The Sine-US Super-Efficient Refrigerator Project

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This paper discusses the Sine-US project to develop and manufacture a super-efficient refrigerator that contains no CFCs. In addition to optimizing the choice of a refrigerant and cycle, improvements include using a more efficient compressor, optimizing the condenser and evaporator design, adding insulation, improving the door gasket and controls, and reducing energy use by valves and other parts. Overall, this combination of improvements may lead to up to 70% energy savings (350 kWh/year per unit) over current refrigerator energy use.

Preliminary work completed so far, both at the Beijing Household Electric Appliance Research Institute and at the University of Maryland includes building, operating and testing of a Chinese refrigerator modified to use no CFCs and to be more energy efficient. Results of these tests and the future stages of the project are presented.

Introduction

From 1980-89, residential energy use in China grew 17% per year while overall energy use grew at only 7% per year. Domestic appliances account for a growing portion of China's energy demand. Therefore, reduction of energy use in the residential sector offers an important cost-effective strategy to reduce emissions of carbon dioxide due to power production. In addition, demand reduction measures reduce the need to build additional coal fired power plants, and frees up capital in the power generation sector that may be more profitably used in other ways.

In 1992, it is estimated that China produced 6.8 million refrigerators for domestic use, 18% more units than during the previous year. Chinese refrigerators of the 1980's use 30% more electricity than similar European or Japanese models. In addition, these refrigerators consume millions of kilograms of ozone destroying chlorofluorocarbons (CFC-11 and CFC-12).

As a signatory of the Montreal Protocol, China has agreed to phase out its use of CFCs. As a part of this cooperative effort, an opportunity arose to vastly improve the energy efficiency of the refrigerators while redesigning them to function without CFCs.

The U.S. Environmental Protection Agency (EPA) is working with the China National Environmental Protection Agency (NEPA) to accelerate this phaseout. Additional participants include the China National Council of Light Industry (NCLI), the Beijing Household Electric Appliance Research Institute (BHEARI), and the University of Maryland. A number of refrigerator factories have been involved with the project. The Haier Group was chosen for the first prototype development based on the quality of their existing products, and on their interest and commitment to the project. The EPA serves as project leader for the U.S. side. EPA 1) works with China to define the scope and schedule for the project, 2) assists the Chinese with applications to the Montreal Protocol Fund and the GEF for grant assistance, 3) evaluates test results and consults on the new design, and 4) is developing a strategy to help assure widespread adoption of energy efficient models by Chinese manufacturers and strong acceptance of and demand for the new products by consumers.

The Chinese government has committed to sponsor the project as part of their country's strategy to phase out CFCs and to conserve energy. NEPA is the Chinese project leader with overall responsibilities for the CFC phaseout. The NCLI is the lead project implementor for the Chinese side and serves as a liaison with the Chinese refrigerator industry. NCLI is also responsible for setting energy standards for appliances in China.

The overall objective of this joint Sine-US project is to transform the domestic refrigeration industry in China. The first stage in this venture is to develop and manufacture super-efficient CFC-free refrigerators at a single factory. Later stages will involve the transfer of the technical developments and redesign methods throughout

the industry. This technical effort will be coordinated with public education and marketing efforts to assist manufacturers and retailers in aggressively promoting widespread adoption of the most energy-efficient models and in assuring consumer preference for models that offer the greatest long term energy savings. This paper discusses progress to date in the first stage of the project.

The project is being done in stages. The purpose of stage 1 is to complete pilot production and testing, with an emphasis on reliability. Stage 1a involves the development and testing of model prototypes. Successful completion of stage 1a will lead to stage lb, in which one or two refrigerator models will be selected for field testing. In stage lb, the prototype test results will be used to build an example model for field testing. This example model will combine all the improvements indicated to assure reliable functioning of the CFC-free unit. A refrigerator line will be modified to allow manufacture of approximately 100-200 of the improved design for use in field testing. Field testing will include life cycle testing and more extensive testing to assure reliable performance in all major Chinese climates (temperature and humidity). Safety testing and performance testing will be reviewed by experts in the field at universities, and in government and industry. During stage lb, a feasibility study will be conducted to identify steps and costs for factory changeover to production of all CFC-free refrigerators.

The final results of stage 1 will be the identification of a reliable CFC-free refrigerator design that has been thoroughly tested for reliability, performance and safety in three major Chinese climates. Stage 1 will also provide a completed feasibility study that outlines the steps and costs for factory changeover and other plans necessary for successful completion of stage 2.

Upon successful completion of stage lb, stage 2 would be started. Stage 2 involves the efficient conversion of the entire factory to the manufacture of reliable CFC-free refrigerators. Technology transfer to the rest of the Chinese refrigerator industry will then follow.

Since a major objective of the project is to speed the adoption of energy efficient technology in China, thereby reducing the rate of growth of energy demand, consumer cost impact is an important factor in the development of the new design. Design decisions at every stage are made with an eye towards minimizing cost increases. Analysis of modifications made so far indicates that minimal cost increases per unit should be expected. The long term energy savings should help offset any increased initial costs, and this fact will be a prominent part of the program's marketing strategy.

Description of Work to Date

Preliminary Work

Preliminary work involved the identification of potential non-CFC refrigerants and blowing agents for insulation. This preliminary work took place from March 1991 through April 1993. The accomplishments to date are summarized below.

- Identification of key personnel and organizations. Selection of key refrigerator and compressor factories for further work.
- Completion of preliminary assessment of equipment, testing capability (including equipment test cells and compressor testing equipment), and ability to alter factories.
- Initiation of work to reduce energy use by refrigerators and to adapt refrigerators to CFC-free materials. Exchange of information between China and the U.S. to facilitate technology transfer activities. Initiation of laboratory and factory testing and evaluation of alternative refrigerants, including performance, cost of changeover, safety, materials availability, materials compatibility, and compressor performance.
- Successful design, construction, operation and testing of an initial prototype refrigerator without CFCs. A conventional vapor compression cycle with two evaporators and a Lorenz cycle which employed an intercooler between the two evaporators were tested for quality of operation and cooling characteristics.
- Planning for the next stages of the project.

