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DEVELOPMENT OF A RESIDENTIAL GAS-ABSORPTION HEAT PUMP*

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MASTER

DEVELOPMENT OF A RESIDENTIAL GAS-ABSORPTION HEAT PUMP

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Abstract

A residential-sized (25KW) absorption heat pump has been developed using organic absorption pairs. Several different absorption pairs were examined during the course of the program. The final choice was R123a ($CCl_2FCHClF$) as the refrigerant and ETFE (ethyltetrahydrofurfurylether) as the absorbent. This pair was found to have good overall physical properties and performance equal to present commercial pairs.

Based on thermodynamic analysis and actual performance tests, the R123a/ETFE pair will give a projected heating COP of 1.50 with a condensing flue system.

The program has demonstrated the feasibility of the organic pairs in general. Combined operational experience of over 36,000 hours on these types of systems has been reached with a maximum of 13,000 hours on any single unit. The thermal stability of the absorption fluids was monitored during these tests and was found to be quite acceptable.

A new solution pump design was developed for use with the organic pairs. Tests on this pump have achieved over 50,000 hours of continuous operation with minimal wear.

The overall results of the program suggest that an absorption heat pump system using organic pairs would give a safe, long lived, efficient heat pump system.

INTRODUCTION

Using the direct combustion of fuel most home heating systems have an efficiency in the 70-80% range. Using condensing flues, an efficiency approaching 100% can be achieved. This is the limit, however, for direct heating equipment. To go beyond this level requires new technology such as the use of the thermal heat pump. With this type of technology, the 100% efficiency barrier can be broken and further substantial improvements in operating costs can be achieved.

Many configurations are possible for a thermal heat pump but a leading candidate is absorption. It has several advantages when compared to other types of thermal heat pumps. The absorption system is a well known cycle, it can operate at low sink temperatures and it can be made to have long life, high reliability and low maintenance. These all combine to make the absorption heat pump a leading candidate for the next generation of high efficiency home heating equipment.

ABSORPTION PAIRS

The search for the "ideal" absorption pair has been going on from the very beginning of absorption technology. The technical literature is filled with proposed systems. Unfortunately, almost all of these systems have serious flaws when examined in detail. Some of the important criteria that must be considered in evaluation of a new pair are shown in Table 1. With this formitable list of requirements, it is very unlikely that any absorption pair will be ideal in every respect, therefore various trade-offs of properties must be accepted.

An extensive evaluation was made of various types of absorption pairs. Using the criteria in Table 1 we identified several new pairs which appeared to have commercial potential. Some of the refrigerants were found, on detailed examinations, to be unsuitable for use due to toxicity or long term instability. The pair which was found and met the criteria of Table 1 to a reasonable degree was R123a ($CCl_2FCHClF$) as the refrigerant and ETFE (ethyltetrahydrofurfurylether) as the absorbent. Some of the key properties of this pair are shown in Table 2.

Table 1.
Important Criteria for Absorption Pairs

Refrigerant	Absorbent
High Latent Heat	Low Volatility
Moderate Operating Pressure	Stability
Stability	Compatibility
High Solubility	Low Viscosity
Low Toxicity	Compatibility
Non Flammable	Low Toxicity
Cost	Non Flammable
	Cost

CALCULATED PERFORMANCE OF R123a/ETFE

Extensive physical and thermodynamic data have been developed on this new pair, including

Table 2.
Fluid Characteristics

R123a	
Name	1,1,2 Trifluoro 1,2 Dichloro Ethane
Formula	$CF_2ClCHClF$
Boiling Point, °C	29
Heat of Vaporization, kJ/kg	174.5
Flammability	None
ETFE	
Name	Ethyltetrahydrofurfuryl Ether
Formula	$C_4H_7O\,CH_2OC_2H_5$
Boiling Point, °C	156
Heat Capacity, kJ/kg °K	1.88
Flash Point, °C	47

experimental determination of the heats of mixing by the Thermochemical Institute at Brigham Young University in Provo, Utah. Based on this thermodynamic data, the calculated performance of the R123a/ETFE was evaluated. The cycle performance is shown in Table 3. Two cycles are shown. One represents heat pumping in mild conditions, 2.2°C evaporator, the second represents performance at low ambient air conditions, -18°C evaporator. The high potential performance of this pair, which is shown by Table 3, compares favorably with other known absorption pairs. The generator temperature levels of 166°C and 171°C, respectively, are quite acceptable for these fluids.

