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NEWS LETTER

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This issue: Absorption heat pumps

Editorial*

In keeping with the main goal of our publication which is to show recent trends in heat pump research, development, and application, we have selected Absorption Heat Pumps as this issue's main topic. One may ask, "Why are absorption heat pumps of interest today?" In terms of market share, electrically driven compression cycle heat pumps dominate the heat pump market. Furthermore this technology is relatively complex and requires knowledge from both chemical and mechanical engineering disciplines.

However, absorption heat pumps and refrigeration systems are presently receiving renewed attention in connection with CFCs and their environmental impact (see Newsletter Volume 6, Number 2, June 1988), since they usually use working fluids which do not affect the ozone layer or contribute to the "greenhouse effect." The commentary in our Feedback section titled "Environmental Aspects of Absorption Technology" discusses this in more detail.

So far, significant changes in the absorption heat pump market have not taken place since our market review two years ago (see Newsletter Volume 4, Number 3, October 1986). Nevertheless as you can see by glancing through the table of contents a number of efforts are underway to take advantage of this technology and to improve its market acceptance. The articles in this issue give an overview of the various development trends in basic research, new cycles, component improvements, and applications.

The heat pump research projects being sponsored by the Commission of the European Communities (CEC) are presently concentrated on absorption cycles with the goal of "efficiency improvement and cost reduction." These projects are described in "R&D of Absorption and Adsorption Heat Pumps and Heat Transformers in the CEC Programme."

Efforts continue to be made to improve the performance of absorption heat pumps by modifying the characteristics of the working fluids with additives. The article "Basic Mechanism of Absorption Heat and Mass Transfer Enhancement by the Marangoni Effect" is one example of work aimed at gaining a better understanding of the effect of such additives.

The development of residential and larger size space heating and cooling absorption units continues to be an active area. One of the trends, particularly in Japan, is towards development of air source absorption units. These systems are using LiBr-water as the working fluid. The article "Development of Air-Cooled Small Sized Gas Absorption Chiller-Heater" describes such work. A joint effort between industry and research institutes to develop an advanced absorption system is shown in "Activities of the Research Project for Development of an Advanced Absorption Heat Pump at the Heat Pump Technology Center of Japan." The goal of this project is to develop a next generation space heating and cooling heat pump for the Japanese market.

In Europe one of the trends in residential absorption technology is towards cycles which eliminate the need for the solution pump found on conventional absorption cycles. One approach which has been under development over a number of years is presented in the article "Diffusion Absorption Heat Pump." The goal of the work described was to develop a modular, hermetic, maintenance free, and silent unit which can easily be installed in residential buildings. The article "Progress in Development of the Periodically Operating Absorption Heat Pump" describes a design for a monovalent absorption heat pump using the working fluid pair Lithium Bromide-Methanol. For both of these projects testing of prototypes is being carried out.

Component improvements for absorption systems has always been an important area of work. For residential as well as other applications, compact, efficient, and low cost heat exchangers are needed. Some results in this direction are shown in "Compact Heat and Mass Exchangers in Sorption Systems."

Absorption heat pumps are also being used for larger space heating applications such as district heating. Some new examples in this area are shown by two articles in this issue. The article "Research on Absorption Heat Pump Which Utilizes River Water" describes how to overcome corrosion and fouling problems encountered when using river water as a heat source. The article titled "A Proposed Cogeneration Cycle for District Heating and Cooling" is an example of how absorption technology can be combined with a Rankine cycle and a low power nuclear reactor to provide performance improvements to the overall system. Its high reliability and low maintenance are features that make the absorption cycle attractive for this application.

We hope that these articles will encourage you to familiarize yourself with absorption heat pump technology. Absorption heat pumps are also widely used in industry where perhaps the greatest application potential currently exists. The March 1989 issue of the Newsletter with the main topic of Industrial Heat Pumps will address this aspect in more detail.

Finally, we invite you to take some time to write us your opinion or ideas on matters related to heat pumps for our Feedback section. Season's Greetings from the staff of the Heat Pump Center.

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Basic Mechanism of Absorption Heat and Mass Transfer Enhancement by the Marangoni Effect

In most commercial absorption machines, absorption enhancement has been done by adding small amounts of various kinds of surfactants, thereby reducing the surface tension of the absorption solution drastically and generating Marangoni convection near the solution surface at the time of refrigerant vapor absorption. This article describes the basic mechanism of the inducement of Marangoni convection by the addition of higher alcohol as the surfactant in the case of Libr/H_2O combination. Furthermore, the behavior of the Marangoni convention in the process of vapor absorption into the falling film is visualized by the double pulse laser holographic interferometry technique.

Introduction

The performance of absorption machines is greatly affected by the characteristics of heat and mass transfer in an absorber. In Japan, most absorption machines use H_2O/LiBr as a typical refrigerant/absorbent combination. It is well known for this combination that the viscosity of the LiBr aqueous solution increases considerably with increasing LiBr concentration. This results in the decrease of mass diffusivity in the practical high concentration range of LiBr. From this point of view, absorption enhancement has been achieved in most commercial machines by adding a small amount of various kinds of surfactants as additives, which reduce the surface tension of the absorbent solution and also generate Marangoni convection near the solution surface during

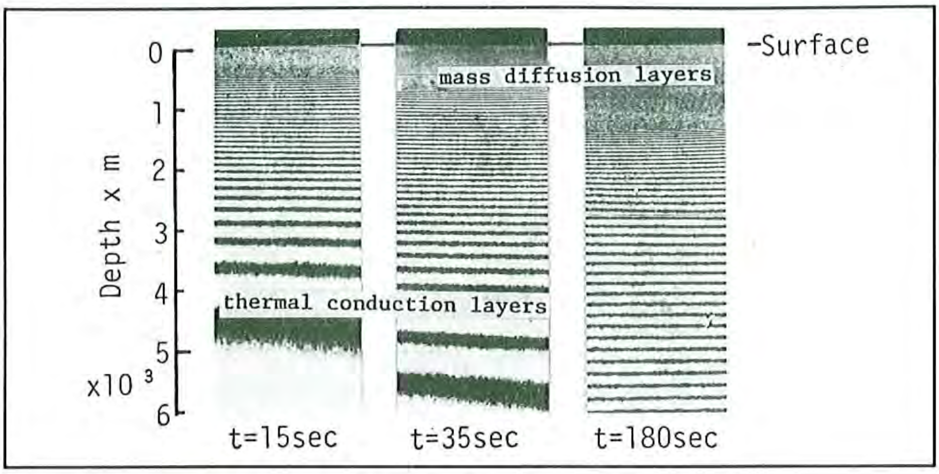

Figure 1. Interference fringes observed when n-octanol was not added (w=0)

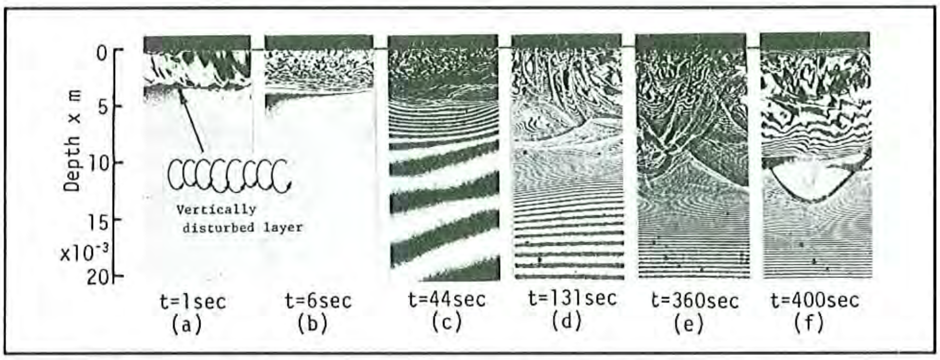

Figure 2. Representative interference fringes observed in the case of W=0.1 mass% (n-octanol addition)

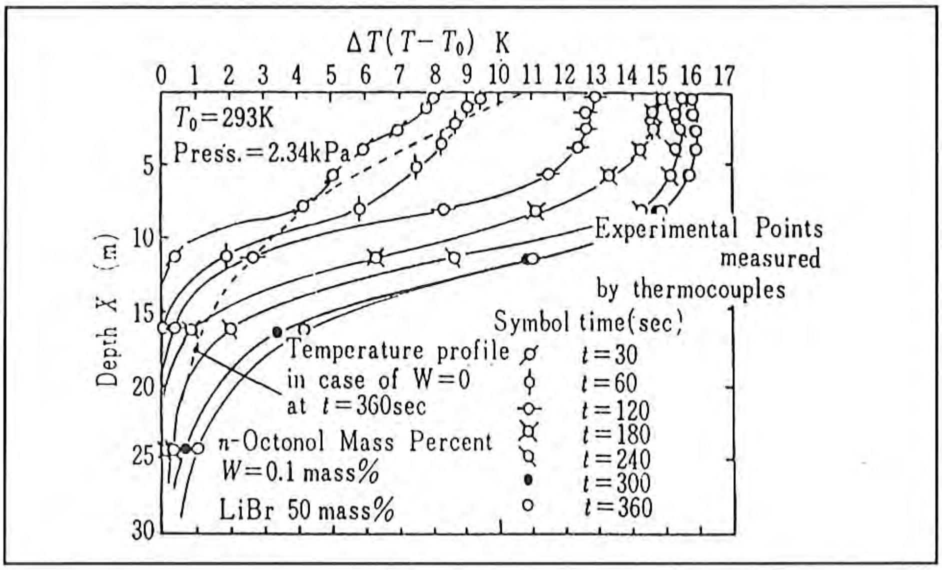

Figure 3. Temperature distribution (W=0.1 mass%)

the refrigerant vapor absorption process.[1,2]

In the absorber a suitable LiBr aqueous solution with a high concentration absorbs the water vapor as a refrigerant. The water vapor is released in the generator. The solution saturated temperature in the absorber varies according to the concentration of the solution even though the absorption process proceeds at a constant pressure.

In order to use this advantage effectively, a vertical falling film type absorber has attracted attention due to the possibility of forming a counterflow type heat exchanger. It is obvious that absorption enhancement using the Marangoni effect is essential in this kind of absorber.

This article summarizes the basic knowledge of heat and mass transfer enhancement in the process of water vapor absorption by the Marangoni effect.

Basic mechanism for the inducement of Marangoni convection by the addition of n-octanol

An absorption experiment was carried out in order to obtain the basic mechanism for inducing Marangoni convection by the addition of surfactant in the process of steam absorption. The H_2O/LiBr combination which is widely used in Japan was selected for refrigerant and absorbent, and n-octanol was used as a surfactant additive. The most basic absorption into stationary LiBr solution with 50% by mass was adopted. A conventional holographic real-time interferometric technique was used to visualize the absorption process by the interference fringes.

The first absorption test was conducted by changing the mass concentration, W, of n-octanol for the LiBr aqueous solution in 20 steps over the range of 0-10 mass%. In order to get the effect of the addition of n-octanol on absorption, it is necessary to know the case without the addition of n-octanol (W=0) as a reference. The interference fringes in the LiBr aqueous solution, which were obtained when n-octanol was not added, are shown in Figure 1. The "t" in the figures represents time passage from the start of steam absorption. Figure 1 shows that the interference fringes moved in a parallel manner without any disturbances as time passed. The interference fringes were extremely dense near the solution surface, but the presence of convection was not observed. In addition, heat and mass transfer may occur mainly due to diffusion since the temperature distribution was also close to the error function.

Based on the temperature distribution and state of the interference fringes observed during the absorption experiments, it became evident that the absorption morphologies could be roughly divided into three types based on the alcohol concentration (W).

The first type was seen in the range of $W<0.01$ mass%. The temperature distribution in the case of $W=0.005$ mass%, which was obtained by adding a small amount of n-octanol, was nearly the same profile as compared with the one obtained in the case of W=0. Within the range of W<0.005 mass%, the addition of n-octanol barely contributed to the enhancement of absorption. However, along with an increase in W, the temperature at the solution surface rose gradually, and starting around W=0.01 mass%, an interfacial disturbance phenomenon was observed in the absorption process.

The second type was seen in the range of 0.01 mass% <W<2 mass%. Within this range of W, an interfacial disturbance phenomenon was observed near the surface of the LiBr aqueous solution. These disturbances started immediately after the initiation of absorption. With regard to temperature distribution, the temperature was highest at the surface of the solution while the concentration distribution was smallest at the surface of the solution making the density smaller towards the surface. Accordingly, the interfacial disturbance, observed immediately after the initiation of absorption, could not have been caused by Rayleigh convection based on buoyant forces. Rather, Marangoni convection based on the imbalance of the surface tension produced by the addition of n-octanol immediately after absorption was the cause. The interfacial disturbance had a tendency to become increasingly violent along with increasing W. But within the range of 0.1-1 mass%, the temperature distribution was almost consistent with the observation result of the interference fringes, and the interfacial disturbances were most violent in

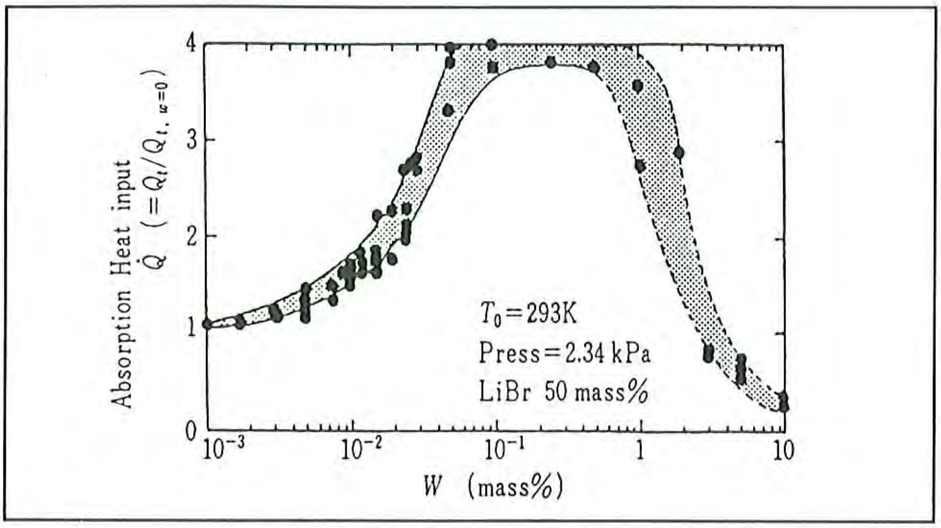

Figure 4. Evaluation of the absorption enhancement effect using absorption heat input at 360 sec

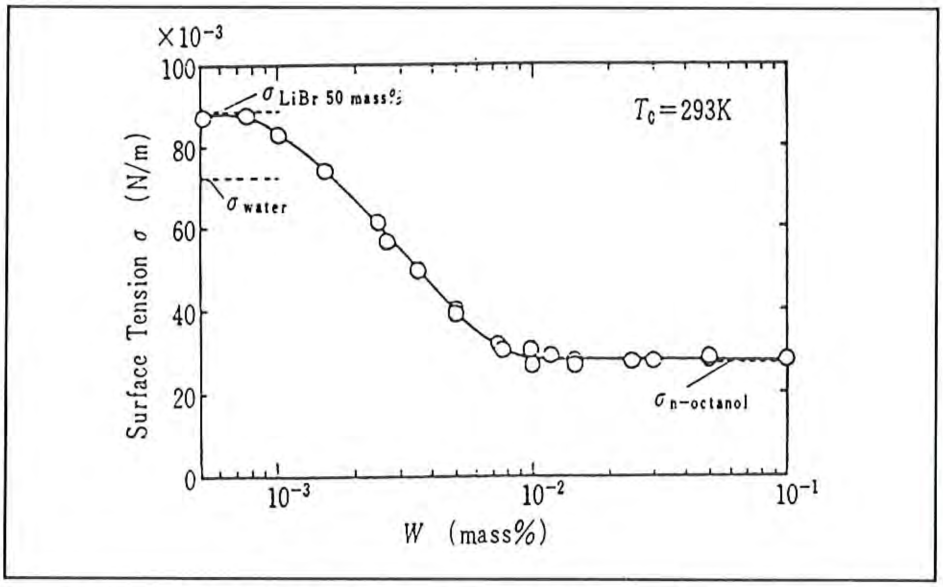

Figure 5. Measured result of the surface tension of the LiBr aqueous solution with 50 mass%, which was produced by the addition of n-octanol

Octanol $C_8H_{17}OH$				dyn/cm
	n-Octanol	2-Octanol	3-Octanol	4-Octanol
Surface tension σ_2	26.71	25.83	25.05	24.52
Interfacial tension σ_3	366	15.01	25.26	32.21
$\sigma_2 + \sigma_3$	30.37	40.84	50.31	56.73
Inducement of the Marangoni convection	Yes	Yes	No	No
Decanol $C_{10}H_{21}OH$			dyn/cm	
	n-Decanol	2-Decanol	3-Decanol	
Surface tension σ_2	27.79	26.82	26.28	
Interfacial tension σ_3	4.69	12.79	25.09	
$\sigma_2 + \sigma_3$	32.48	39.61	51.37	
Inducement of the Marangoni convection	No	No	Yes	

Table 1. Measured values of surface tension σ_2 of the higher alcohol and the interfacial tension σ_3 between 50 mass% LiBr aqueous solution and the higher alcohol

