the 1024-fpm tube, and about 40 to 70% with respect to the 1575-fpm tube.

The HFC-236fa performed better than CFC-114 and HFC-236ea during condensation for all the tube types tested except the Turbo-CII tube. The HFC-236fa yielded a maximum increase of 40% compared with CFC-114 and 30% compared with HFC-236ea. The condensation heat transfer coefficients produced by the Turbo-CII tube were similar for both HFC-236fa and -236ea. Data were not taken on the Turbo-CII tube with CFC-114.

Pool Boiling Results

Heat transfer coefficients on four tube types (1024- and 1575-fpm, and Turbo-B and -BII) were determined for pool boiling of HFC-236fa as well as HFC-236fa/oil mixtures. The effects of oil and tube types on the boiling heat transfer performance of HFC-236fa were assessed. In addition, comparison was also made for these test tubes with the previous results of CFC-114 and HFC-236ea in order to evaluate the effects of refrigerant type on the boiling performance.

The best heat transfer performance with HFC-236fa was provided by the high performance Turbo-BII tube with heat transfer coefficients of around 2 to 2.9, 2.4 to 3.8, and 1.2 to 1.8 times the values for the 1024- and 1575-fpm, and Turbo-B tubes, respectively.

The HFC-236fa performed better than CFC-114 and HFC-236ea during pool boiling for all the tube types tested. The HFC-236fa provided a maximum heat transfer coefficient increase of 80% compared with CFC-114 and 70% compared with HFC-236ea.

The small amount of oil, up to 3% concentration, present during pool boiling was found to affect the heat transfer performance by less than 10% relative to the pure HFC-236fa results for all but one of the tubes tested. The exception was the Turbo-BII tube. As noted, the Turbo-BII tube showed the largest increase in performance with a 30% enhancement at 1% oil and a 15% enhancement at 3% oil over the pure refrigerant value.

Summary

The heat transfer coefficients of HFC-236fa, proposed as a CFC-114 substitute, were measured for 1024- and 1575-fpm conventional finned tubes and Turbo-Cll, -B, and -Bll high performance enhanced tubes during shell-side condensation and pool boiling on the outside of a single horizontal tube. The high performance enhanced tubes were found to effectively increase heat transfer and produced higher heat transfer coefficients than the conventional finned tubes.

The Turbo-CII tube produced noticeably higher heat transfer coefficients in condensation than the 1024- and 1575-fpm tubes, and yielded around 1.2 to 1.8 times the values of the 1024-fpm tube and 1.4 to 1.7 times those of the 1575-fpm tube.

The pool boiling results for both pure HFC-236fa and HFC-236fa with oil show that the tube performance in descending order was Turbo-BII and -B, and 1024- and 1575-fpm tubes. Heat transfer coefficients for pure HFC-236fa provided by the Turbo-B tube are 1.6 to 1.7 and 1.9 to 2.2 times those by the 1024- and 1575-fpm tubes, respectively. The Turbo-BII tube outperformed the other tubes tested and produced 1.2 to 1.8 times the heat transfer coefficients of the Turbo-B tube.

For the pool boiling testing, a miscible polyolester oil with a viscosity of 340 SSU at 37.8°C was added to HFC-236fa. The oil concentrations in the HFC-236fa were 1 and 3% by weight. The oil effects on HFC-236fa caused the boiling coefficients to deviate less than 10% from those for the pure HFC-236fa tested with all the tubes tested except the Turbo-BII tube.

Although the high performance Turbo-BII tube produced the highest heat transfer coefficients of all the tubes tested, it showed larger changes in pool boiling performance with the addition of oil. Specifically, the Turbo-BII tube had a 10 to 30% increase at the 1% oil concentration over the results for pure HFC-236fa and a 10% decrease to 15% increase at the 3% oil concentration.

A comparison of shell-side heat transfer coefficients was made for CFC-114 and its two proposed alternative refrigerants; i.e., HFC-236fa and -236ea. In general, HFC-236fa was found to have better heat transfer performance than CFC-114 and HFC-236ea during both shell-side condensation and pool boiling. For condensation, HFC-236fa yielded a maximum increase of 40% compared with CFC-114 and 30% compared with HFC-236ea. For pool boiling, HFC-236fa provided a maximum increase of 80% compared with CFC-114 and 70% compared with HFC-236ea.

Replacing CFC-114 with HFC-236fa is desirable in terms of the heat transfer performance based on the comparison of CFC-114, and HFC-236ea and -236fa made in this study. In addition, the high performance enhanced tubes outperformed the finned tubes at all the testing conditions in this research.

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The complete report, entitled "Heat Transfer Evaluation of HFC-236fa in Condensation and Evaporation," (Order No. PB98-136203; Cost: $27.00, subject to change) will be available only from:

National Technical Information Service
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