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Project Summary

Heat Transfer Evaluation of HFC-236ea and CFC-114 in Condensation and Evaporation

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With the mandatory phaseout of chlorofluorocarbons (CFCs), as dictated by the Montreal Protocol and the Clean Air Act Amendments, it is imperative for the Navy to find a replacement for 1,1,2,2-dichloro-tetrafluoroethane (CFC-114) that is environmentally safe and possesses similar performance characteristics. Currently, one of the leading candidates to replace CFC-114 is hexafluoropropane (HFC-236ea). This research focuses on comparing the refrigerants not only in condensation and pool boiling, but also with various tube surfaces.

The test facility used in this study was initially used for spray evaporation testing; however, it was redesigned and modified for use with condensation, pool boiling, or spray evaporation testing. During condensation, the rig was capable of producing saturated or superheated vapor. During pool boiling or spray evaporation, the test facility was capable of testing pure refrigerants or refrigerant/lubricant mixtures. The test facility is described in detail in the full report.

The two refrigerants produced similar performance characteristics in condensing vapor on integral-fin tubes, so that the transition to HFC-236ea should be accomplished without major modifications to existing condensers. The results also showed that the condensation of superheated vapor had negligible effects on the shell-side heat transfer coefficient as compared to condensation of saturated vapor results. The superheated vapor data for the 26 and 40 fpi (fins per inch) tubes were within 5 and 3%, respectively, of the saturated vapor results for the same tube surface.

HFC-236ea produced higher boiling coefficients than CFC-114 for all tubes tested. In addition, the 26 fpi tube outperformed the 40 fpi tube by 18% and the plain tube by 41% for HFC-236ea. The maximum increase in boiling with HFC-236ea was 39% for the 26 fpi tube and 34% for the 40 fpi tube.

The mineral oil used with CFC-114 showed a general improvement in the heat transfer performance, while the polyol-ester oil consistently degraded the performance of HFC-236ea. Even then the boiling performance of HFC-236ea was either equal to or greater than the performance of CFC-114 for all tested parameters.

This Project Summary was developed by EPA's 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

The U.S. Navy presently uses CFC-114 as the working refrigerant in shipboard and submarine chiller units. With the mandatory phaseout of CFCs dictated by the Montreal Protocol, it is imperative for the Navy to find a replacement that is environmentally safe and possesses similar performance characteristics to CFC-114. Currently, one of the leading candidates to replace CFC-114 is HFC-236ea. This alternative refrigerant is the focus of the results presented here. There are several reasons for choosing this refrigerant to replace CFC-114. First, there is currently a commercial production route available for acquiring the refrigerant. Of special importance, the operating capacities, pressures, and temperatures are very similar to those of CFC-114, and initial modeling indicates that the performance is within 1% of that of CFC-114.

This research focuses on comparing the refrigerants not only in condensation and pool boiling but also with various tube surfaces. Horizontal, integral finned tubes have been in service for over 40 years, and these tubes are widely used because of their higher performance compared to plain tubes.

The scope of this project was:

- Modify an existing spray evaporation test facility so it can perform condensation and pool boiling tests using a two-pass single-tube setup.
- Test alternative refrigerant HFC-236ea and compare its performance to CFC-114 as the reference fluid.
- Evaluate the plain and 26 and 40 fpi tubes for condensation.
- Evaluate the plain and 26 and 40 fpi tubes for flooded evaporation.
- Investigate oil effects in pool boiling on the shell-side heat transfer performance by varying the oil concentration from 0 to 3%.
- Compare results to published correlations for condensation and pool boiling.

Experimental Apparatus

The test facility used in this study was initially used for spray evaporation testing; however, it was redesigned and modified for use with condensation, pool boiling, or spray evaporation testing. During condensation, the rig was capable of producing saturated or superheated vapor. During pool boiling or spray evaporation, the test facility was capable of testing pure refrigerants or refrigerant/lubricant mixtures. The test facility is described in detail in the full report.

During some boiling experiments, lubricant was mixed with the refrigerant. Miscibility and solubility testing for CFC-114 and HFC-236ea were performed previous to this research in another portion of the project. These results along with other criteria such as material compatibility determined which lubricants would be used in the refrigerant/lubricant mixtures. The mineral oil used with CFC-114 was York "C" with a viscosity of 315 SUS (68 cSt--centistoke-- at 40°C). The miscibility data also showed that a synthetic ester refrigerant oil was to be used with HFC-236ea. This lubricant is a polyol-ester oil with a viscosity of 340 SUS. The trade name is Castrol Icematic SW-68. The two lubricants were miscible with the corresponding refrigerants over the entire range of conditions tested in this research.

Results and Discussion

The main objective of this study was to conduct an experimental heat transfer evaluation comparing the performance of CFC-114 and HFC-236ea in the condensation and pool boiling environments. The condensation testing included an investigation of saturated and superheated vapor on fin-tube surfaces. The pool boiling research involved nucleate boiling of pure refrigerant and refrigerant/lubricant mixtures on fin-tube surfaces.

All of the tubes used in this study had a nominal outside diameter of 19.1 mm (0.75 in.) and a length of 838.2 mm (33 in.). The shell-side heat transfer coefficients presented in this study were based on the outside surface area of a corresponding smooth tube, with the outer diameter measured over the surface enhancement. Therefore, the calculated heat transfer coefficient takes into account the area enhancement, fin efficiency, and surface enhancement of the tubes tested.

Condensation Heat Transfer

The refrigerants CFC-114 and HFC-236ea were evaluated in the condensation environment on the plain and 26 and 40 fpi tube surfaces. In addition, the effects on the heat transfer performance from condensing superheated vapor were investigated with CFC-114. During saturated vapor testing, the saturation temperature was held constant at 40°C. For condensation of superheated vapor, the saturation temperature was also 40°C, but the incoming vapor was 3 to 5°C higher than T_{sat}.

