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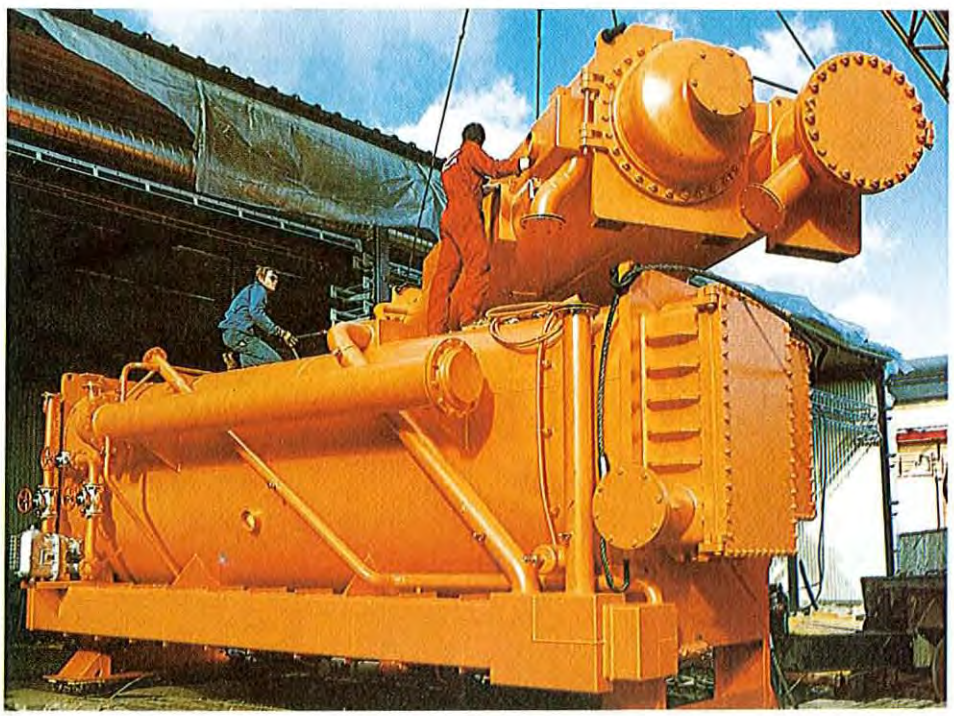

Installation of the world's largest absorption heat pump in Trollhättan, Sweden (see page 17)

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Advances in Non-Azeotropic Mixture Refrigerants: Symposia and Workshop Summary

Various benefits of refrigerant mixtures have been recognized for more than a century, yet their application remains quite limited. Using the rate of publication on the subject as a measure, interest in non-azeotropic mixtures has dramatically decreased in recent years. Within the last decade, several efforts have been undertaken to develop analytical models for research and development of systems using such refrigerants. Moreover, a number of researchers have begun to measure and develop techniques to predict essential thermodynamic and thermophysical data. Premature efforts to commercialize several specific mixtures have been attempted without success, leading a few people to question whether non-azeotropic mixtures are a solution looking for a problem. The majority view remains considerably more optimistic regarding the future potential for such mixtures.

The term "non-azeotropic mixture refrigerants" refers to fluids consisting of multiple components of different volatilities

Contents

that, when used in refrigeration cycles, change composition as they evaporate (boil) or condense. The description "non-azeotropic" is derived from the Greek words "zeo" (to boil) and "tropos" (to change) preceded by two cancelling negation prefixes, the Latin antecedent, "a", and the English, "non". The double negative results from interest following the chronological acceptance of azeotropic mixtures (refrigerants compositions that act as single components often with properties more favorable, for specific applications, than the separate constituents). Purists sometimes revert to "zeotropic" as a synonym to "non-azeotropic". Not surprisingly, some researchers have adopted acronyms (e.g. NARBs for Non-Azeotropic Refrigerant Blends) or simpler descriptions (e.g. "blends to connote the deliberate mixing of fluids to obtain desired properties).

Whatever they are called, experts agree that non-azeotropic mixtures offer unique characteristics as refrigerants. These features have been investigated in hopes of achieving improvements in efficiency, capacity, and - by composition management - capacity modulation in heat pump and refrigeration systems. Additional benefits investigated include system optimization, when desired refrigerant properties fall between discrete choices afforded by single-component and azeotropic refrigerants, and split-temperature evaporator or condenser functions (e.g. refrigerator/freezer or space/water heating applications).