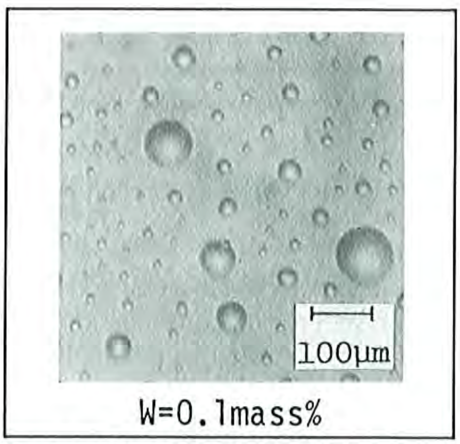

Figure 6. Microscopic photos of the surface of the LiBr aqueous solution

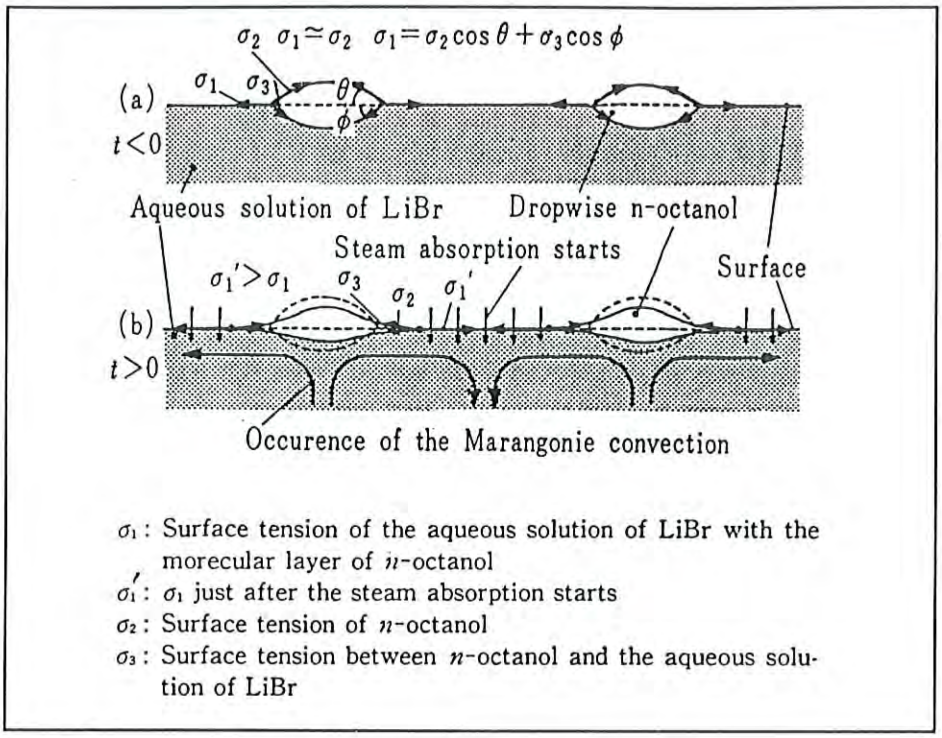

Figure 7. Model of the mechanism generating Marangoni convection

this range. On the contrary, when W was greater than 1 mass%, due to an increase in the area of the solution surface covered by the liquid film of n-octanol, interfacial disturbances were reduced considerably.

Figures 2 and 3 provide the photos of interference fringes and temperature distribution for the case W = 0.1 mass%. The photo (a) in Figure 2 clearly reveals the generation of convection layers near the surface immediately after the start of absorption. This strong convection was observed in all the photos of Figure 2. Figure 2(d) in particular showed convection that flowed in the vertical direction. As seen in Figure 3, there was a tendency towards uniform temperature distribution in the convective layers, due to the presence of strong convection in the vertical direction.

In the range of W > 2 mass%, n-octanol covered the surface of the LiBr aqueous solution completely in the liquid film state. Due to the fact that n-octanol is almost insoluble in water, only a very small amount of steam was absorbed.

Figure 4 was drawn to evaluate the absorption enhancement effect of W. It shows that in the 0.01-0.05 mass% range of W, absorption is enhanced considerably, and when W is 0.05-1 mass%, compared with the case without the addition (W = 0), absorption heat input was increased approximately four times.

Based on the experimental result using n-octanol described above, it was clear that when n-octanol was added in concentrations higher than its predicted solubility in the LiBr aqueous solution, violent convection was generated near the solution surface immediately after the initiation of steam absorption. Thus the absorption was enhanced greatly. In the vapor absorption process in the case of no addition (W = 0), which is shown in Figure 1, if the density inversion region in the direction of depth x is not present, then the generation of convection at values of W > 0 may be attributed to the

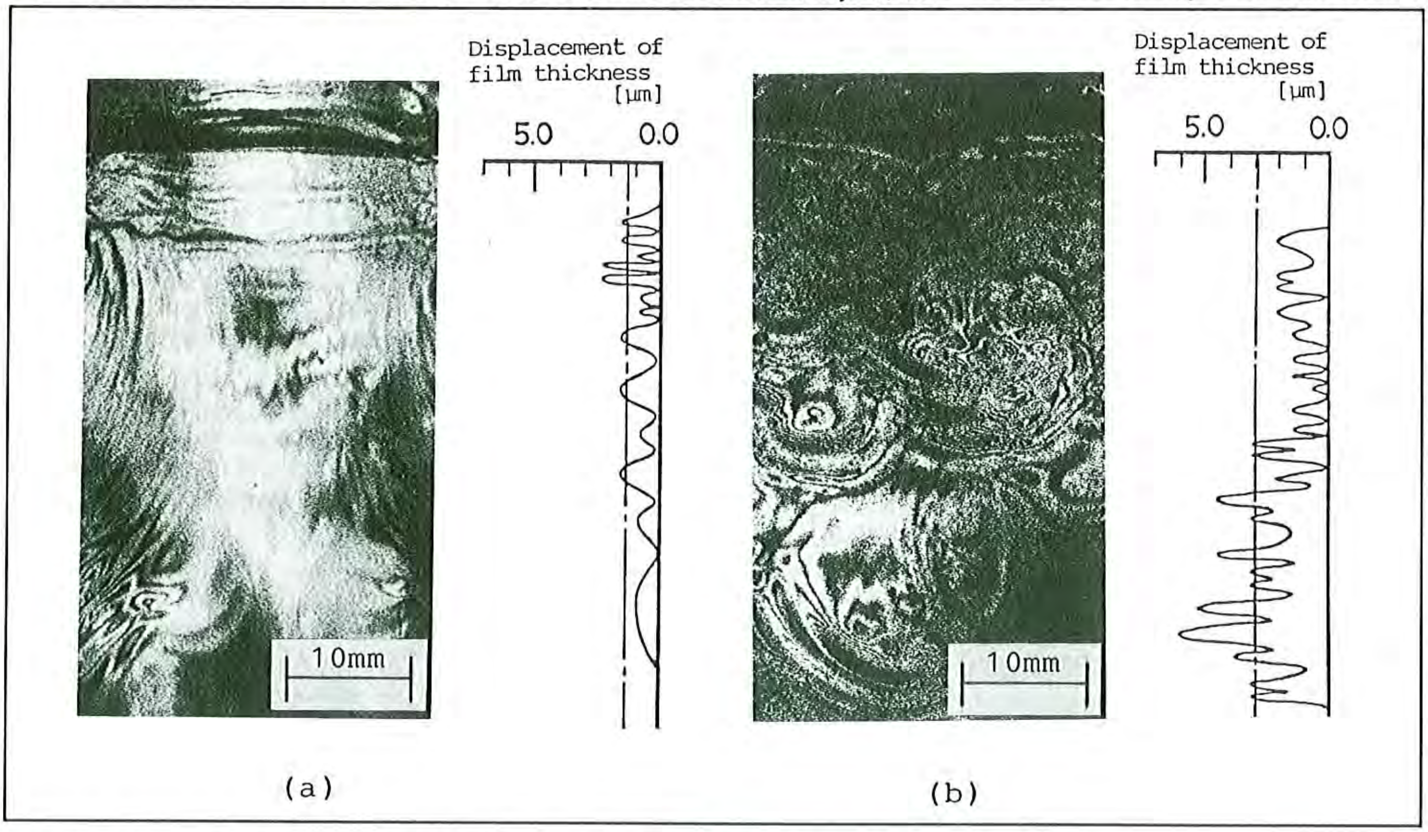

Figure 8. Representative interferogram of vertical falling film [(a): without n-octanol vapor, (b): with octanol vapor]

sudden change in the surface tension at the solution surface at the initiation of absorption, and to the imbalance created thereafter. In order to obtain the properties of the solution surface and the state of existence of n-octanol, the surface tension was measured and the solution surface was observed using a microscope. Figure 5 shows the results of the surface tension measurement. Since the value remained constant even when W was further increased, W=0.01 mass% was believed to be the solubility limit of n-octanol for the LiBr aqueous solution of 50 mass%. On the other hand, with regard to the results of the solution surface observation, a difference from the case without any addition was not observed within the range of W<0.01 mass%. However, in the range of W>0.01 mass%, the distribution of drops of n-octanol not dissolved into the LiBr aqueous solution was observed on the solution surface. Microscopic photos taken in the case of W=0.1 mass% are shown in Figure 6.

When the results shown in Figures 4 and 6 are taken into consideration, it can be concluded that the presence of n-octanol in the drop wise state at the surface of the solution contributed greatly to the generation of violent Marangoni convection. At this point, as shown in Figure 7(a), it was assumed that the absorption of water vapor began under the condition of the presence of n-octanol drops on the surface of the solution. Steam was absorbed on the surface of the solution that excluded the droplets as shown in Figure 7(b), and as a result of the rapid increase in the surface tension (surface tension of water: 72×10^{-3}N/m, 293K) near the droplets, an imbalance of the surface tension occurred. This imbalance of forces generated the Marangoni convection. From the model shown in Figure 7, the condition for generating Marangoni convection can be given as $\sigma_1 > \sigma_2 + \sigma_3$. To verify the validity of this model, isomers of the higher alcohols were used as additives and investigated.

Effects of the isomers of octanol and decanol on absorption enhancement

These steam absorption experiments were conducted in the same manner as described above. Octanol and decanol were selected as the isomer additives. The experiments were carried out by adding 2-octanol, 3-octanol, 4-octanol, n-decanol, 2-decanol, and 3-decanol with W=0.1 mass%. The interferometric technique was also employed to visualize the absorption phenomena. As a result of the steam absorption test, the interfacial disturbance as seen in the case of n-octanol was also observed in the cases of 2-octanol, n-decanol, and 2-decanol. However, in the cases of 3-octanol, 4-octanol, and 3-decanol, there was no absorption enhancement. And in all cases, except with the addition of 4-octanol, the presence of droplets could be recognized on the LiBr aqueous solution. The measurements of the surface tension and interfacial tension between the 50% LiBr aqueous solution and the surfactants, which are denoted σ_2 and σ_3 in Figure 7, respectively, were carried out by using the vertical plate method. The results are listed in Table 1.

Note that although the surface tensions σ_2 take nearly the same values among the isomers, the interfacial tensions σ_3 are remarkably varied and strongly affected by the molecular structure of the higher alcohol. For example, σ_3 of 3-octanol takes on a value nearly 7 times as large as the one measured for n-octanol. It is clear from the model presented in Figure 7 that the interfacial tension "σ_3" is strongly affected, thereby inducing Marangoni convection. When the summations of σ_2 and σ_3 for each surfactant listed in Table 1 are taken into consideration, it can be concluded that σ_1 takes on a value in the range of 40-50 dyn/cm. The significance here is that there is finally a method to characterize this elusive phenomenon.

Visualization of Marangoni convection in a vertical falling film

Further effort was made to visualize the Marangoni convective behavior in the process of steam absorption into a vertically falling film of LiBr aqueous solution with the addition of n-octanol.[3] A double-pulsed holographic interferometer was adopted for the flow visualization of the 0.5mm thick falling film.

Representative interferograms are shown in Figure 8. From the comparison between these interferograms with and without the addition of n-octanol, significant differences in the fringe pattern can be clearly seen. In the case without the addition, the interference fringes are scarcely observed in the entire visualized region of falling film. This indicates that the flow pattern of the film can be smooth. However, in the case with the addition, complicated shapes of interference fringes are observed in the entire region of the falling film. It should be emphasized here that the macroscopic Marangoni convective cells which are clearly seen at irregular positions have a diameter of nearly 10mm. This information will be highly important in designing the configuration of high efficiency absorber tubes for vertical falling film type absorber.

Conclusion

This article summarized the recent research done by the author in the area of heat and mass transfer enhancement. It was shown that surfactant additives in quantities higher than their solubilities to the absorbent solution were distributed as droplets on the solution surface. These droplets were the initial cause of violent Marangoni convection. A model of the mechanism generating this Marangoni convection was presented. Through experiments using various isomers of octanol and decanol as the additives, it was shown that the inducement of Marangoni convection is strongly affected not only by the presence of droplets on the solution surface but also by the value of the interfacial tension.

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R&D of Absorption and Adsorption Heat Pumps and Heat Transformers in the CEC Programme

This paper was presented at the CEC-British Gas International Workshop in London, April 1988, and is reprinted here with permission.

Introduction

In the EC programme "rational usage of energy" the heat pump as a system with a high potential of energy conservation gets much attention. This programme supports high risk R&D on topics which have a high potential for energy saving and pollution abatement; it tries to coordinate R&D in Europe and to activate joint activities in the EC. For heat pumps the aim is to increase the efficiency and reduce the cost. The programme 1985-1988 gives a special weight to R&D on absorption systems and on exploratory research of adsorption systems. In this paper, a short overview is presented of the projects related to absorption and adsorption systems. In total, 26 projects on heat pumps are carried out; 16 are sorption systems. These projects are listed at the end of this article, and project numbers are referenced throughout.

Fluid pairs and adsorbents/refrigerants

The activities of the research on new fluid pairs has resulted in some interesting combinations (0024). It is shown that the criteria should be related to the field of application. The most promising fluid pairs are tested in a heat pump. To clarify the possibilities of the adsorption systems a number of directly coordinated contracts are carried out (0097, 0099, 0100, 0101). The following combinations are considered: active carbon/methanol and zeolith/water. The tests include measurement of the heat conductivity, corrosion, etc. Special attention is given to the stability, aging, and the possibility to increase the heat conductivity by adding aluminum and steel powder to the adsorbent. The possibility to increase the heat conductivity of salts such as $MnCl_2$, etc., for the absorption of NH_3 is the aim of another contract (0023) in this area.

Components

The optimization and increase of performance of the major components is an important development area, particularly in view of cost reduction for heat pumps and heat transformers. In the field of adsorption systems with periodical cycles, the design of the adsorber is important; this is the aim of a contract (0098) which is complementary to the industrial heat pump development in project 0100. The optimization of the absorber, and in particular of the heat exchanger, is the aim of contract 0041; this work should result in an increase of the heat transfer by a factor of 2 to 3. The use of an expert system (0029) for the selection of heat exchangers will result in a better performance of the whole system.

Systems with storage

Besides the adsorption systems, which are always periodical, also absorption systems can be made suitable for storage by making them periodical. In one of the contracts (0019) a periodic absorption heat pump with LiBr-methanol as fluid pair is applied and water is added to prevent crystallization. This activity has resulted in the development of the main components and the design of a special type of absorber. The integration of storage and advanced design of the regenerator/condenser and absorber/evaporator has resulted in a very flexible heat pump, working in different modes (0022) with LiBr-water as fluid pair. The prediction of the yearly performance of the periodical systems is difficult and extensive usage is made of mathematical models supported by experimental measurements.

Two-stage systems

In this area, a number of industrial developments are of interest. A two-stage heat pump for the generation of heat at 120°C has been developed, to be integrated in installations for paper production (0035); LiBr-water is used as a fluid pair.

The combination heat pump/heat transformer for temperatures up to 100°C (generator 165°C) is very flexible and is expected to find a broad application (0032). The applied fluid pair is LiBr-water and the design of the components has resulted in a horizontal absorber. Special attention is given to the wetting of the pipes.

The development of a two-stage heat transformer of 20 kW and the introduction of a new fluid pair is the aim of another interesting contract (0025). From experience, it is learned that the introduction of new refrigerants, for instance TFE, is hampered by environmental regulations. An interesting development is the integration of a two-stage half open absorption heat pump in a 4-stage evaporator (0138) for the production of concentrated juice and skimmed milk, etc. Cost calculations show that NaOH is the optimal absorbent. Besides the introduction of the heat pump, the possibility to apply a higher inlet temperature of the drive steam results in an extra reduction of the required energy.

Compression heat pumps

To complete this overview, CEC contracts on compression heat pumps will be briefly mentioned. The research on the impact of lubrication oil on the performance (0017) is continued, including the testing of a new cycle. R134a is used as refrigerant.

The development of combustion engine driven compressors is the aim of contracts 0016 and 0020. Special attention is given to the impact on the environment.

A new rotating oil free compressor (0036) has reached the testing stage. The development of a high speed electric motor (up to 30,000 rpm) opens the possibility for small turbo compressors in heat pumps. The potential for nonazeotropic refrigerant mixtures in industrial high temperature heat pumps is large and the development of such systems is important (0125). This project combines testing and an economic evaluation. This activity is strongly supported by a very broad market study (0127).

An expert system (0130) is being developed aimed at adapting the heat pump system to the requirements of the building (e.g., load and its fluctuation in time); this can lead to considerable energy savings. It has been established that under certain conditions, on/off operation with short cycle times (20-60 sec) can improve heat pump performance by as much as 20% (0021).

Future developments

The economic application of heat pumps is today under heavy pressure due to the low energy price and the low exchange rate of the dollar. The high investment cost and uncertainty about the future energy price make users reluctant to apply heat pumps. The potential for energy savings with heat pumps is still attractive and the field of applications is broad. It is expected that the future development is determined by the following trends:

- Due to the technology development, sorption systems can now be applied in an increased temperature range
- Increase of capacity and performance of the components
- The introduction of two-stage systems and herewith coupled advanced and reliable control systems to make the system less sensitive to disturbances
- More flexible systems are possible with combinations of heat pumps, heat transformers and refrigeration systems
- The integration of sorption systems in processes and the development of industrial sorption systems which are directly coupled to a specific process.