For condensation of both refrigerants, the integral-fin tubes yielded heat transfer coefficients approximately four times those produced from the plain tube. In addition, all combinations of the finned tubes and refrigerants produced similar shell-side condensation coefficients in the heat flux range tested, with a maximum deviation of 9%.

The results also showed that the condensation of superheated vapor had negligible effects on the shell-side heat transfer coefficient with respect to saturated vapor results. The superheated vapor data for the 26 and 40 fpi tubes were within 5 and 3%, respectively, of the saturated vapor results for the same tube surface.

The correlation comparison made with the plain tube results showed excellent agreement with the Nusselt correlation. The CFC-114 and HFC-236ea data were predicted within ±3 and ±10%, respectively. The Beatty and Katz correlation was able to predict the 26 fpi tube data for both refrigerants with a maximum deviation of 15%. The predictions for the 40 fpi tube resulted in larger deviations. The Beatty and Katz correlation predicted the 40 fpi tube data within 18 and 21% for CFC-114 and HFC-236ea, respectively.

The two refrigerants produced similar performance characteristics in condensing vapor on integral-fin tubes, so the transition to HFC-236ea should be accomplished without major modifications to existing condensers. Overall, the above information shows that HFC-236ea is a valid replacement for CFC-114 in the condensation environment.

Pool Boiling Heat Transfer

CFC-114 and HFC-236ea were evaluated in the pool boiling environment on plain and 26 and 40 fpi tube surfaces. In addition, this study investigated the effects of small concentrations of oil on the heat transfer performance. The concentrations tested were 1 and 3% by mass using a 68 cSt mineral oil for CFC-114 and a 340 SUS polyol-ester oil for HFC-236ea. During pool boiling, data were taken at a constant saturation temperature of 2°C for both pure refrigerant and refrigerant/lubricant mixtures.

The pool boiling results for the pure refrigerants show that the tube performance for CFC-114 and HFC-236ea fall in the following order from high to low: 26 fpi, 40 fpi, and plain tube. The 26 fpi tube produced boiling coefficients for CFC-114 that were 12 and 30% higher than for the 40 fpi tube and the plain tube, respectively. For HFC-236ea, the 26 fpi tube outperformed the 40 fpi tube by 18% and the plain tube by 41%. In addition, HFC-236ea produced higher boiling coefficients than CFC-114 for all tubes tested. The maximum increase in boiling with HFC-236ea was 39% for the 26 fpi tube and 34% for the 40 fpi tube.

The lubricant addition with CFC-114 produced enhancements in the boiling coefficients for the three tubes tested with oil. The maximum enhancement occurred at a 3% oil concentration for each tube. The addition of oil at a 1% concentration improved the heat transfer coefficients for the 26 fpi tube by 27%, while the 3% oil concentration only showed minor improvement over the 1% results. The 40 fpi tube produced similar trends to the 26 fpi tube at both oil concentrations.

Pool boiling of HFC-236ea with the polyol-ester oil produced consistent decreases in the heat transfer performance at both concentrations. The 26 fpi tube showed a decrease in performance of 6 and 17% at oil concentrations of 1 and 3%, respectively. The 40 fpi tube had only a 10% decrease in the boiling coefficients at a 3% concentration with respect to the pure refrigerant. At an oil concentration of 1%, the 40 fpi tube showed negligible oil effects in the low heat flux range. It is evident that the oil enhancement gained from the turbulent mixing within the foaming layer is dependent upon the type of oil. The mineral oil used with CFC-114 showed a general improvement in the heat transfer performance, while the polyol-ester oil consistently degraded the performance of HFC-236ea.

It is also worth noting that, even though the pure HFC-236ea results are higher than those for CFC-114, the oil effects on both refrigerants cause the boiling coefficients to be within 12% for the 26 fpi tube at an oil concentration of 3%. Therefore, the addition of oil decreased the deviation in the heat transfer coefficients between the two refrigerants. CFC-114 consistently produced higher boiling coefficients than HFC-236ea for both finned tubes at a 3% oil concentration.

A review of the above information shows that HFC-236ea is a valid replacement for CFC-114 in the nucleate boiling environment. The boiling performance of HFC-236ea was either equal to or greater than the performance of CFC-114 for all testing parameters. With the similar boiling characteristics, transition to HFC-236ea in a flooded evaporator would be relatively simple.

Summary

The two refrigerants produced similar performance characteristics in condensing vapor on integral-fin tubes, so that the transition to HFC-236ea should be accomplished without major modifications to existing condensers. The results also showed that the condensation of superheated vapor had negligible effects on the shell-side heat transfer coefficient with respect to the saturated vapor results. The superheated vapor data for the 26 and 40 fpi tubes were within 5 and 3%, respectively, of the saturated vapor results for the same tube surface.

HFC-236ea produced higher boiling coefficients than CFC-114 for all tubes tested. In addition, the 26 fpi tube outperformed the 40 fpi tube by 18% and the plain tube by 41% for HFC-236ea. The maximum increase in the boiling heat transfer coefficient with HFC-236ea was 39% for the 26 fpi tube and 34% for the 40 fpi tube. The mineral oil used with CFC-114 produced a general improvement in the heat transfer performance, while the polyol-ester oil consistently degraded the performance of HFC-236ea. Even then, the boiling performance of HFC-236ea was either equal to or greater than the performance of CFC-114 for all testing parameters.

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The complete report, entitled "Heat Transfer Evaluation of HFC-236ea and CFC-114 in Condensation and Evaporation," (Order No. PB96-183900; Cost: $31.00, subject to change) will be available only from:
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