The Coefficient of Performance (COP) defined in Table 3 is a net or thermodynamic COP based on the net heat out divided by the net heat into the system.

The cycle calculations shown in Table 3 were made with reasonable ΔT values included and therefore represent practical performance limits for this pair. They do not, however, include the solution pump power requirements which would decrease the COP values by about 4%.

Table 3.
Calculated Performance
R123a/ETFE

Evaporator Temp, °C	2	-18
Condenser Temp, °C	49	49
Absorber Out Temp, °C	41	43
Generator Peak Temp, °C	166	171
Heat Input, kW	15.8	15.8
Refrig. Effect, kW	10.5	7.36
Heat Output, kW	26.3	22.0
COP Heating (Thermodynamic)	1.66	1.39

PERFORMANCE TESTS ON R123a/ETFE

Preliminary test results on a breadboard configured system have confirmed the high performance potential of the R123a/ETFE. Some typical test results are shown in Table 4 representing operation at moderate and low evaporator temperatures. While these results are somewhat below the calculated potential given in Table 3, our previous experience indicates that improvement to this higher level is reasonable with complete development of the system.

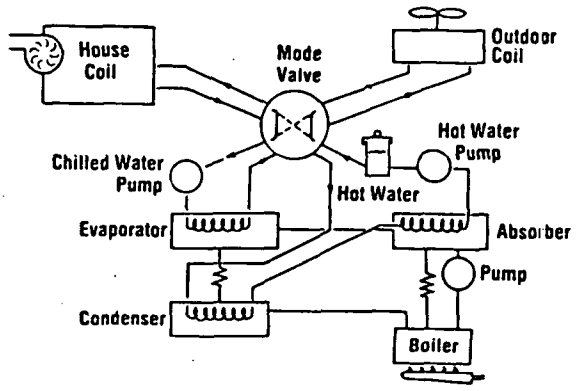
Table 4.
R123a/ETFE Test Results

Evaporator Temp., °C	4.4	-6.2
Evaporator Press., kPa	35.9	21.4
Condenser Temp., °C	50.3	49.2
Condenser Press., kPa	207	200
Refrigerant Flow, kg/hr	196	161
Weak Liquid Flow, kg/hr	420	467
Net Heat Input, kW	14.55	14.11
Heat Output, kW	22.5	20.6
COP (Thermodynamic)	1.56	1.46

BASIC DESIGN

The basic heat pump system design is shown in Figure 1. Because the unit was designed for both heating and cooling, a secondary loop of ethylene-glycol/water is circulated as a heat transfer fluid. This arrangement simplifies the change from heating to cooling mode and offers a convenient method to defrost the unit. The defrost is accomplished by switching the mode valve and sending hot water to the outside coil. This has proved effective in actual use.

Figure 1.
Absorption Heat Pump Circuit



FIELD TRIAL UNITS

In order to gain actual field experience with the operation of the organic absorption heat pump, six units of an early design were built and put into service. Two of these were in homes, two were operated on a continuous basis, and the last two were put on cycling operation. The units did not use the R123a/ETFE pair but used one of the earlier candidates which was chemically similar.

Home Installations

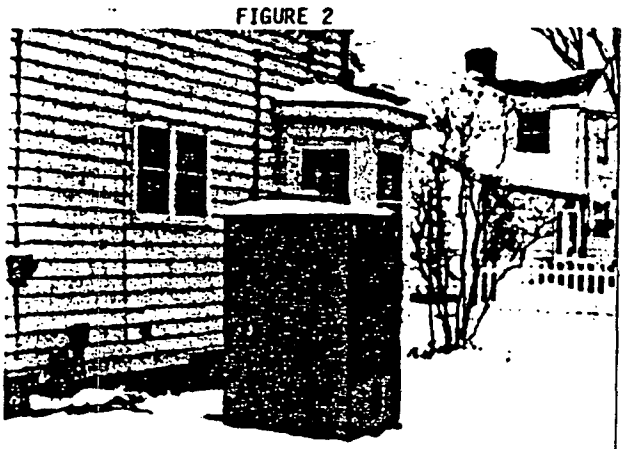
The two home installations were located in St. Joseph, Michigan. One of the two homes was 150M^2 in area and of wood frame construction. The second was 200M^2 in area and of masonry construction. The units operated with an on-off control

only as previous tests showed a cycling efficiency of over 90%. Minimum temperatures in this region are usually in the -20 to -25°C range with 1 to 4 meters of annual snowfall. Figure 2 shows one of the home installations. The unit was 1.4 meters high, since it did not incorporate the compact heat exchanger designs developed later in the program.