Prototype Model Development

CFC-free prototypes were built and tested. The goal was to identify and optimize 1 or 2 designs which would successfully and effectively improve energy efficiency and use CFC substitutes. BHEARI, the Haier Refrigerator Factory, and the NCLI were involved during this stage. Haier Refrigerator Factory is the second largest refrigerator factory in China, with an estimated 6% of the market in 1991. Work at Haier would serve as a template for the other factories in China. Prototype model development work is summarized below.

- Determination of the amount, location and type of non-CFC foam insulation necessary to optimize refrigerator performance. Based on research conducted during preliminary work, the primary CFC-free foam

blowing agent under consideration was HCFC-141b. As technology advances, the project will move out of this temporary material and into a material with lower or no ozone depleting properties, such as cyclopentane.

- Determination of the compatibility of non-CFC foam with other materials in the unit, as well as the durability and structural suitability of the foam through testing in the laboratory and at the factory.
- Determination of other changes necessary to optimize the performance of the CFC-free insulation.
- Redesign and construction of prototype cabinets with the CFC-free foam.
- Determination of compressor size and type, and identification of compatible lubricating oils for a compressor which will reliably run on non-CFC refrigerants. Based on the most recent findings, refrigerants under consideration included HFC-152a, HFC-152a/HCFC-22 blends and hydrocarbons for conventional cycles; and HFC-152a/HCFC-22/HCFC-123 blends and hydrocarbons for Lorenz cycles.
- Choose condensers, evaporators, anti-sweat devices based on test results from current Chinese technology adapted to work with the chosen CFC-free refrigerant.
- Construct and test the performance of the redesigned units and make further suggestions to improve performance.

Prototype Model Test Results

Prototype cabinets were built at the Qindao Refrigerator Factory. The improvements to the basic 220 liter bottom-freezer model are summarized below.

- HCFC-14lb blown foam supplied by ICI Polyurethane.
- 2.3 centimeters of foam insulation added to the sides, back and bottom of the unit.
- 1.5 centimeters of foam insulation added to the doors.

Cabinets were then shipped to BHEARI and The University of Maryland, where refrigeration cycles were added and the systems tested. Tests to date performed at BHEARI were done at Chinese standard conditions and are summarized in Table 1. Tests performed at the U. Md. have been performed at standard DOE conditions and are summarized in Table 2.

In addition to the above prototype models, approximately 200 units were made with the BHEARI design in late 1993. Approximately 70% of these had conventional cycles and 30% Lorenz cycles. Tests to date have shown an average 42% energy reduction for these units.

Future Work

Analyses made using the EPA Refrigerator Analysis Program have shown that about 60% energy savings are possible using the conventional cycle and 70% with the Lorenz cycle. These analyses include:

- addition of one additional centimeter of insulation to the cabinet and doors, and
- incorporation of an improved gasket to the fresh food and freezer compartments.

These improvements and continued work on the selection of refrigerants, components and optimization of the entire system are continuing.

Table 1. Summary of BHEARI Test Results

Refrigerant	30% HCFC-22 + 70% HFC-152a	30% HCFC-22 + 40% HFC-152a + 30% HCFC-123
Cycle	Conventional	Lorenz
Compressor	Aspera BK112Z	Aspera BK112Z
Fresh Food Evaporator	Area increased 30%	Area increased 40%
Freezer Evaporator	unchanged	unchanged
Condenser	unchanged	unchanged
% Energy Reduction	>40%	>50%

Table 2. Summary of University of Maryland Test Results

Refrigerant	HFC-152a	68% Propane + 32% n-Butane
Cycle	Conventional	Lorenz
Compressor	Americold TG105-12	Americold TG105-12
Fresh Food Evaporator	Area increased 50%	Area increased 50%
Freezer Evaporator	unchanged	unchanged
Condenser	unchanged	unchanged
% Energy Reduction	>40%	>50%

Two hundred field test units will be manufactured using the most energy efficient, cost effective modifications identified. Preliminary plans are to place 40 units in each of three apartment buildings, with each building in a different Chinese climate. Ten of the baseline models would also be placed in the same buildings for comparison. Wattmeters would be used to record actual energy use in typical household situations. Information would be gathered from the occupants on the performance of the unit for chilling ability, noise, and marketing factors such as appearance. Ideally, life-cycle testing should last one year. But at a minimum, three seasons including the hot summer period will be included. Units would be sent to Underwriter's Laboratory for safety testing, and to specialized facilities for mechanical testing to assure the overall function and quality of the new designs.

Business Opportunities

As a signatory to the Framework Convention on Climate Change, the U.S. government is involved in this project because of the importance of reducing China's growth in energy demand in order to help prevent global climate change. While this objective is shared by the Chinese government, the factories have an additional interest in export opportunities. Due to their size and electrical systems, the Chinese refrigerators are not generally suitable for use in the U.S. However, the Chinese designs are based on European and Japanese models. It is possible that the new Chinese models would be competitive with the European and Japanese models if exported. This is especially true in countries like Germany that highly value energy efficiency.

One of the key modifications necessary to assure significant energy use reduction is the adoption of highly efficient compressors. Compressors now available within China are often not as efficient as those available from the U.S. and elsewhere. This offers U.S. and other compressor manufacturers opportunities to sell both compressors and compressor plants to China. Other potential export opportunities for U.S. firms include tooling for the production of the more complicated plastic parts used in the refrigerators.

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