An update on research and development of non-azeotropic mixture refrigerants was included in two symposia at the June 1985 Annual Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), held in Honolulu. These sessions, comprising eight papers, were cosponsored by ASHRAE Technical Committees 3.1, Refrigerants and Brines; 7.6, Unitary Air Conditioners and Heat Pumps; and 9.4, Applied Heat Pump and Heat Recovery Systems. These papers include:

- "The ABCs of NARBs (Non-Azeotropic Refrigerants Blends)" by T. Atwood,
- "The Characteristics of Fluid Mixtures and Their Utilization in Vapor Compression Refrigeration Systems" by U.W. Schulz,
- "Two Refrigerant Mixtures and the Hard Sphere Fluid" by G. Morrison and M. McLinden,
- "Prediction of Refrigerant Ternary Mixture Properties Using the Redlich-Kwong-Soave Equation of State" by E.G. Wright,
- "Heat Transfer of Non-Azeotropic Mixtures in a Falling Film Evaporator" by T. Berntsson, K.M. Berntsson, and H. Panholzer,
- "Condensing Coefficients when Using Mixtures" by W.F. Stoecker and E. Kornota,
- "Simulation of a Heat Pump Operating with a Non-Azeotropic Mixture" by P.A. Domanski and D.A. Didion, and
- "Theoretical and Experimental Investigations of Advantageous Refrigerant Mixture Applications, by H. Kruse, M. Küver, U. Quast, M. Schröder, and B. Upmeier.

A workshop on research and development of non-azeotropic mixture refrigerants for heat pumps, conducted after the ASHRAE meeting, was organized and sponsored by the Electric Power Research Institute with the cooperation of the Hawaiian Electric Company and the National Bureau of Standards. The intent ot this workshop was to:

- Assess the status and potential of non-azeotropic mixture refrigerants,
- Identify research and development needs associated with such refrigerants and the equipment in which they would be used, and
- Encourage international cooperation and coordination in the conduct of such research.

Participation in the workshop was by invitations extended to the authors of the symposia papers, internationally recognized researchers in non-azeotropic mixtures, representatives of both refrigerant producers and heat pump manufacturers, utility representatives, and others selected from research organizations. The workshop was held on June 27, 1985, at the Hawaiian Electric Company in Honolulu.

The following specific research and development topics were proposed for the near term:

- Completion and validation of current efforts to develop equations of state for binary and ternary mixtures.
- Integration of these equations of state into simulation models to enable development studies.
- Theoretical cycle analyses, including hybrid absorption-compression cycles, to identify opportunities.
- Screening of non-azeotropic mixture candidate fluids suitable for vapor-compression cycles.
- Collection of property data as needed for the above; sensitivity analyses based on these data to determine precision requirements for future data collection.
- Laboratory tests of new concepts and fluids as they emerge (considerable attention has already focused on R22/R114, R12/R114 and R13B1/152a mixtures; R23/R12, R23/R22 are possible candidates warranting evaluation for increased capacity for low evaporator temperature applications).
- Impact study identifying likely applications and quantifying the increase in performance as well as the return to the manufacturer and consumer.

Several conclusions were derived from the workshop discussions:

- Non-azeotropic mixture refrigerants are not ready for widespread commercialization. Demonstration of their practical utility will require at least several more years.
- Research, both basic and applied, is needed to identify and establish the viability of specific non-azeotropic mixtures and associated cycle modifications. This research must develop the necessary data, design tools, and thermodynamic impact of selected cycles for specific applications.
- Because of opportunities to exploit the advantages of gliding temperature evaporation and/or condensation (e.g., a Lorenz rather than a Carnot cycle), non-azeotropic mixture refrigerants may initially be found more attractive in heat pumps and refrigeration systems requiring high temperature glide. Such systems may include heat pump water heaters, community heat pump systems, industrial heat pumps, and multistage refrigeration systems.
- Although nearly 100 years have passed since the use of refrigerant mixtures was first proposed, the full potential of non-azeotropic mixtures in refrigeration systems is still relatively unexplored. Opportunities for identification and development of appropriate mixtures and associated cycles exist, and more intensive research and development are needed, and believed justified, to evaluate their ultimate potential.
- To date, test results with mixtures have shown only modest improvements over single component refrigerants. It is felt that this has been due to inadequate design changes to the hardware systems to fully capitalize on mixture attributes.
- Commercialization of mixtures introduces a number of complexities in all stages of industry practice - from equipmnet design to field services - presenting additional cost elements beyond those directly attributable to the refrigerants themselves.
- This workshop provided a useful forum for examination of non-azeotropic mixture refrigerant status. Moreover, this meeting afforded international leaders in

this field an opportunity to meet and establish a basis for further communication and cooperation.

The eight ASHRAE symposia papers, resulting discussion, and a summary of the workshop are available in a bound volume entitled "Advances in Non-Azeotropic Mixture Refrigerants for Heat Pumps" (TDB-54) from ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, USA. The cost is US $ 15 for ASHRAE members and US $ 30 for others.

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