The home units operated over two heating and cooling seasons supplying the entire heating and cooling demand down to -18°C, which was the lowest temperature encountered during the test.

The test units operated with minimal difficulties as regards the basic absorption components. Minor problems were encountered in the auxiliary systems such as controls and gas burner ignition. The defrost experience was unusual and somewhat unexpected as the units were found to require very little defrost, usually only during direct snowfall on the unit. These tests were terminated after the second cooling season but have demonstrated the practical use of the organic absorption heat pump in actual home service.

FIGURE 2



HOME INSTALLATION - 20KW

Continuous Operation of Test Systems

Two units of similar design to the home installations were placed in continuous operation to accumulate the maximum hours of operation. This test was designed to look for signs of corrosion or decomposition in regards to the working fluids or water/glycol loops. The two units operated a total of 20,000 hours, with the longest running exceeding 13,000 hours of operation. During this period the organic fluids were sampled periodically. Analysis of these samples showed no evidence of decomposition or impurity increase. Based on this, we believe that fluids of this type could be used for the entire life of the system (15-20 years) and would never have to be replaced under normal circumstances.

The second unit in continuous use was shut down after operating for approximately 8,000 hours. The unit was dis-assembled and the various internal and external heat exchange surfaces examined. No evidence of corrosion was seen even at the hottest points in the generator.

Cycling Operation

Considerable testing and development was done on improving the cycling operation of the system. Generally a cycling efficiency of over 90% can be achieved, even at 50% cycle duty, if the total cycle time is sufficient. That is, if short cycling is avoided.

The combined operational hours of all six test units totaled over 36,000 hours. These tests indicate the organic type absorption heat pump can have a life in the 15 year range without excessive corrosion or fluid decomposition.

SOLUTION PUMP DEVELOPMENT

Another major aspect in this program was the development of a high performance, reliable solution pump. This has always been an area of concern in the absorption cycle. Several pump designs were considered and tested early in the program. Of these, the regenerative turbine type system was chosen for final development.

This design has proved to be extremely reliable. Life tests have now exceeded 50,000 hours of operation on several pumps. Periodic examination of the units has shown negligible wear. Other test pumps have been put on cycling tests and have exceeded 200,000 on/off cycles. Both the total hours of operation and the on/off cycles represent real time evaluations. Using 2,500 operational hours per year the 50,000 hours test represents the equivalent of 20 years of operation.

The development of this pump is an important milestone in the overall development of a long-lived reliable absorption heat pump system.

FINAL DESIGN DEVELOPMENT

In order to reduce the size of the system and improve operational performance, new heat exchange configurations were developed. The heat exchangers utilize aluminum extrusions allowing low cost fabrication. We have found that for optimum performance the various heat exchange surfaces must be carefully designed with regard to specific properties of the fluid pair. Figure 3 shows a mock up of the 25 KW output unit. The unit now has the dimensions of 1.05 x 1.05 x 1.0 meters. The reduction in size from the earlier test units is due primarily to the use of the aluminum extrusions in the heat exchangers.

FIGURE 3

25KW MOCK UP UNIT

The projected performance of the final design is shown in Table 5 and is based on a condensing flue system which has not yet been incorporated into the unit. Without a condensing flue, the COP for the system was 1.25 at 8°C ambient.

Table 5.
Performance Specifications

Heating Mode	
Heat Input, kW	17.6
Heat Output, kW	26.4
Water delivery temp., °C	54.4
Water return temp., °C	35
Electrical Power, kW	0.75
COP	1.50
Cooling Mode	
Cooling Capacity, kW	10.6
Chilled water out, °C	7.2
Chilled water return, °C	12.8
COP	0.65

CONCLUSIONS

A residential sized absorption heat pump based on organic working fluids has been demonstrated in actual operation. Several of the major questions regarding this type of system such as pump life and fluid stability have been successfully answered. There now appears to be no major technical hurdle to overcome to the development of a high performance, reliable and safe residential absorption heat pump.

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