R&D contracts on heat pumps and heat transformers

EN3E-0016-D Research for drastic reduction of exhaust emissions of I.C. engine driven heat pumps. Contractor: Fichtel & Sachs.

EN3E-0019-D Development, investigation and process simulation of single- and multi-stage periodically gasfired absorption units. Contractor: RWTH, Aachen.

EN3E-0020-D Entwicklung eines erdgasbetriebenen Verbrennungsmotors und integriertem Kolbenkompressor zum Betrieb in Waermepumpen. Contractor: Ficht GmbH.

EN3E-0021-DK An investigation of short running time. Contractor: European Heat Pump Consultors Ltd.

EN3E-0022-F Une pompe à chaleur à absorption à fonctionnement cyclique avec stockage incorporé de l'exergie adaptable aux divers climats d'Europe. Contractor: CNRS, Nancy.

EN3E-0023-F Stockage de l'énergie thermique par pompe à chaleur utilisant les composés d'insertion du graphite. Contractor: ENSEEG

EN3E-0024-D Investigation of heat and mass transfer of new working fluids systems in absorption heat pumps. Contractor: Institut fuer Angewandte Thermodynamik und Klimatechnik.

EN3E-0025-D Development of an advanced heat transformer and investigation of the combination heat transformer absorption heat pump. Contractor: GEA

EN3E-0029-DK The development of expert systems for the application of heat exchangers and heat pumps in energy conservation. Contractor: IRD

EN3E-0032-D Absorptions Waermepumpentransformator. Contractor: Technische Universitaet Muenchen, Physik Dept.

EN3E-0035-D Entwicklung einer Hochtemperatur-Absorptionswaermepumpe zur industriellen Abwaermenutzung und Nutzwaermeerzeugung bei Temperaturen von 100°C bis 130°C. Contractor: Battelle

EN3E-0036-GR Development and optimization of a universal rotating machine used as oil-free compressor with organic fluid. Contractor: General Supply Co. Ltd.

EN3E-0041-F Absorbeur gaz-liquide avec échangeur intégré pour réactions à forte thermicité. Contractor: CRIFIC, Nancy

EN3E-0097-F Dynamic study of solid adsorption heat pumps. Experiments and numerical simulation. Economic analysis for development. Contractor: CNRS, Orsay

EN3E-0098-F Echangeurs de chaleur utilisés das les cycles à adsorption. Contractor: CETIAT

EN3E-0099-F Etude en dynamique de pompes à chaleur à adsorption solide. Contractor: Université de Technologie de Compiègne

EN3E-0100-F Etude en dynamique de pompes à chaleur à adsorption solide. Analyse technico-économique des possibilités de développement. Contractor: Brissonneau & Lotz Marine S.A. (BLM)

EN3E-0101-I Dynamic study of solid adsorption heat pumps. Experiments and numerical simulation. Economic analysis for development. Contractor: CNR

EN3E-0125-F Etude de pompes à chaleur haute température (>110°C) à compression et mélanges de fluides non azéotropiques. Contractor: ELF Aquitaine

EN3E-0127-B Etude de pompes à chaleur haute température (>110°C) à compression et mélanges de fluides non azéotropiques. Contractor: Katholieke Universiteit Leuven (KUL)

EN3E-0128-UK Improvement of COP of vapour compression heat pump by using a new cycle. Contractor: University of Ulster

EN3E-0130-NL The development of expert systems for the application of heat exchangers and heat pumps in energy conservation. Contractor: Comprimo B.V.

EN3E-0137-F Prototype de moteur électrique à vitesse variable et grande vitesse. Contractor: Société BERTIN & Cie

EN3E-0138-GR Absorption driven multiple effect evaporator. Contractor: HVAC Eng. Saving Systems

EN3E-0157-F Market assessment for absorption heat pumps and heat transformers. Contractor: MAC

EN3E-0164-E Development of a prototype gas heat pump. Contractor: BUTAMO S.A.

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Development of Air-Cooled Small Sized Gas Absorption Chiller-Heater

By considering the available research and development work on air heat exchangers with excellent air heat transfer characteristics and the methods for exchanging heat with air, it was concluded that the completion of an air-cooled absorption system by using a working medium of water-lithium bromide group substances was the shortest way to implement a successful unit under the present market situation. This is the approach being used in this development project which started in October 1984. The work is being sponsored by Tokyo Gas Co., Osaka Gas Co., Toho Gas Co., and Hitachi, Ltd. The new type absorption system will be put on the market in December 1988. With this new double-effect cycle using water-lithium bromide group substances, a successful air-cooled gas absorption chiller-heater has been developed. This was previously considered to be impossible.

Background for the implementation of an air-cooled absorption system

In the absorption system, the use of ammonia-water group substances as working fluids can be considered in order to allow implementation of an air-cooled system. However, it is quite difficult to put these working fluids to practical use in Japan because of the poisonous and volatile properties of ammonia. For this reason a number of research and development projects which employed freon were undertaken. However, because of the drawbacks of this working medium, such as low cooling COP and large pumping power for circulation, freon has not been put to practical use. Although there were some other instances of research which used alcohol working media, these still remain in the breadboard stage.

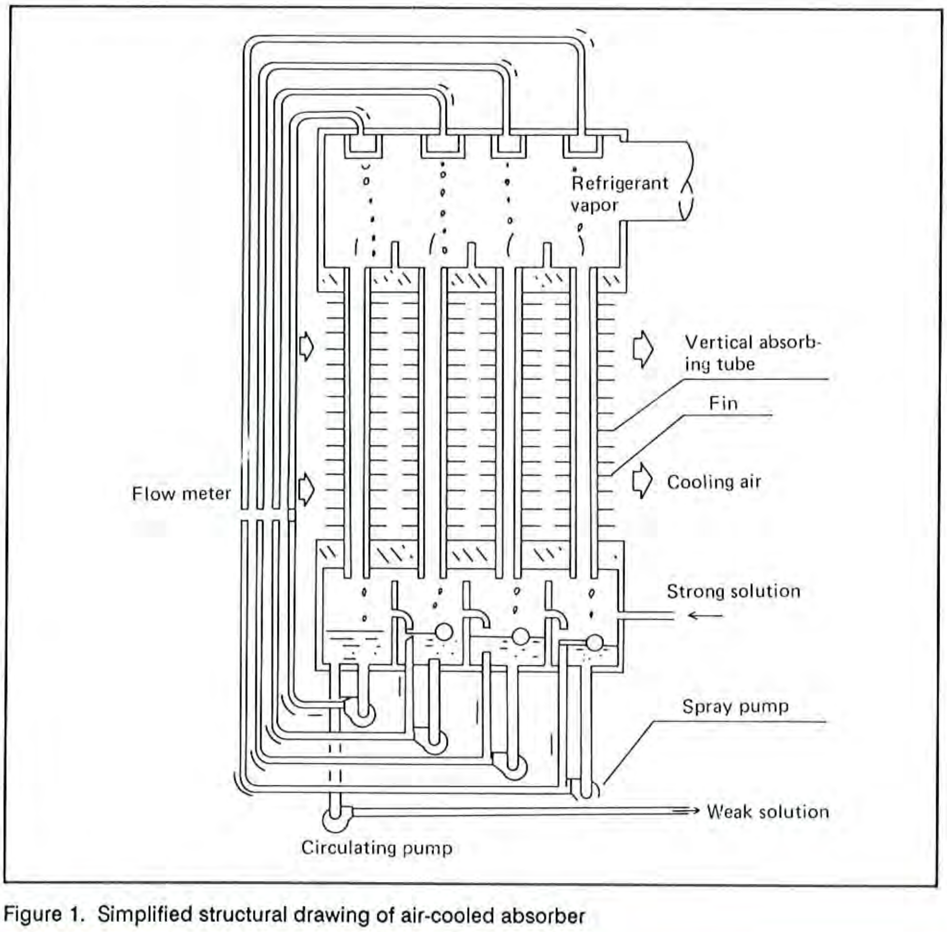

Figure 1. Simplified structural drawing of air-cooled absorber

Problems in constructing an air-cooled system

In order to design an air-cooled absorption system for the water-lithium bromide group, the only combination which puts the double-effect cycle to practical use, the difficulties listed below had to be overcome.

Cycle difficulties--In the case of an air-cooled system the air outlet temperature is 40 to 50°C so that the cooling cycle (absorber/condenser) temperature is 50 to 55°C, 10 to 15°C higher than the water-cooled absorber temperature of 0°C. For this reason the concentration of the absorbing solution rises 5 to 8% and the temperature inside the high-temperature regenerator is about 50°C higher.

Accordingly, the working pressure exceeds atmospheric pressure and the absorbing solution reaches the crystallization line and as a result cannot be operated under these conditions. In order to realize the absorption system, it was decided that operating parameters similar to that of a water-cooled system must be achieved.

Heat transfer difficulties--In the case of a water-cooled system where heat is exchanged between the cooling water and the lithium bromide solution, the rate of heat transfer on the water side is about 1,030 kcal/m^2·h·°C. In contrast, for an air-cooled system the rate of heat transfer on the air side of the absorber is about 21 kcal/m^2·h·°C in terms of the standard heat transfer area on the air side. If the air-side heat transfer area is 15 times as large as the absorbing-solution-side heat transfer area, this value will be equivalent to about 300 kcal/m^2·h·°C in terms of the standard absorbing solution heat transfer area. Therefore, to insure practical temperatures in the absorber, a heat transfer area which is three times as large as that of the water-cooled system is neces-

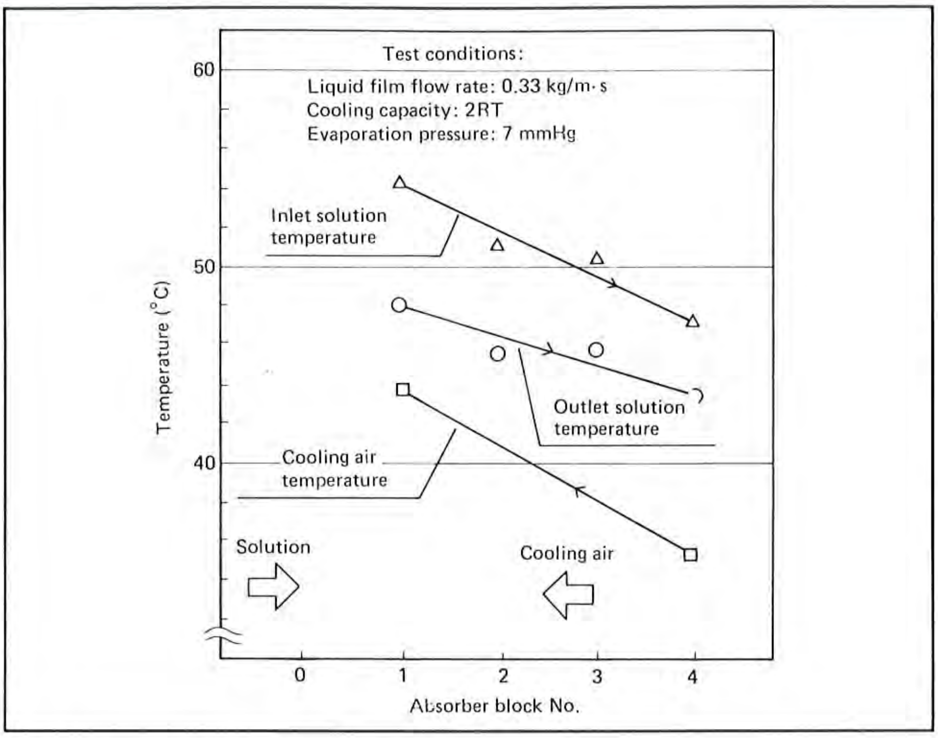

Figure 2. Air-cooled absorber temperature changes

sary. Also, the volume of air needed for cooling of the double-effect type absorption cycle is 1.5 times as much as that of an electrically driven compression cycle air-cooled system. To solve these difficulties, it was necessary to develop new technology in order to complete a compactly built air-cooled system.

Technology developed

Absorption improvements

The typical absorption cycle uses the absorbing solution circulating cycle which has conventionally been called the "series flow cycle." This operates as follows: the diluted solution from the absorber is sent by the solution pump to the high-temperature regenerator. By utilizing the difference in pressure, it flows from the low-temperature regenerator in series to the absorber. In this unit a parallel flow is employed. Its process is as follows: the diluted solution from the absorber is divided by the solution pump into two portions; one flows to the low-temperature regenerator and the other flows to the high-temperature regenerator. This flow arrangement dilutes the concentration of the solution in the low-temperature regenerator and thereby lowers its pressure and temperature compared to the solution in the series cycle.

Cooling capacity		kW	35	70	105
Heating capacity		kW	31	63	94
Chilled/hot water	Chilled water temp.	°C		12.5 - 7.0	
	Hot water temp.	°C		55.0 - 60.0	
	Circulating water rate	m^2/h	5.5	11.0	16.5
Cooling air inlet temp.		°C		35.0	
Electric power	Power source	V		3-phase 200/200	
	Frequency	Hz		50/60	
	Consumption, cooling/heating	kW		5.4/0.1	
Gas consumption	Type			13A	
	Pressure	mmAq		200	
	Gas consumption cooling/heating	Nm^3/h	3.0/3.0	6.0/6.0	9.0/9.0

Table 1. Specifications for air-cooled gas absorption chiller-heater

Design of the air-cooled absorber

The design of an air-cooled absorber depends on the heat exchange between the absorbing solution and cooling air via a heat transfer surface. In this design, the liquid film flows down inside the tube and is cooled by means of the cooling fin installed on the outer surface of the tube. Figure 1 shows the experimental air-cooled absorber. The air-cooled absorber consists of a vertical absorbing tube, whose inner surface is smooth. On the outer surface aluminum fins are installed at right angles to the tube. The fin is a plate fin with multi-stage slits. This structure, although its flow resistance is about 1.3 times as large as that of the conventional plate fin, has a heat transfer rate eight times as large.

The heat exchanger has an upper header which supplies refrigerant steam and absorbing solution and a lower header having a vertical absorbing tube and a spray pump which are connected to the upper header. Both headers are combined into a block and four of such blocks are arranged in the direction of the cooling air flow. The condensate from the regenerator flows into the block on the cooling air outlet side first, then flows down the inner surface of the vertical absorbing tube and after exchanging its heat with the cooling air to have itself cooled, it absorbs refrigerant vapor to have itself diluted. It is then sent to the block on the cooling air inlet side. The absorbing liquid, which has sequentially been sent to each of the blocks and diluted, is sent by the solution pump to the regenerator. As described above, the air-cooled system is constructed as a 4-stage scattered type absorber. Considering the relation between the cooling air and absorbing liquid temperature, it may be considered as a 4-pass cross flow heat exchanging system.

To prevent spray pump cavitation the liquid sink at each stage is equipped with a float valve in order to control the amount of absorbing liquid supplied to the next stage.

Figure 2 shows the performance capabilities of an air-cooled absorber by means of the changes in temperature. According to this figure, the temperature of the absorbing solution at the outlet of the air-cooled absorber is about 44°C which approximates the value assumed by the water-cooled cycle. Therefore, with a cooling air inlet temperature of about 35°C, the temperature and concentration values existing in a water-cooled absorber can be approximated, making it possible to realize the double-effect cycle.

Design of the air-cooled condenser

In the case of a water-cooled system, the cooling water outlet temperature reaches about 38°C and the temperature of the condensed refrigerant is 42 to 43°C. For an air-cooled condenser the transfer of the condensing heat is done at a fixed temperature. By allowing sufficient area the liquid can be cooled to a temperature which approximates the cooling air outlet temperature, thus posing no problems as far as the temperature is concerned. To limit the physical size of the heat exchangers, "super-slit" fins were used to increase the fin efficiency.

Evaporator efficiency enhancement

As a result of examining various combinations of refrigerant-side heat transfer surfaces and water-side heat transfer surfaces, it was found that when the refrigerant-side surface was pin-shaped and the water-side surface was corrugated, the highest heat transfer rates could be attained. These were five times larger than those of a unit whose inner and outer tube surfaces were smooth. By using this highly efficient tube it was possible to raise the evaporating temperature of the refrigerant from 4.5°C to 5.5°C while still obtaining the same cooling water outlet temperature. For this reason the evaporator pressure was raised from 5 mmHg to 8 mmHg with the result that the performance of the air-cooled absorber increased.

The final product and its benefits

With an air-cooled type gas absorption chiller-heater being available, the following benefits can be expected:

-- Economic advantage by eliminating attachments such as the cooling tower, cooling water pump, and piping installations.
-- Simpler installation due to smaller space requirements.
-- Convenience and reliability. Since the need for cooling water along with its maintenance requirements has been eliminated, the reliability level of the equipment has been enhanced.
-- Opening of the air-cooled market to absorption units by meeting the requirements placed on air-cooled absorbers. In cases when replacement of the existing absorbers occurs, it is most suitable as a heat source machine having a simple installation.

Specifications

The air source unit is available in three models with cooling capacities of 10, 20, or 30RT. By installing multiple units, cooling capacities of up to 120RT are achievable. The COP in terms of the standard delivery of high-temperature heat is 0.92, and the heating efficiency in terms of same standard is 0.83. The weight during operation is 2000 kg. Compared with the external dimensions, width x depth x height, of the 20RT-class unit by the same manufacturer, the dimensions of the air-cooled system are 2866 x 1843 x 2431 while those of the air-cooled compression system are 2250 x 1850 x 2300, showing that all of these air-cooled systems are similar in dimension. Table 1 lists the specifications for the equipment.

The cover photo shows the external appearance of the air-cooled small-size absorption chiller-heater with a capacity of 20RT. As shown, the cooling air enters on two side surfaces and one back surface and exits at the upper part of the equipment. Six fans circulate the air in this manner.

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Activities of the New Research Project on Advanced Absorption Heat Pumps in the Heat Pump Technology Center of Japan

The new research project on Advanced Absorption Heat Pumps was organized at the Heat Pump Technology Center of Japan in February 1988. The main objective of this project is to develop a next-generation gas-fired absorption heat pump for space heating and cooling purposes. This article describes the present activities of this new research project.

Introduction

Recently absorption heat pumps using water, alcohol, and ammonia as representative working fluids have received a great deal of attention due to the advantage of their energy savings characteristics. This attention has increased rapidly due to the international problem of ozone depletion by CFC refrigerant emissions. In Japan, most absorption machines use H_2O/LiBr as a typical refrigerant/absorbent combination. Currently, gas-fired absorption water chiller-heaters using a double effect cycle have a large market share in space cooling and heating. Although it

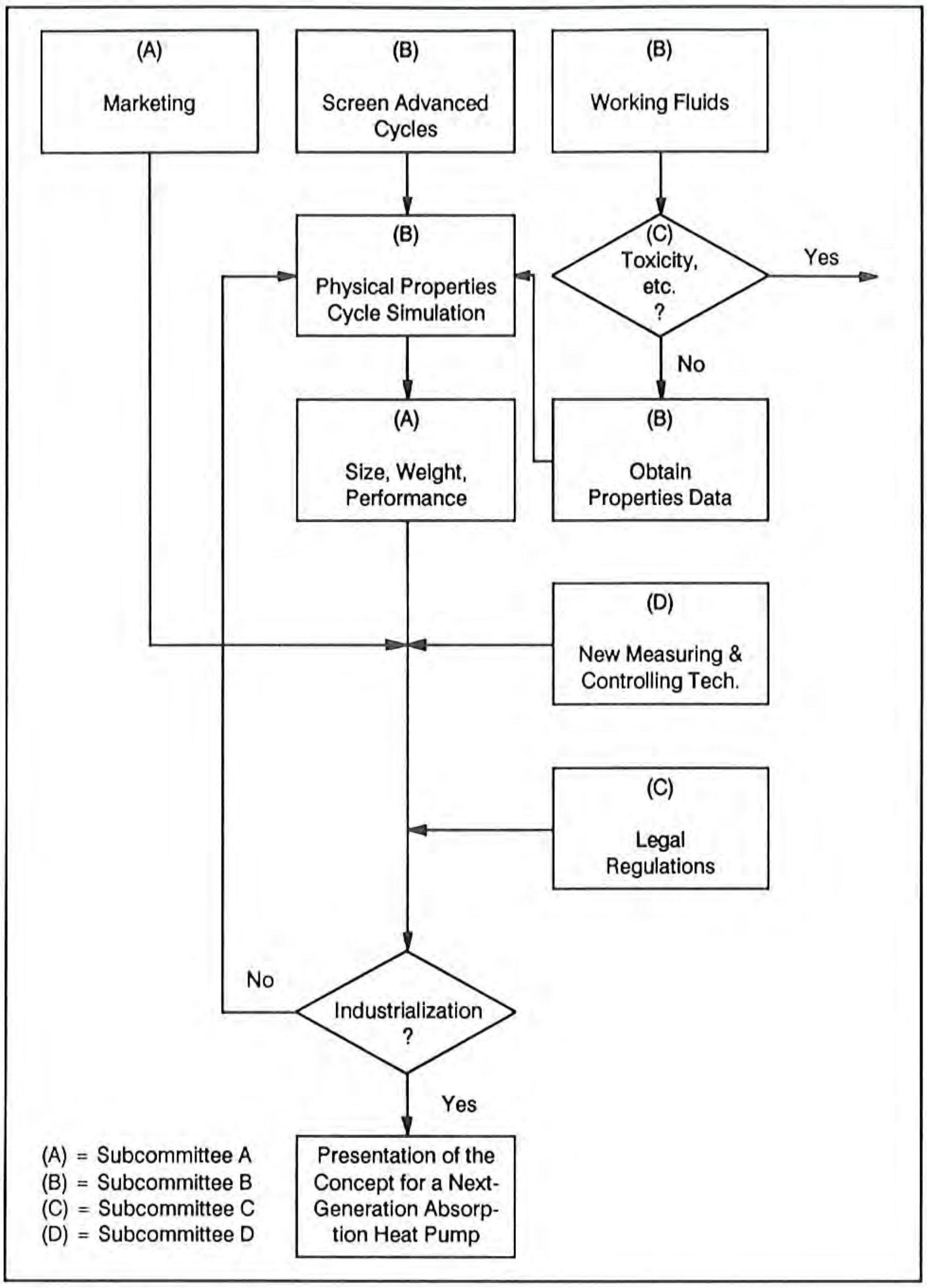

Figure 1. Flow chart of the tasks

Advanced Cycles \ Refrigerant / Absorbent		R-22: E-181 DMETEG (Dimethylether tetraethylene glycol)	R-22: E-141 DMEDEG (Dimethylether diethylene glycol)	R-123a: ETFE (Ethyl tetrahydro furfurylether)	TFE: E-181	TFE: NMP (N-Methyl - 2-Pyrrolidone)	H_2O: LiBr
#1	GAX Generator/absorber heat exchange	●	●	◉	●		
#2	GAX-R Generator/absorber heat exchange with the utilization of rectification heat		●		●	●	
#3	RESORPTION Resorber/desorber	●					
#4	HYBRID 2-STAGE Includes the concept of the dual cycle	● ← Low temp stage					→ ● High temp stage
				● ← Low temp stage			→ ● High temp stage
					● ← Low temp stage		→ ● High temp stage
						● ← Low temp stage	→ ● High temp stage

Table 1. Appropriate working fluid pairs and advanced cycles

is said that the H_2O/LiBr absorption machine is already mature, a strong desire for the development of an air-cooled machine still exists in Japan.

With this background, the new research project on Advanced Absorption Heat Pumps was organized at the Heat Pump Technology Center of Japan (HPTCJ). This research project started in February 1988 with 17 absorption experts from universities, government institutes, gas companies, and manufacturers.

The overall objective of this project is to present a concept of a next-generation gas-fired absorption heat pump for relatively small-sized commercial applications using advanced cycles with working fluids whose properties are reasonably well known. Target COP's are 1.5 in heating mode and 0.8 in cooling mode. These goals refer to air-to-air heat pump operation at the rating conditions of 7°C outdoor ambient temperature in the heating mode and 35°C ambient temperature for the cooling mode.

As a first step in accomplishing this objective, literature data and advanced cycles were surveyed and investigated by participating members on a task-sharing basis. Now the matrix of appropriate working fluid pairs and advanced cycles are being determined, and the cycle simulations are being carried out to evaluate the performance.

Organization

The 17 participating members are divided into four sub-committees (A, B, C, and D) in order to share the tasks. The main task for each sub-committee is shown below.

Sub-committee A: Marketing
- Cost analysis
- Performance
- Determination of specifications

Sub-committee B: Research & Development
- Advanced cycle
- Working fluid pairs
- Cycle simulation
- Proposals for research subjects

Sub-committee C: Industrialization
- Legal regulations

Toxicity
High pressure
Environmental effects
Evaluation for industrialization

Sub-committee D: Measuring & Control Technology
Sensors
Visualization
Concentration Measurement
Propose appropriate measuring and controlling technology

Procedure for the evaluation of the project

Each sub-committee is working in co-operation with the others. Figure 1 shows a flowchart of the procedure to propose the recommended system.

Working fluids survey

Working fluid pairs play a very important role in heat pump performance. They are also closely related to the heat pump cycles. Since many reports on refrigerant and absorbent pairs have been published in the world, an effort was made to screen and evaluate the appropriate refrigerants and absorbents by this research project. The first screening of refrigerants and absorbents has been performed.

Matrix of promising working fluids and advanced cycles

Taking their heat of evaporation into consideration, water, ammonia and methylamine should be selected as effective refrigerants. If ammonia could be selected for this project, it will be highly desirable to extend the possibility for the applicable range to advanced cycles. However, it is well known that the toxicity and explosiveness of ammonia have made the commercialization of machines of this type virtually impossible in Japan. The chemical investigation also showed that methylamine might have a higher toxicity than ammonia. Therefore, these refrigerants were not selected in this project.

The refrigerants R22 and R123a are receiving attention as CFC alternatives due to their possible application below 0°C. TFE (trifluoroethanol) should also be selected due to its relatively large heat of vaporization and high thermal stability.

From the total considerations described above, the matrix of appropriate working fluid pairs and advanced cycles was determined as shown in Table 1.

Conclusion

This article gave an overview of the activities of the research project on Advanced Absorption Heat Pumps organized in Japan. By the end of September 1988, the cycle simulations have almost been finished. The final concept of the next-generation absorption heat pump will be presented by the end of December 1988.

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Diffusion Absorption Heat Pump

The paper deals with a Gas Absorption Heat Pump of the diffusion type, i.e., with no moving parts, noise or mechanical wear. The working fluids are water-ammonia and helium as inert gas. The design target is as follows: Hermetically sealed modules of 3 KW heating or 1 KW refrigerating performance. Temperatures: 53°C hot side, -3°C cold side. COP: 1.5 (neglecting flue losses, 8%, but not using latent heat of flue-gases). Cold side with secondary system (glycol-water fluid circulation). The unit contains less than 1 kg of ammonia; therefore, no regulations have to be fulfilled. The modules can easily be combined to bigger units of 3, 6, 9 ... KW performance. Simple control by either in-out regulation or varying the input. Dimensions of module: 56 x 24 x 190 cm. Several working prototypes have been built and tested. Performance and COP graphs which are based on practical tests will show that the above mentioned design target will be fulfilled. Based on the experience of millions of manufactured refrigerators of the absorption-type, a trouble free and service free life-time of more than 10 years can be expected from these units.

In the past, attempts made to solve the problems of absorption heat pumps (AHP) have almost all been with absorption refrigeration machines using mechanical solution pumps. These pumps are used successfully on large absorption cooling machines of 50-1000 kW and more. Miniaturizing such machines presents difficulties which involved the small inefficient solution pump. This led to the evaluation of the diffusion type absorption cycle (DAHP).[1]

To show that this evaluation was not a waste of time, here are the design targets and results:

	Targets (1982)	Results Achieved (1987)
COP	≥ 1.5	1.5
t_{hot}	≥ 50°	53°
t_o	≤ 0°	-3°
Amortizing time (including service costs)	≤ 10 yrs	as target
Noise	≤ 30 db	≤ 10 db
Change-over between hot and cold		as target

The sometimes rather difficult way to get these results is now described.

Absorption cooling units working with ammonia-water and hydrogen as auxiliary gas are well known. Millions have been built and are mainly used in domestic, camping and caravan refrigerators. They are powered electrically, by LPG, natural gas or kerosene.

The cooling performance of such a cooling unit is in the order of 20 to 50 watts in contract to 1000 watts required for a 3 kW heat pump. Contrary to the miniaturizing problems mentioned above, one now faces enlargement problems of the diffusion absorption units.

Sporadic attempts in this direction were already undertaken years ago. Servel Inc., for example, in 1937 manufactured a water-cooled, gas powered unit with the following specifications:[2]

Cooling performance:	1750 watts
Gas input:	9120 watts
Cooling water temperature:	24-35°C
Cabinet temperature:	+ 5°C
Auxiliary gas:	H_2
COP:	19.2%

These results, of course, are far from what is needed for a DAHP. But in the last 50 years, such important improvements have been accomplished that today completely new performance qualities are at our disposal.

Probably the most important step forward was the introduction of a completely new boiler, the so called 3x boiler. As a consequence of counterflow heat exchange between weak solution, rich solution and the vapor leaving the boiler, it became possible to re-introduce almost the total rectification heat usefully into the process. This improved the COP of the unit by not less than 50%!

Stierlin presented a paper on this boiler at the 12th International Refrigeration Congress in Madrid in 1967.[3] Figure 1 shows a cooling unit incorporating the 3x boiler of which hundreds of thousands have been produced for domestic refrigerators.

A further very important step was the introduction of the so- called multiflow evaporator-gas heat exchanger.[4] Stierlin presented a paper on this at the 13th International Refrigeration Congress in Washington in 1971.

The principle of this component lies in the ability to split up the auxiliary gas circuit into a great number of parallel channels. Each upgoing channel is connected at the top to one and only one downgoing channel, thus forming a separate pair being in connection only at the bottom with the other pairs. In each down going channel evaporation takes place, each pair of channels having therefore its own driving force.

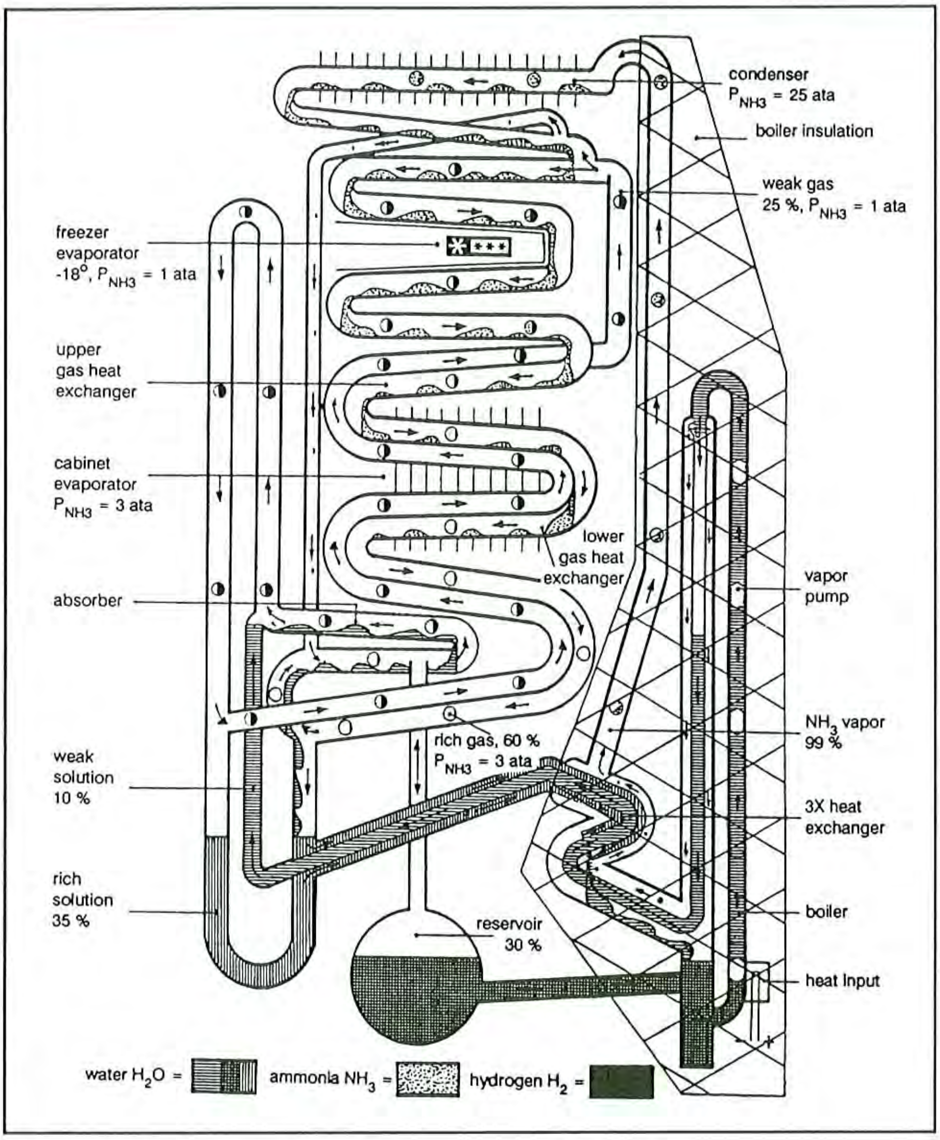

Figure 1. Diffusion absorption cooling unit incorporating the 3x boiler

By this arrangement the mass-balance in each pair of channels is of course absolutely correct and also the distribution of the total mass of auxiliary gas is quite evenly distributed over the total number of pairs. As the total driving force in the unit is less than 0.1 mbar, such measures are inevitable to get sufficient heat exchange (this has been described in detail in reference 4).

A third problem had to be solved, namely, whether several bubble pumps are able to work properly in parallel and are able to lift liquids higher than 1 meter.

In fact, six parallel pumps easily lifted the necessary quantity of weak solution high enough for a 3 kW DAHP. The heat input is applied with six small atmospheric gas-burners. The efficiency of the combustion reaches 92% of the lower calorific value of the natural gas.

There were, of course, quite a number of other problems. Based on several years of research, development and experiments, and 45 years of practical experience the DAHP was developed (see schematic in Figure 2).[5]

Modules with a heating capacity of 3 kW were planned and have been built.

At the evaporator side a secondary circuit is integrated with circulation of brine, connected to an outside heat exchanger aerated by a ventilator. Any other decent source of low-temperature heat, such as solar collectors or running water, etc., may be used.

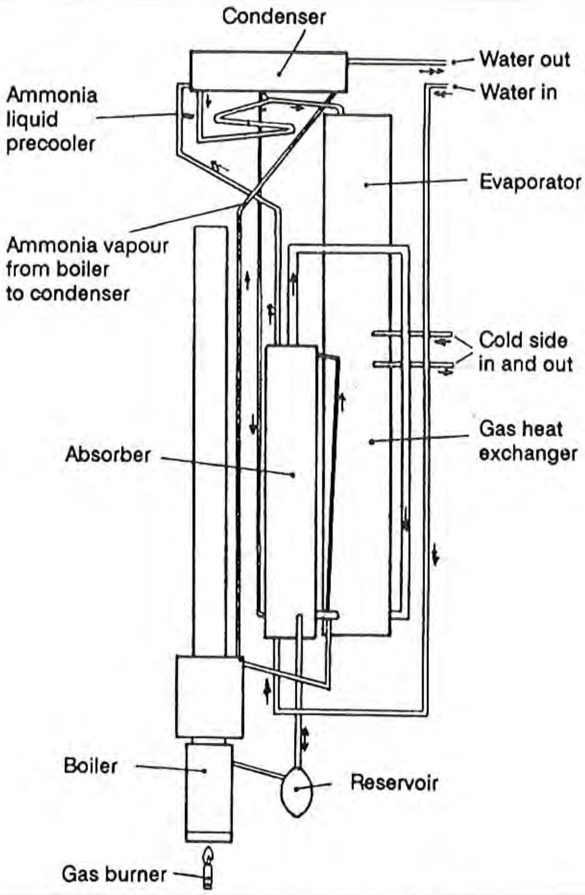

Figure 2. Schematic of the diffusion absorption heat pump (DAHP)

This secondary system also allows the DAHP to be used for cooling purposes, either for air conditioning in summer and winter, or for cooling only or as a dehumidifier. This unit will actually be the only medium performance cooling unit which reaches temperatures far below the freezing point and has no need of electricity or combustion engines.

The rectangular modules have a height of 1.9m, a depth of 24cm, and a width of 56cm. The extreme height of 1.9m is due to the necessity to produce enough drive for the helium circulation. Remarkable on the other hand is the rather small standing area of only 0.14m^2.

By using only modules of 3 kW heating capacity, the quantity of NH_3 is held below 1 kg and no special regulations have to be fulfilled. Also the total volume at high pressure is below the critical figure. In fact, the DAHP can be located at any place where a gas-fired refrigerator may stand. This is an enormous advantage and lowers the cost of installation.

In most cases 3 kW is not enough heat to keep a house warm. The modules are therefore built so that they can easily be connected together, thus producing 6, 9, 12 ... kW performance. For comparison with conventional boilers one has to keep in mind the fact that for the few really cold days one has anyway to boost with about 2 kW. The DAHP represents for comparisons in fact a heating power of approximately 5 kW. Units of 5, 10, 15 ... kW heating performance will therefore be available.

Regulation: Very simple regulation of the effective heat transferred to the house is possible; a standard gas- thermostat, which controls according to the warm water temperature, is sufficient. It can be combined with the usual thermostatic control depending on outdoor conditions. Also an on-off control is useful in some cases, since the control of the proper mixture of gas and air is not necessary to realize the best possible COP of combustion. The DAHP can even then work without a pilot flame, using the help of an electronic ignition and re-ignition device.

It is also possible to let the unit work like a refrigerator at two different input rates, i.e., a bypass-rate of 1/3 and the full rate. In this case, the combustion air must be balanced to the varying gas rate with the help of a throttle-valve.

Another important advantage of the DAHP is the fact that the cooling performance is not produced at one given temperature, but on a gliding temperature scale. The brine will leave the module at, for example, -15°C and re-enter the unit at -3°C. It is, therefore, possible to cool the air to a very low temperature; less air is therefore needed which means smaller air-ducts, smaller ventilators, and especially far less frost production. This makes defrosting less of a problem.

The DAHP modules are not filled with hydrogen as inert gas. Because of the relatively high volume of the unit and the pressure of 25 bar, a possible leak could produce a danger of explosion. In order to exclude any possibility of explosions, the hydrogen is replaced by helium.

Last, but not least, the total absence of noise and moving parts should be remembered along with the fact of the total absence of Freon and an exhaust of only 40% of CO_2 compared with an oil-fired boiler.

The production cost of the total aggregate is in the order of the actual price of a mechanical solution pump of a traditional AHP. Most of the expensive control devices necessary for other heat-pumps are not needed for the DAHP. The hermetically sealed DAHP unit consists mainly of welded steel tubes. Very important is of course the cost of labor. To keep this cost as low as possible, a high level of automation is required. This means a relatively high investment which means high volume production. These are only possible if the production of the hermetically sealed unit, the so called "heart" of the DAHP, is concentrated at few places as is the case with compressors for domestic refrigerators. The set-up of complete DAHPs in different variations, sizes, designs, would be reserved to those who already have the know-how for gas boiler design and installation.

For the reasons mentioned, an amortizing time of less than 10 years can be obtained even with today's relatively low gas prices. Important for these considerations is the fact that, based on the

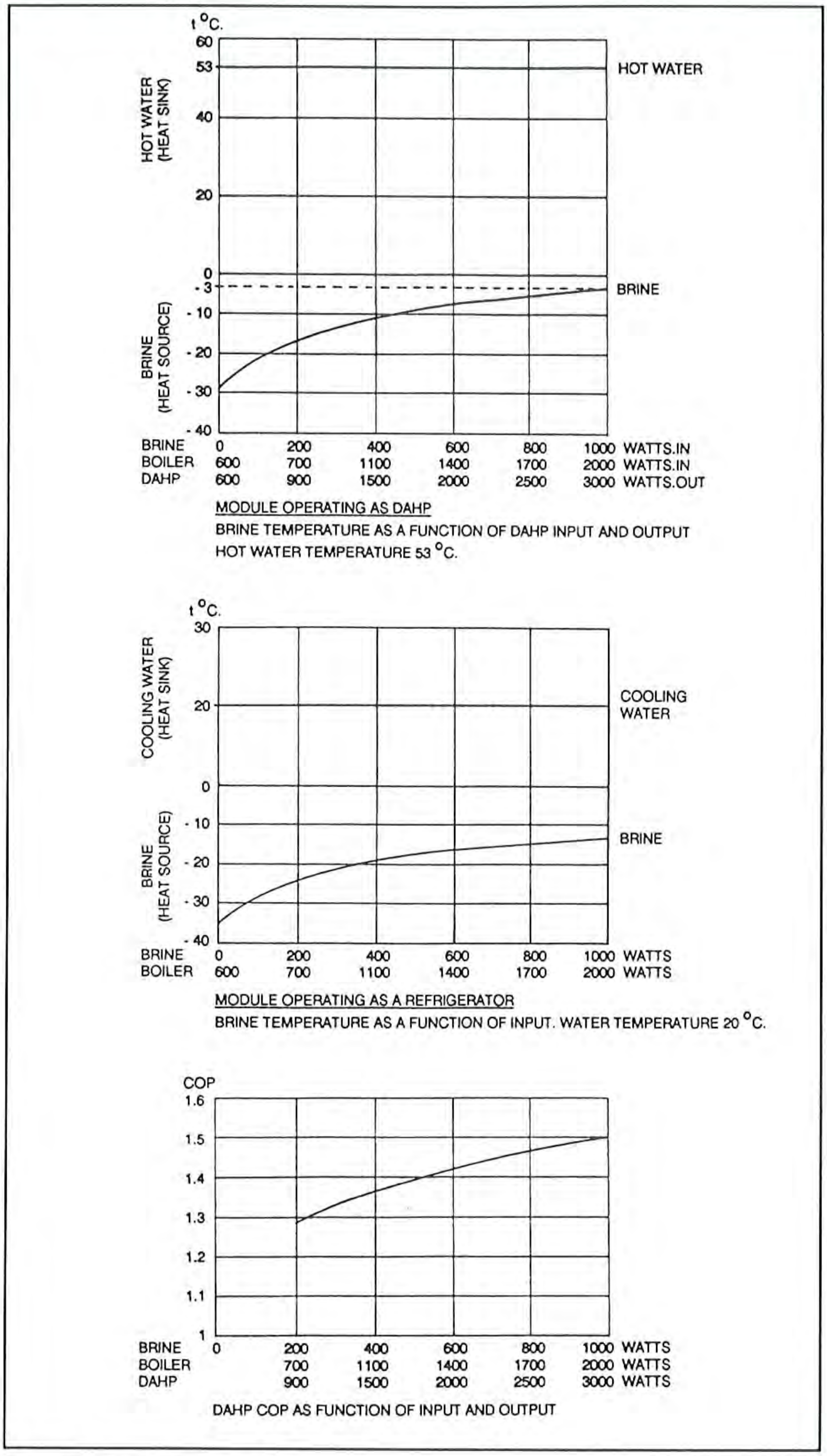

Figure 3. Performance of the DAHP

experience of millions of absorption refrigerators, service costs will be negligible for this period of 10 years.

Figure 3 shows the temperatures and the COPs measured on such a unit as described. We think they are remarkable.

A general use of such diffusion absorption heat pumps saving 1/3 of the gas used for heating purposes could influence positively the national economy of many countries.

Finally, we draw attention to the possible applications of this machine for the gas industry:

1. It can be used as the "heart" of a gas operated heat pump with an output of 5/10/15 ... kW.

2. It can be used as the basis for a gas operated refrigeration plant with a cooling capacity of 1/2/3 ... kW.

3. It can be used as the basis for a gas operated air conditioning unit with a heating output of 3/6/9 ... kW and a cooling capacity of 1/2/3 ... kW.

4. It can be used as the basis for a gas operated dehumidifier with a cooling capacity of 1 kW or multiples of 1 kW.

We submit that these are a completely new range of applications which, if exploited by the world gas industry, would put it into a highly competitive position compared to the electric industry.

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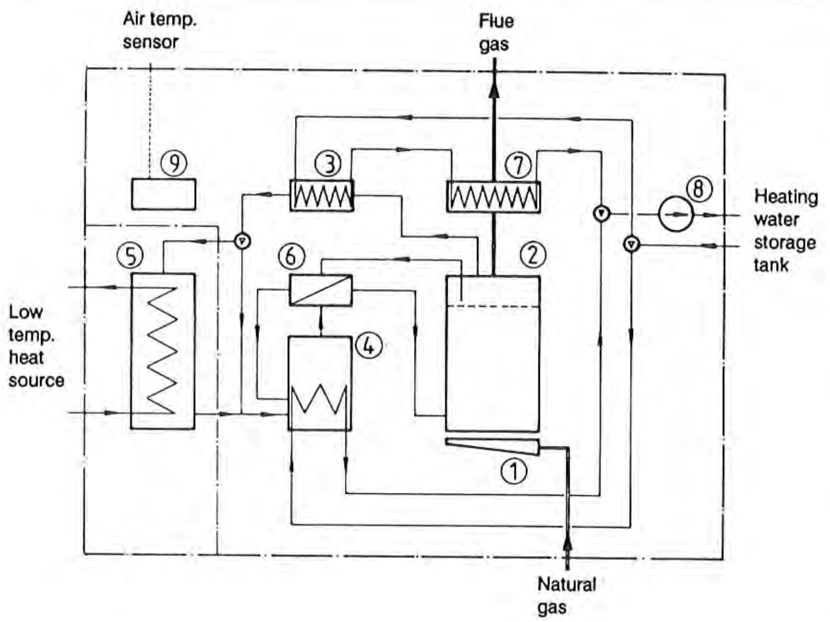
Progress in Development of the Periodically Operating Absorption Heat Pump

This article describes the development of a low-temperature heating system with a maximum useful heat output of 10 kW for a one-family house on the basis of a periodically operating absorption heat pump (PAHP). The working fluid is CH_3OH-LiBr. The concept of the unit allows the availability of the yearly required useful heat with one appliance. The development presented here includes the layout and the construction of two prototypes and the practical experience gained, as well as investigations concerning the vapor pressures, the phase composition, the thermal stability and the corrosivity of the applied working fluid with and without addition of water and inhibitors. The partial heat load behavior and the control system is discussed.

Introduction

The aim of one of the research activities at the Institute for Technical Thermodynamics of the Rheinisch-Westfaelische Technische Hochschule (RWTH) Aachen is the development of a low-temperature heating system. This system shall provide domestic heat with a low amount of primary energy. Furthermore, this system must be able to compete with conventional oil- or gas heating systems. Under these marginal conditions there are certain constraints in terms of investment costs, maintenance and efficiency.



1) Gas burner
2) Generator
3) Condenser
4) Absorber
5) Evaporator
6) Internal heat exchanger
7) Flue gas cooler
8) Heating water pump
9) Control system

Figure 1. Schematic of the heating unit

Throughout this article, the following notations are used:

COP	(-)	coefficient of performance
PER	(-)	primary energy ratio
Q	(kJ)	heat
t	(min)	time
λ	(-)	water content in refrigerant, mass fraction
ϑ	(°C)	temperature

Subscripts:

a	annual
abs	absorber, absorption
AL	ambient air
B	burner
con	condenser
evp	evaporator
G	generator
gen	generation
N	useful
max	maximum

Superscripts:

$\cdot$	with respect to time
-	mean

Basic concept

The concept of the periodically operating heat pump is chosen in such a way that the system can cover the yearly heat requirement of a single-family house with only one unit.

Basic concept: Monovalent heat generator on the basis of a periodically operating absorption heat pump.

Heating capacity: Max. heating capacity 10 kW at -12°C ambient air temperature with a low temperature hydronic heating circuit 55/47°C.

Heat input: High temperature heat by an atmospheric gas burner in the generator, modulation possible, $Q_{B,max}$ = 20 kW; low temperature heat depending on evaporator concept; air-evaporator - ambient air, below 0°C air temperature boiler mode of operation; brine-evaporator - depending on heat source (for example, soil, groundwater, etc.) all year heat pump mode of operation.

Heat output: From condenser and absorber to heating water storage tank, preparation of water for domestic use possible.

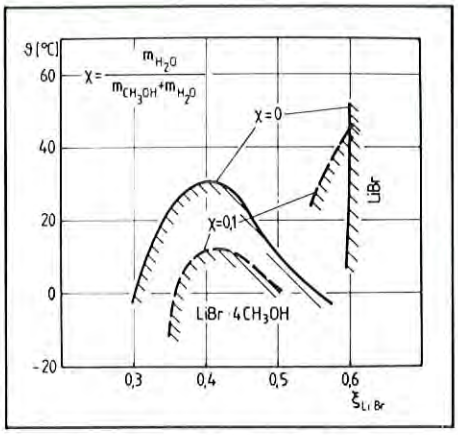


Figure 2. Field of solubility of the binary and ternary working fluid

Weight and dimension of the unit: Approx. 120 kg, 72 x 80 x 80 cm (excluding evaporator).

The heat pump works without a solution pump and has a very simple design. This ensures reliable operation. At evaporator temperatures above -3°C the unit works in the heat pump mode of operation, at lower evaporator temperatures the operation mode is switched to the boiler mode.

Figure 1 shows a schematic of the whole unit. The main components are generator with separator, condenser, evaporator, absorber, and internal heat exchanger.

Description of the PAHP operation

The generator with separator uses the thermosiphon principle and is heated by an atmospheric gas burner. The gas burner can be modulated over a power range of 0 to 20 kW. The expelled refrigerant vapor is separated from the poor solution in the separator and is led to the condenser. There, the refrigerant vapor is condensed and the useful heat Q_{con} is released. The condensate can either directly be mixed with the poor solution in the absorber (boiler mode of operation) or can be supplied to the evaporator (heat pump mode of operation). In the flooded evaporator the condensate can evaporate by consumption of low temperature heat Q_{evp} and is carried to the absorber. In the bubble absorber the refrigerant vapor is absorbed by the poor solution under release of the useful heat Q_{abs}. The generated rich solution is preheated in the internal heat exchanger by cooling of the hot poor solution and is supplied to the generator.

In the heat pump mode of operation two operation phases are interchanged periodically: the generation- and condensation-phase and the evaporation- and absorption-phase. At a corresponding heat requirement the generation phase is determined by the degasification of the working pair. Then, the gas burner is turned off and the pressure in the whole unit decreases. The condensate in the evaporator can be evaporated after a short phase of cooling. After reabsorption the cycle can start again.

In the boiler mode of operation the working fluid and the condensate is cycled continuously until the heat demand is fulfilled.[1,2]

Working fluid

The absorption unit can be operated with the binary working fluid CH_3OH-LiBr or with the ternary system CH_3OH/H_2O-LiBr. As presented in Figure 2, the field of solubility of the binary system can be increased by addition of few mass percent H_2O.

On the other hand the addition of H_2O leads to a decrease in pressure gradient between the refrigerant in the evaporator and the poor solution in the absorber. Then, a heat pump mode of operation is not possible below evaporator temperatures of +4°C, which heavily affects the yearly primary energy ratio. Assuming a realistic temperature gradient of 5 K and a pressure drop of 5 mbar the lower temperature limit is -3°C for the heat pump mode of operation using the binary fluid.

For an expedient operation of the PAHP according to the marginal conditions the binary fluid has to be chosen where the concentration of the refrigerant poor and rich solution should be 0.42 and 0.51 mass fraction, respectively. At the institute, intensive studies concerning vapor pressures,[4,5] phase composition,[6] thermal stability,[3,5] and corrosivity with the binary and ternary fluid have been undertaken.

In terms of thermal stability, the poor solution of the binary fluid is stable up to 120°C. Above this temperature a decomposition of methanol into dimethylether and water occurs. By adding a few mass per mil LiOH the solution can be heated up, without decomposition, to temperatures of 150°C.[3] For domestic heating the maximum temperature of the poor solution has to be 130°C.

The binary fluid is very corrosive. Up to now, there are only two container materials resistant against the solution: stainless steel 1.4571 and AlMgSi 05. At present, investigations are being undertaken to study whether LiOH will influence the corrosivity.

With the binary fluid, the absorption heat pump can exceed a coefficient of performance of 1.7 including temperature gradients for the heat exchange. The working fluid costs approx. 7 DM per kg rich solution. This is relatively low compared to other possible working fluid systems. Considering a working fluid filling of 40 kg, the time for degasification takes approx. 12 minutes or 18 minutes with a burner load of 11 or 16.5 kW, respectively.

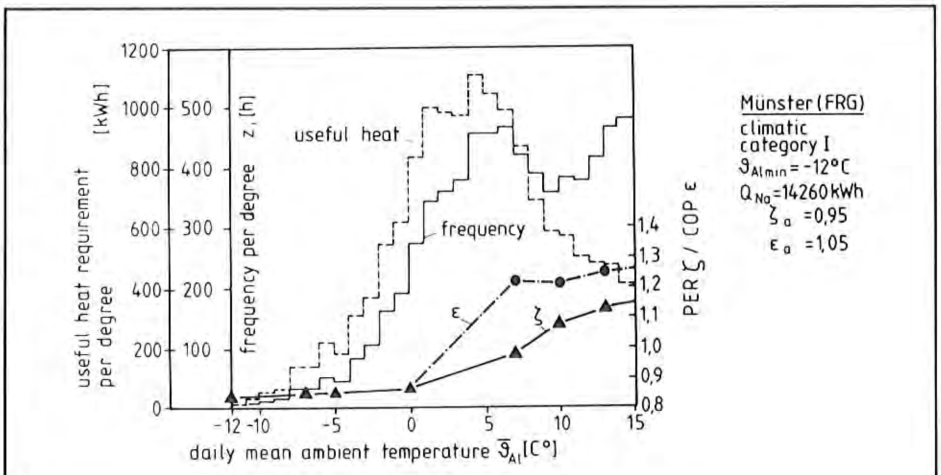


Figure 3. Experimental results of the first prototype and required heat distribution at different ambient air temperatures

Development of the first and second prototype

The performance of this heating unit has been confirmed with investigations using a first prototype[2] operating with the ternary system CH_3OH/H_2O-LiBr. The low temperature heat source was simulated by a climatic channel, with which the desired air conditions could be supplied to the air evaporator. Figure 3 shows the experimental results of the first prototype in the heat pump and boiler mode of operation and the required heat distribution at different air temperatures. The yearly primary energy ratio (ζ) is 0.95 and the yearly coefficient of performance (ϵ) reaches 1.05. Figure 3 also shows that the heat pump mode of operation at lower evaporator temperatures will greatly increase the yearly primary energy ratio and the yearly COP.

With the experimental experience of the first prototype the design of the second prototype was undertaken.[8] Improvements were made to the generator and absorber.

In contrast to the first generator, the second generator had the following characteristics:[7]

-- Improved heat flux at the thermosiphon tubes

-- More surface area in the thermosiphon tubes in order to get more heat input from the gas burner

-- Better separation of the vapor-liquid mixture in the separator in order to improve the condensate production

Goals for the design of the second absorber have been:[7]

-- Improvement of the heat and mass transfer

-- Low static pressure difference between evaporator and absorber in order to maintain low evaporating temperatures

-- Reduction of stored heat in the absorber during the generation phase

The new bubble absorber is constructed of three single absorber units which are connected by tubes and are concentrically arranged around the generator. The maximum solution level is only 34 mm, therefore a maximum static pressure difference of approx. 4 mbar has to be overcome. The refrigerant vapor, coming from the evaporator, is introduced by the inlet geometry into the bottom of the absorber through a fine metal grid. These small vapor bubbles are then absorbed by the poor solution. The heat of absorption is directly transferred via ribbed tubes to the heating water circuit.

Between the lower two absorbers an internal heat exchanger is connected, heating the cold rich solution by cooling the hot poor solution during the generation phase. In Figure 4 one of the absorbers with an internal heat exchanger is shown. With the internal tube bundle heat exchanger the induced generator heat to the solution can be used more effectively for condensate production. Under practical assumptions the COP can be raised by 7% using the internal heat exchanger.

Figure 4. Bubble absorber with internal heat exchanger

In a first experimental period the newly constructed generator-condenser-unit was tested. The efficiency in the boiler mode of operation could be increased by 6% compared to the first prototype. With this efficiency the unit can compete with conventional oil- or gas-furnaces. The observed heat flux in the condenser was 7 kW at 13 kW burner input, where the total useful heat output was approx. 12 kW. With the new absorber and internal heat exchanger the heat flux from the condenser shall increase in order to discharge the evaporator. Experiments with the new absorber and internal heat exchanger are being carried out. The unit can now be operated in the boiler mode of operation. The internal heat exchanger reaches an efficiency of approx. 90% which results in a heat output in the absorbers of only a few hundred watts. Almost all the useful heat can be released to the condenser during the generation mode.

Costs and prospective

Based on a 1986 cost estimate of the material and manufacturing costs of the heating unit with an air evaporator by an industrial heating device manufacturer, the first prototype will cost approx. 4,600 DM, where the material (stainless steel 1.4571) of the unit costs 2,100 DM. These costs include the generator, absorber, condenser, air evaporator, flue gas cooler, gas burner, control unit, and insulation. Mass production could reduce the costs to approx. 4,300 DM. For a design according to the second prototype, the costs would be approx. 5,500 DM to 6,000 DM. The total unit including working fluid, heating water storage tank, and control system would cost approx. 10,000 DM. The installation costs are approx. 4,000 DM while the costs for an air or brine evaporator are almost the same depending on the local situation. Maintenance costs will be comparable to those of conventional heating systems in this power range. The proposed investigations on the second prototype will be finished by mid-1989.

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Compact Heat and Mass Exchangers in Sorption Systems

Small scale sorption systems can only become competitive when built in quantity using automated production. For this reason the application of compact heat and mass exchangers can be recommended. Two types of exchangers are tested. One exchanger is used in an absorption heat pump (AHP) for domestic heating operating with the working pair CH_3OH - LiBr/ZnBr2 and exchangers of the plate fin type. The other is used in an absorption heat transformer (AHT) for upgrading waste heat. Here the working pair Tri-Fluoro Ethanol (TFE) - 2-Pyrrolidone (Pyr) will be used. The latter exchangers are made of spot-welded cushion plates.

Introduction

The main attraction of the AHT and the AHP is their ability to transform low level heat into useful heat. The gas-fired AHP has a good chance to replace the conventional domestic heating system in the future. Compared to the conventional boiler, a saving on primary energy of 30 to 40% is possible. The AHT operates on industrial waste heat exclusively to produce useful and reject heat. The only primary energy needed is for the circulation pumps. The COP calculated as the ratio useful heat (output)/primary energy (input) is between 20 and 50, and as the ratio of useful heat/waste heat it is 0.45.

So sorption systems may contribute to a considerable energy saving. Although one is more interested in money saving, it is necessary to know for what capital costs this energy can be saved. Material and construction costs form the main part of the total costs. Both can only become competitive when they are built in quantity production, i.e., when large transfer areas are paired to low costs. Large transfer areas lead to small temperature/concentration differences and improved performance, and low costs can be achieved by cheap manufacturing techniques.

In the framework of the National Heat Pump Research Program, the Laboratory for Refrigeration Engineering of the University of Technology Delft has started research on the possibilities of the application of "Compact Heat and Mass Exchangers" (CHME's) in a 10 kW output gas-fired AHP for domestic heating. A second project includes the design, construction, and testing of a 20 kW input AHT.

Absorption heat pump project

The research is concentrated on the theoretical (simulation) and experimental (pilot plant) testing of this type of

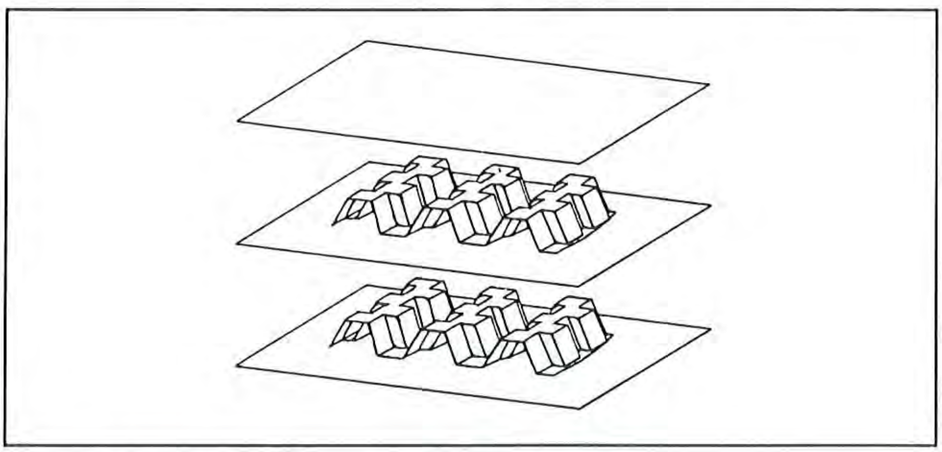

Figure 1. A stack of parallel plain and corrugated (finned) plates

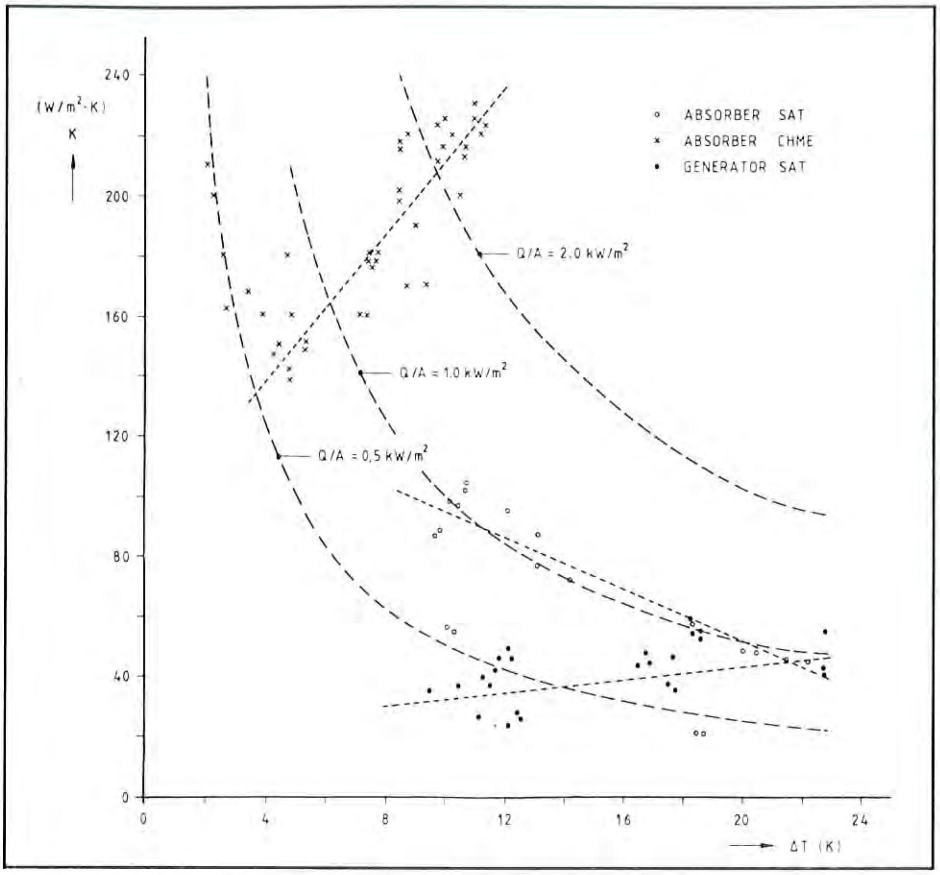

Figure 2. The overall heat transfer coefficient K as a function of the mean log. temperature difference dT for the CHME absorber and the SAT absorber/generator

exchanger in a sorption system.[1,2,3] This type of exchanger[4,5] has a compact construction with "extra" transfer surface and a relatively small volume. In this discussion, "compact" stands not only for compact physically, but also for enhanced. Enhancement is achieved by adding extended surface to the prime surface. This is done by adding interruptions on the surface and by reducing the area of the flow passages. This increase of the transfer surface area A (m^2) and the overall heat transfer coefficient K ($W/m^2 \cdot K$) leads to an increased amount of transferred heat Q (W).

For the exchanger itself, it leads to a compact, strong and stable construction, with a small weight and volume. The CHM considered in this research work is of the plate type, consisting of a stack of parallel plain plates. The space between the plates is filled up with a corrugated plate (see Figure 1). Together with headers, the stack is welded or brazed together.

This type of design offers an extensive choice in the type and the area density of the surface on both sides and the reduction of the total weight and volume of the exchanger. The way of stacking and brazing or welding is very suitable for automated production techniques.

	Advantages	Disadvantages
AHT	-- More technical knowledge available (historical adv.) -- One throttling valve -- Easier to control -- One heat exchanger	-- Sometimes rectification necessary
RHT	-- Pressures freely to be chosen, so more independent variables to control, so a better fit of the machine to the process possible -- Lower working pressures -- Heat transfer over a temperature range -- Possibility of "overlap"	-- Extra mass flow causing: extra friction losses, irreversibilities in the second heat exchanger, and extra throttling valve more pumping work -- Resorption in the resorber more difficult than condensation

Table 1. Qualitative comparison of the absorption and resorption cycle

An AHP test plant[1] was built with this type of CHME components, except for the generator which is a conventional shell and tube exchanger (SAT) used as an absorber in a previous test plant. The applied corrugated/finned plates were of the offset type, with a rectangular, triangular or trapezium fin. The working pair CH_3OH-LiBr/ZnBr2 (2:1 mol) was used, with working pressures below 1013 mbar and only methanol in the vapor phase.

The compactness of both types of exchangers, the plate type (CHME) and the shell and tube type (SAT), can be compared by means of the area density B (m^2/m^3) of the exchanger:

$$B = \text{transfer surface area } A\ (m^2) / \text{volume } V\ (m^3)$$

The surface of the plate fin in the CHME's is not taken into account. The CHME components have an area density of 600 on the working pair side and 900 m^2/m^3 on the cooling/heating side. In contrast, the SAT generator only has an area density of 250 m^2/m^3. The influence of the plate fin would make the CHME even more favorable.

Experiments took place to investigate the heat and mass transfer in the CHME components. Because of the instability of the methanol in the working pair at temperatures above 125°C, this working pair is only suited for a low temperature heating system (air, floor). In Figure 2, the overall heat transfer coefficient K ($W/m^2 \cdot K$) is shown as a function of the mean log. temp. diff. dT (K) for the CHME absorber as well as for the SAT generator/absorber. For comparison, lines of a constant heat flow and transfer surface ratio, Q/A (kW/m^2), are drawn. The input parameters of the AHP are the cooling water temperature (30-60°C) and the working pair mass flow (25-100 g/s). It can also be observed that the Q/A values of the CHME absorber are overall higher than those of the SAT generator/absorber. However, it should be mentioned that the (plate) transfer surface of the CHME absorber is half that of the SAT one, but at an almost equal volume. This CHME absorber, however, does not have the optimal construction and, together with other components in an integrated AHP, the plate type is far more suitable from the point of view of both the construction and the production than the conventional SAT.[6]

A computer simulation program has been developed for the AHP test plant based on heat and mass transfer coefficients from literature. Every component is put in a separate subroutine. The iteration parameter is the solvent mass flow and the overall iteration is terminated when each component and the AHP as a whole is thermodynamically in balance. Later the program will be verified and modified by experimental results. It will then be a program that can be used as a design tool for any sorption system with a flexibility in cycle configuration, components, and working pair.

For verification and validation of the simulation and the experimental results, the object is to run tests with another working pair. The limitations of the test plant (gaskets, no rectification) and of the possible working pairs (pressure level, presence of thermodynamic and physical data), led to the choice of the working pair R123a-DTG (trifluorodichloroethane/dimethylether tetraethylene glycol). This working pair will be tested in the simulation program first and then in the AHP test plant.

Absorption heat transformer project

There are two main principles for heat transformation: absorption and resorption.[7] Literature about resorption refrigeration machines (RRM) and resorption heat pumps/transformers (RHP/RHT) contradict each other in pointing out the best principle.

Only a few resorption machines are really built, and in this field nearly no research is done. To insure that the better principle will not be cast aside, it was important to consider resorption. Working pairs with a small difference in boiling point between solvent and absorbent can still be used in the RHT. Another advantage is the lower working pressures. Table 1 shows a qualitative comparison of the two cycles. To be able to make a good quantitative comparison, calculations with the RHT and with the AHT were executed.[8] From this investigation it was clear that for an ammonia/water HT the AHT has a higher heat ratio than the RHT.

The working pair used in the AHT has a great influence on the heat ratio. So it is important to find the working pair that is the best according to present-day knowledge. A literature survey provided information about the suitable working pairs.[9] Apart from that, calculations were undertaken with 18 working pairs by means of the earlier mentioned simple model of the HT. Table 2 shows the selected working pairs. Figure 3 shows an example of a calculation for four working pairs.

Although H_2O-NaOH and H_2O-LiBr give high heat ratios, there is always the possibility of crystallization. From the literature survey and from the calculations, the working pair 2,2,2-TriFluorEthanol - 2-Pyrrolidone (TFE- Pyr) proved to be the best suited. The computer calculations are executed with TFE-NMP (N-Methyl-Pyrrolidone). This has nearly the same thermodynamic properties as TFE-Pyr, according to several researchers consulted. The main difference is the boiling point difference between solvent and absorbent, for TFE-Pyr 171 K and for TFE-NMP 129 K. So for TFEPyr there is no rectification necessary.

TFE as the solvent has many advantages: low working pressures, relatively high heat of evaporation, high thermal stability, etc. The main disadvantage, however, is the toxicity.[10] In Switzerland, TFE is in the same toxicity class as NH_3. But TFE does not smell as intensely as NH_3. The concentration is already over the maximum allowable concentration (MAC) value if smelled. The low pressure part of the HT is below atmospheric pressure, but the high pressure part is mostly above it, although it will not exceed 3 bar absolute. The toxicity makes precautions necessary, but in the industry (apart from food processing) where this HT will be used, these precautions are usually already taken because of the process fluid.

In the AHT test plant the waste heat is simulated by means of electrically heated thermal oil, the absorber heat is extracted by means of the same type of oil. The condenser is cooled by water. These four components are of the falling film type. They are made of so-

1	NH_3	-	H_2O
2	NH_3	-	NaSCN
3	NH_3	-	$LiNO_3$
4	NH_3	-	$H_2O/LiNO_3$ (1:3)
5	NH_3	-	H_2O-LiBr
6	R22	-	DTrG
7	R22	-	DTG
8	R22	-	DDG
9	CH_2NH_2	-	$C_2H_6O_3$
10	CH_3NH_2	-	LiSCN
11	CH_3NH_2	-	H_2O-LiBr
12	R123a	-	DTG
13	CH_3OH	-	LiBr
14	CH_3OH	-	$LiBr/ZnBr_2$ (2:1)
15	TFE	-	NMP
16	H_2O	-	H_2SO_4
17	H_2O	-	LiBr
18	H_2O	-	NaOH

Table 2. Selected working pairs for calculations

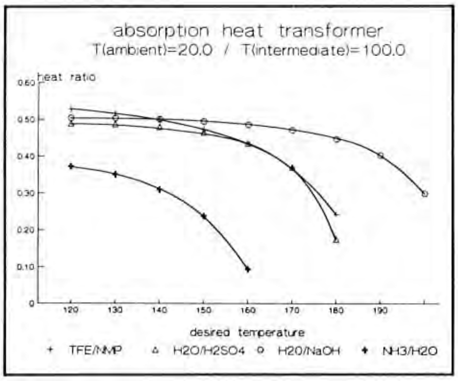

Figure 3. The heat ratio for four working pairs as a function of the desired outlet temperature

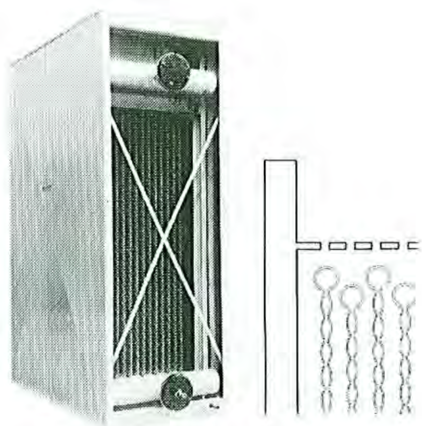

Figure 4. Temp-plate[R] in stainless steel (double embossed)

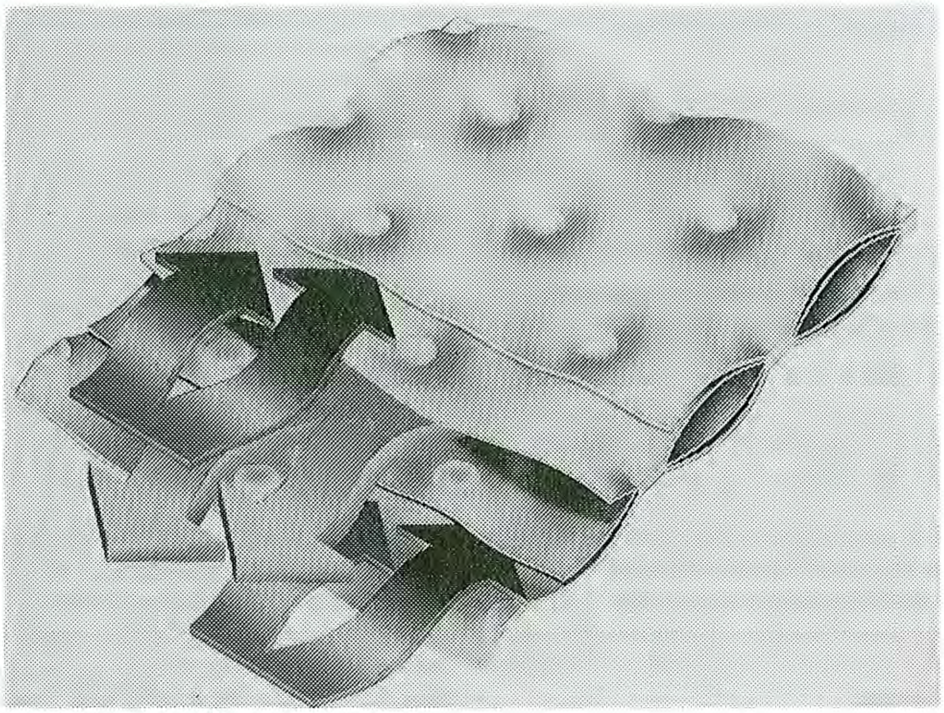

Figure 5. Multi-plate^R in stainless steel

Component	Plate Type	Max. dimensions per plate in mm	Surface in m2	No. of plates	Heating/Cooling capacity in kW
Absorber	Temp	1100 x 1241 x 365	10.5	7	12
Generator	Temp	1100 x 1241 x 365	10.5	7	12
Evaporator	Temp	1100 x 1241 x 365	4.5	7	15
Condenser	Temp	1100 x 1241 x 365	4.5	7	15
Heat exch.	Multi	920 x 940 x 11	1.7	1	>2

Table 3. Geometry, surfaces, and heating/cooling capacity of the AHT components

called Temp-plate™ with a header welded to it (Figure 4). The thermal oil or cooling water flows through the plates. The working pair/solvent flows on the plate surface. The liquid distribution system for the different components is still being designed. The heat exchanger is made of so-called Multi-plate™ (Figure 5). Table 3 provides the most important information of the components. They are all made of AISI 316 stainless steel.

Conclusions

The CHME components showed an improved heat and mass transfer compared to the conventional SAT component. This is expressed as a 2 to 4 times larger overall heat transfer coefficient K (at correspondingly smaller mean log. temp. difference dT) and a 1 to 2 times greater Q/A-value. Optimization of the construction of the CHME components can be achieved by the computer simulation program based on the experimental results. The simulation model itself will be verified by tests (theoretical and experimental) with a new working pair. The experiments with the AHT test plant will start next year. The result will be used to validate a computer model of the plant. When ready, it can be a design tool for sorption equipment, and for optimization and testing of new components and/or cycle configurations.

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Research on Absorption Heat Pump Which Utilizes River Water

This research work is being carried out for an area situated on the mouth of the Sumida River facing Tokyo Bay. It is concerned with the practical use of a gas absorption heat pump system utilizing river water.

Introduction

As city redevelopment projects in Japan are making headway, the development of the waterfront of cities is attracting public attention. This usually involves coastlands which are separated from the river or sea by embankments. For these areas, various ways of utilizing river or sea water are being considered. One of these involves a hot water supply system driven by a gas absorption heat pump which uses the river water as its heat source.

A flow schematic of this heat pump which utilizes river water as its heat source is shown in Figure 1. By pumping heat up from the river water, the system generates hot water of 60°C which is used to heat service water. By means of a heat exchanger, this water can be used to supply hot air for space heating.

The prototype unit

During the one-year period between October 1985 and September 1986, the water of the Sumida River at high tide and low tide was sampled monthly for a quality analysis. The fouling factor of samples exposed to the river water was also determined.

These results, which indicated that the river water has practically the same composition as sea water, were used to choose the material for heat transfer tubes of the absorption heat pump. Because of its excellent corrosion resistance and durability and limited accumulation of scales, titanium was chosen as the engineering material for the tubes.

A prototype of a gas absorption heat pump capable of delivering 290 kW of hot water was manufactured on an experimental basis for conducting experiments. As for its rated conditions, it was designed to use the river water heat source at 11°C to raise 20°C city water up to 60°C.

The prototype unit was tested under various operating conditions. Figure 2 shows the COPs at various heat source and heat sink temperatures. At design conditions, the measured COP is 1.4; it is 1.3 at the lowest heat source water temperature (8°C) which could be assumed in winter. At the highest heat source water temperature (29°C) which could be assumed in summer, the COP is 1.7. The rated COP according to the specifications is given as 1.24 when taking into account fouling on the heat transfer surface. At hot water inlet temperatures higher than 40°C and at sufficiently low heat source water inlet temperatures, the COP of the heat pump becomes less than 1.0. In this case the efficiency of the heat pump is equal to that of a boiler. This condition corresponds to a temperature lift of approximately 40°C. With a return water temperature of 20°C and a minimum heat source temperature of 8°C, economical year-round operation of the heat pump is expected.

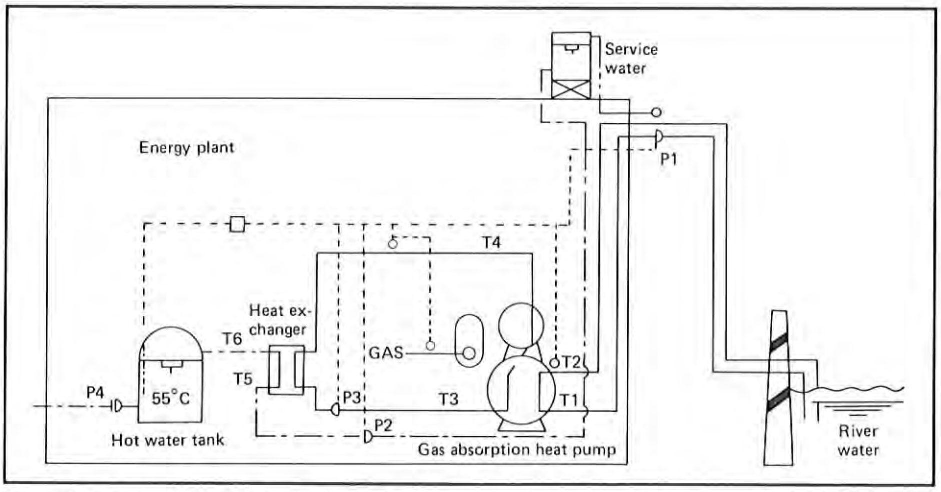

Figure 1. An example of hot water supply system that utilizes river water

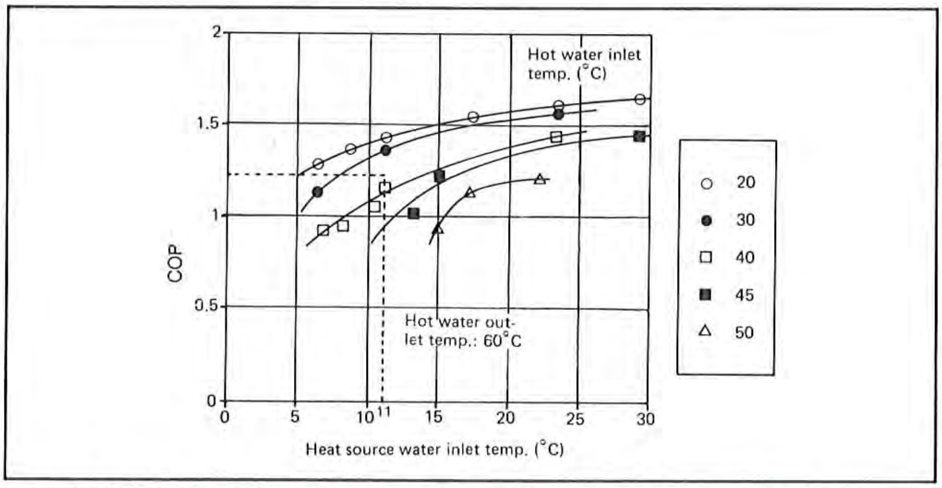

Figure 2. COP characteristics to hot water inlet temperature and heat source water inlet temperature

Summary

This has been the first attempt in Tokyo to use river water, whose temperature is lower than that of other common waste heat sources, as the heat source for an absorption heat pump. The water quality was analyzed and the operating characteristics of the heat pump were investigated through construction and operation of a prototype. Tests showed that the proposed gas absorption heat pump system utilizing the water of the Sumida River is practical and allows year-round recovery of heat under the predicted operating conditions.

**S. Kurosawa and S. Fujimaki, Tokyo Gas Co., Ltd., Tokyo, Japan*

S.M. Sami*

A Proposed Cogeneration Cycle for District Heating and Cooling

The scope of this study is focused on the analysis of heating/cooling applications of the SLOWPOKE nuclear reactor coupled with an absorption heat pump in a typical Canadian climate. The behavior of the proposed cogeneration cycle has been determined with a computer-aided analysis scheme. This includes modeling and simulation of the freon SLOWPOKE Rankine cycle and the absorption heat pump system. Several scenarios have been proposed to meet the heating and cooling loads of some typical Canadian building complexes. The study concludes that the implementation of the proposed dual-cycle results in substantial gains in the overall thermal efficiency of the system. This article presents a brief overview of this work which was carried out for the Atomic Energy of Canada Ltd.

Introduction

A survey of the market in remote regions of Canada concluded that there is sufficient potential for the use of small unit reactors (in the range of 2-20 MW) for heat and electricity production.[1-4] Several prototypes of the Safe Low Power Critical Experiment (SLOWPOKE) units were and are being studied by the Atomic Energy of Canada Ltd.[1-4] for an assessment of their potential. Studies include conceptual designs, cost estimates, safety aspects, and Canadian and foreign market potentials. Among the different SLOWPOKE prototypes, the 10 MW super SLOWPOKE reactor concept has been considered in this study (see Figure 1). The thermodynamic efficiency of the Rankine cycle ranges between 4 and 5% depending on the boiler operating conditions.[5] In order to enhance the capacity factor of this system and to make use of it for heating/cooling applications and electricity production, it is proposed to couple the system with an absorption heat pump.

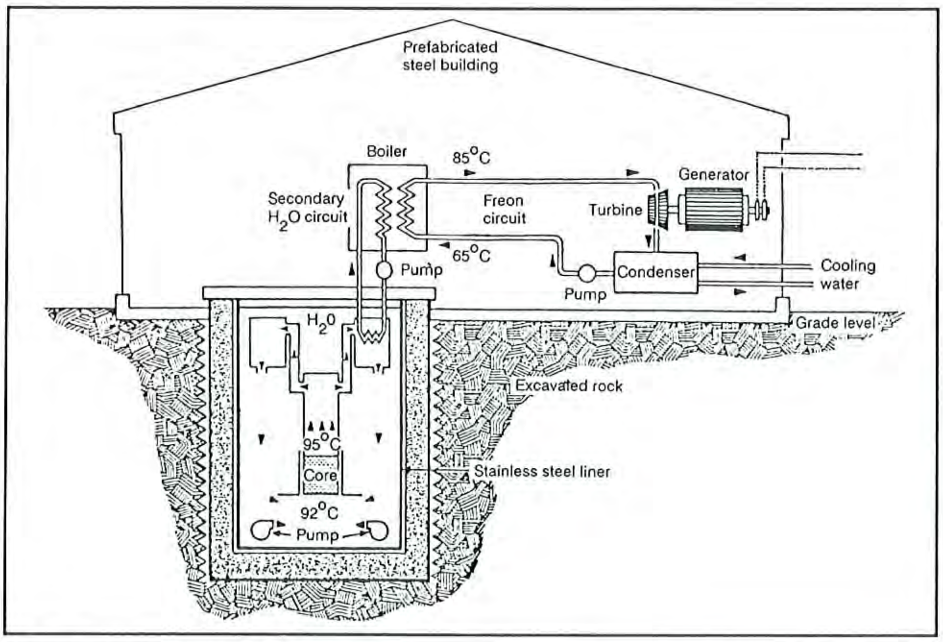

Figure 1. Super SLOWPOKE power reactor

Absorption systems have been proven in many applications as long-life, low maintenance, low operating cost machines with a low purchase cost.[6] The proposed dual-cycle represents a good opportunity for early commercialization of a low-cost, effective, and reliable system.

The scope of the work presented in this report is focused on the assessment of the SLOWPOKE energy system combined with an absorption heat pump for meeting heating and cooling loads in a Canadian climate. Electricity generation is not a prime consideration in this study. However, attention has been paid to the improvement of the Rankine cycle included in the SLOWPOKE Energy System. This eventually enhances the overall thermal efficiency of the system and increases the electricity generated at the turbine shaft. The overall thermal efficiency is defined here as:

$$\eta_{th} = \left.\frac{Q_{output}}{Q_{input}}\right|_{\text{SLOWPOKE reactor and absorption heat pump}}$$

Super SLOWPOKE prototype

The important features of this particular prototype are shown in Figure 1. Conceptual designs, operating, control and shutdown systems are outlined in references 1-4. This version of the SLOWPOKE system uses a freon Rankine cycle engine. At full power of the SLOWPOKE (10 MW), the maximum return and supply temperatures are 85°C and 65°C at the boiler outlet and inlet, respectively. This results in a conversion efficiency of 4 to 5% depending on the turbine, pump isentropic efficiencies and assuming heat rejection at 65°C. Methods of enhancing the Rankine cycle efficiency are outlined elsewhere.

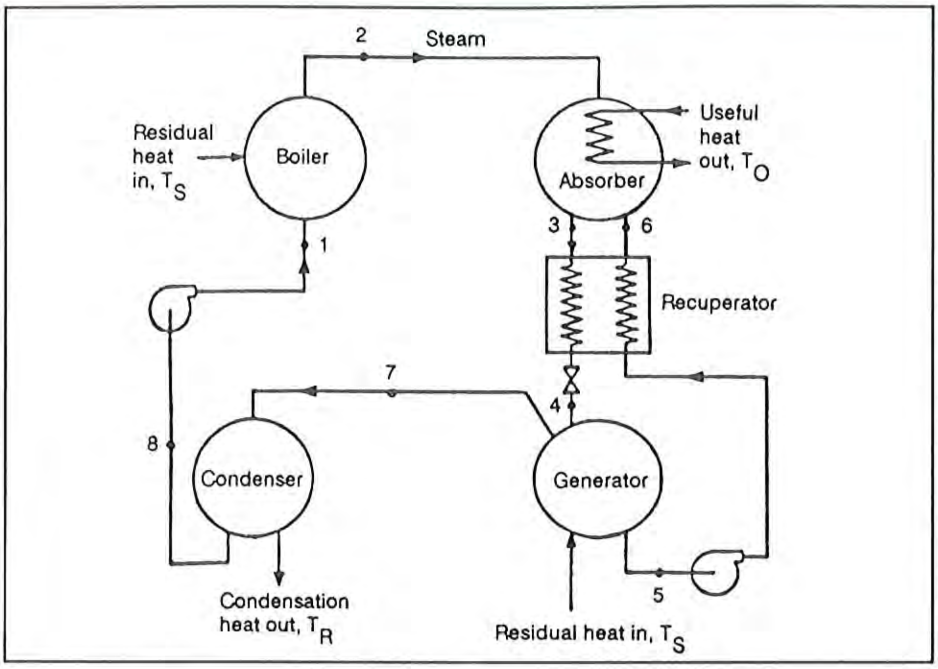

Figure 2a. One arrangement of components in a commercial unit (heat transformer)

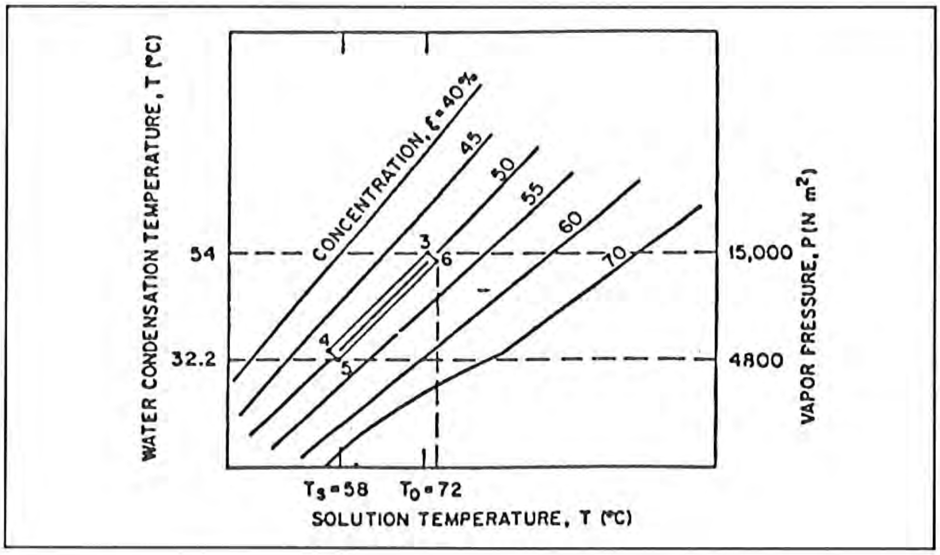

Figure 2b. Absorption heat pump cycle in a P-T diagram for LiBr/water

Absorption heat pump

The absorption cycle is known as the heat operated refrigerant cycle because most of the operating costs are associated with providing the heat that drives off the vapor from the high-pressure liquid (see Figure 2). Some work is required to drive the pump. However, it is minor compared to other forms of energy in vapor-compression cycles. Detailed descriptions of the heat-flow processes taking place during operation as well as their mathematical modeling are discussed in references 6-8.

Proposed dual-cycle

The proposed dual-cycle is a SLOWPOKE freon Rankine cycle coupled with an absorption heat pump (SCWAHP). The basic components of this dual-cycle are shown in Figure 3. The applications of the SCWAHP system for meeting building heating and cooling loads are achieved through various scenarios. Detailed information about these scenarios may be found in reference 9.

Development of the code SAAP

In recent years, absorption heat pumps have received growing interest. This is largely due to their potential to recover part of the residual energy (in the form of hot water with temperatures between 40 and 70°C) and upgrade it for use as process heat for industrial and other applications.[6,7,8] These systems are the reverse of the conventional absorption chillers in that the heating effect is of primary interest rather than the cooling effect.

One of the objectives of this study is to develop a digital computer simulation model to predict the performance of an absorption heat pump under varying operating conditions. This model has been established for a single-stage heat transformer and chiller with lithium bromide-water as the working fluid.[8] However, two- or multi-stages could be simulated with this program with minor modifications. The program calculates the temperature, composition, flow rate, and pressure at each state point of the system and the heat quantities at each unit. This model is a very valuable tool for computer-aided design/analysis for absorption units to be implemented in industry.

The computer-developed simulation model uses the energy balance, continuity equation, heat transfer coefficient and thermodynamic property relations in terms of the state point properties.

This computer program is intended for the steady-state analysis of absorption pumps (SAAP). It contains several subroutines describing the different components: absorber, desorber, recuperator (liquid-to-liquid heat exchanger), condenser, and evaporator, as well as property subroutines.

Vapor power cycle (Rankine cycle)

A single vapor power plant such as that coupled with the SLOWPOKE system operates in a Rankine cycle. The processes involved in this cycle are reversible adiabatic pumping in the pump, constant-pressure transfer of heat in the boiler, reversible adiabatic expansion in the turbine and constant-pressure transfer of heat in the condenser.

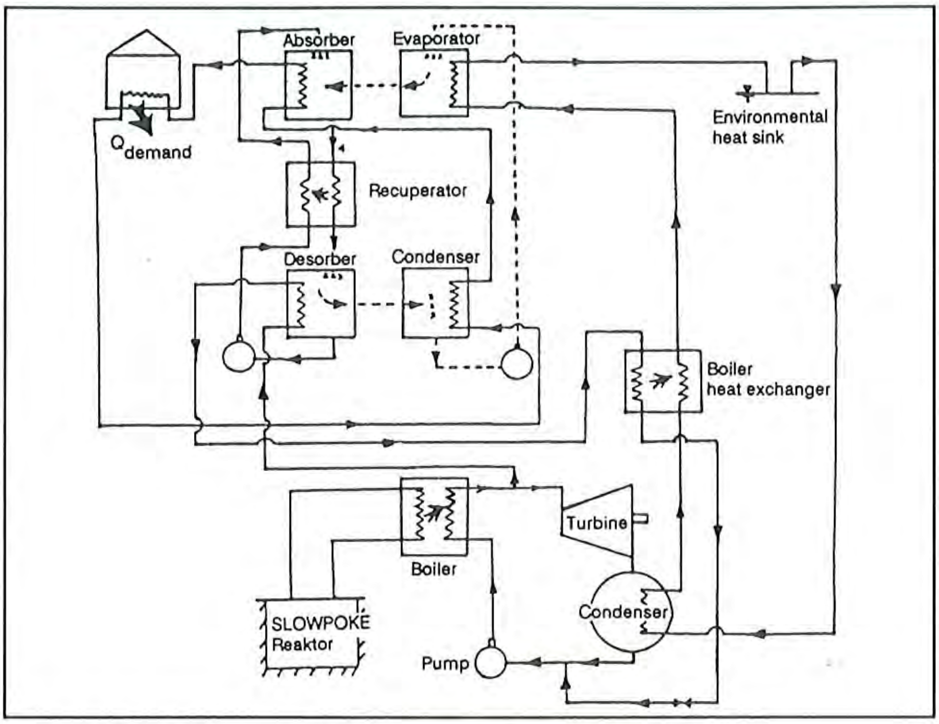

Figure 3. SLOWPOKE coupled with an absorption heat pump scenario (SCWAHP)

It is worthwhile to point out that the Rankine cycle efficiency can be enhanced by lowering the exhaust pressure, increasing pressure during heat addition (boiler), superheating the steam and also by using a regenerative cycle with open feed-heaters. Detailed discussions of these options are cited in reference 10. In this study, only the regenerative cycle with open feed-heaters and superheating steam is employed. The Rankine cycle can be numerically simulated utilizing the control volume surface approach.[10] This can be applied to the different components of the cycle such as the pump, boiler, turbine, and condenser. It is assumed that the potential and kinetic energies are negligible under the steady state operating conditions. The thermodynamic behavior of the Rankine cycle is predicted by the computer code CAARC (Computer Aided Analysis of Rankine Cycle). The property subroutines integrated into this program include steam-water and freon refrigerants such as R12, R22, R502, R113 and R114 as working fluids.[9]

Proposed SLOWPOKE energy system

The Canadian SLOWPOKE technology has been used for space heating since 1976. The configurations of the super SLOWPOKE concept are the secondary H_2O and the freon circuits (see Figure 1). Extensive studies of the thermodynamics of the freon circuit suggested the use of refrigerant R114 as a working fluid to achieve a minimum electric power of 400 KW and to meet the building cooling and heating requirements during the reactor's full power operation.

The heating and cooling loads of the campuses of the University of Quebec, Trois-Rivière, and the University of Sherbrooke have been selected as typical applications for a SLOWPOKE Energy System. The source data for this analysis have been compiled from the energy profiles for these particular sites during 1986 and 1985. These data indicate that the peak heating load (7.22×10^9 MJ) occurs during the month of January for both campuses. On the other hand, the peak cooling load (2.13×10^9 MJ) is during the month of July.

Among the various scenarios considered in this study for the coupling between the SLOWPOKE energy system and the absorption heat pump, the SCWBU (SLOWPOKE coupled with a booster unit) system was recommended (see Figure 4). In this particular system, the saturated freon vapor from the boiler is superheated in the absorber and forwarded to the turbine. The steam bled from the turbine is directed to the generator and the vapor-water heat exchanger. The return from both components is feedback to the boiler. The rejected heat from the Rankine cycle's condenser is supplied to the absorption heat pump evaporator. It is worthwhile to point out that the net heat

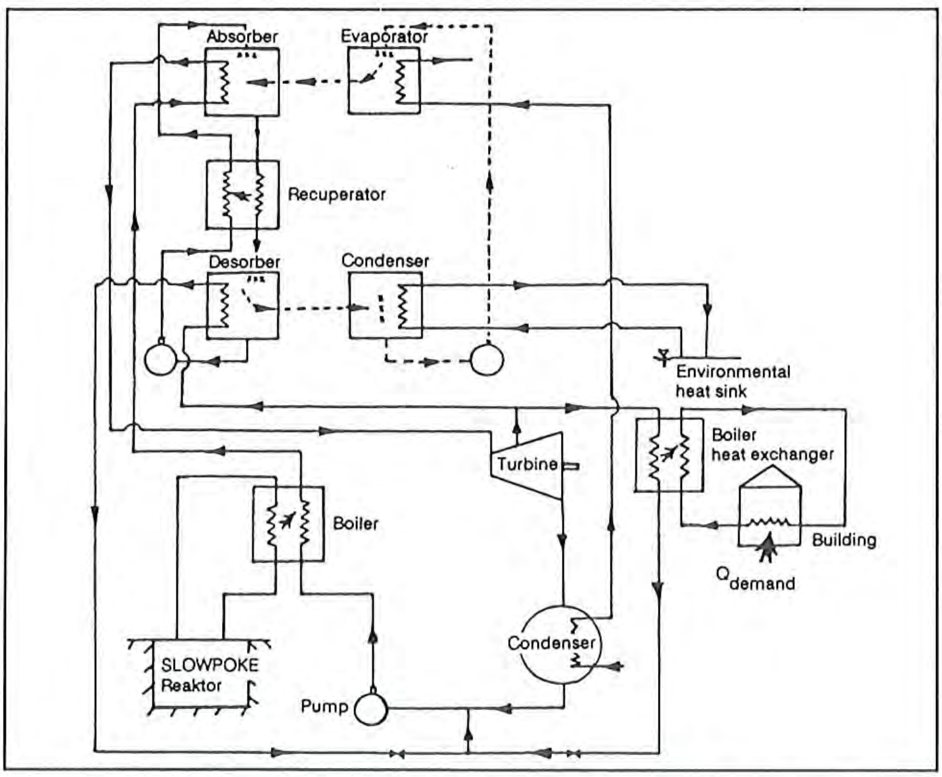

Figure 4. SLOWPOKE coupled with a booster unit (heat transformer) scenario, heating load

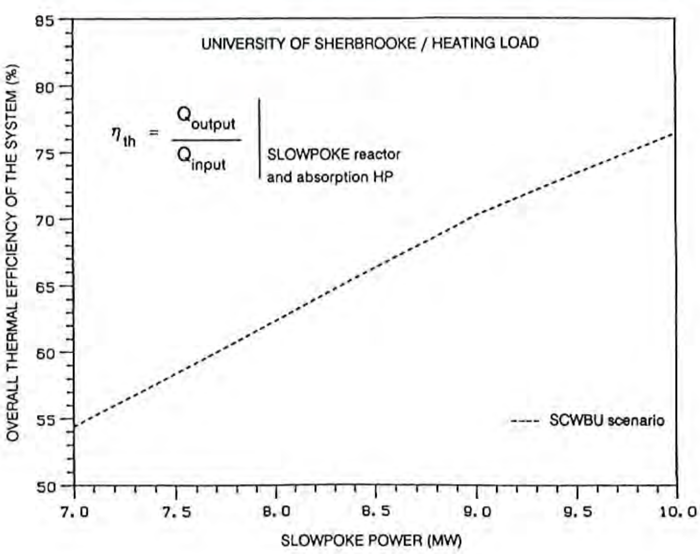

Figure 5. Predicted overall efficiencies as a function of SLOWPOKE power

rejected by the condenser-evaporator of the absorption heat pump can be used to provide domestic hot water or to heat a swimming pool. This eventually enhances the COP of the cogeneration cycle.

Overall efficiency

Because of the limitations imposed by the maximum supply and return temperatures across the boiler, the four feed-heaters with a 10°C temperature rise across feed-heaters pumps are considered as an optimum design condition for the Rankine cycle.

Simulation of the energy needs at the campus of the University of Sherbrooke (see Figure 5) shows the enhancement in the overall efficiency with the use of the SLOWPOKE energy system coupled with an absorption heat pump as a booster unit. In addition, this figure illustrates the effect of operating the SLOWPOKE reactor at different power levels on the overall thermal efficiency of the proposed system.

Conclusion

During the course of this study, the potential application of absorption heat pumps coupled with SLOWPOKE energy system for district heating and cooling has been exploited. A cogeneration cycle was proposed to meet the energy demands in a typical Canadian climate. The overall thermal efficiency of the proposed cycle is significantly higher than that of the SLOWPOKE energy system.

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10. Sami, S. and B. Colombe. "Simulation of Rankine Cycle with Various Freon Refrigerant." Technical report, MEC/87/3, University of Sherbrooke, Sherbrooke, Canada, December 1986.

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New HPC Publications

The following new publications are available from the IEA Heat Pump Center:

Inverter-Driven Heat Pumps: Analysis of Heat Pump Units and Systems

by Halozan, H., O. Katona, and P.V. Gilli
Report Number HPC-R-4, September 1988, 109 pages, cost: DM 50 (US$ 30)

This final report gives the results of an analysis investigating the interaction of inverter-driven heat pumps (variable speed heat pumps) with hydronic heating systems. The tasks carried out in this analysis were the comparison of heat pump units without and with inverter by means of performance characteristics of compressors (contributed by the Japanese industry and the Graz Institute of Thermal Engineering), investigation of sizing criteria of heat pump units, dimensioning of the main components, modes of integration into hydronic systems, and SPF modeling of hydronic heat pump systems. It was determined that inverter-driven units are favorable for heating systems having a low balance temperature. In this case, the avoided cycling and mixing losses are larger than the losses of the inverter. When properly optimized, variable speed heat pumps provide improved performance over single speed heat pumps. Furthermore, the components of a variable speed unit are smaller than those of an equal capacity single speed unit.

Comparison of National Standards Testing and Rating Procedures for Heat Pumps

by Edler, A., and P. Schaup
Report Number HPC-R3-1, 162 pages, cost: DM 50 (US$ 30)

This report, completed in December 1986, gives an analysis and evaluation of relevant heat pump related standards with special emphasis on a comparison of standardized national testing and rating procedures. The investigation was carried out for Austria, Germany, Japan, Sweden, Switzerland, the United States, and France. Since the existence of standards specifically for absorption type heat pumps is unknown, this report emphasizes electrically driven compression type heat pumps. The report is of interest for the planner, installer, and user who needs to understand acronyms such as COP, SPF, and EER as well as their dependence on operating conditions. For the planner and installer, the report provides detailed knowledge of applicable testing and rating procedures. For the manufacturer, the report provides information on relevant national standards, regulations, and laws important for the export of heat pumps.

HPC Publications

The following publications are available from the IEA Heat Pump Center. To order, use the order form on page 39. Contact the HPC for a complete listing of publications. All publications are in English.

National Reports on the Status of Heat Pumps. Report No. HPC-WR-3, 1987, 105 pages, cost: DM 40 (US$ 25).

This publication contains 16 papers from the World Energy Conference (WEC) held in Cannes, France, on October 5-11, 1986. The papers were presented during expert's meeting number two dealing with heat pumps. An overview article, market development paper, and papers from 14 countries are included in this publication.

The overview article, prepared by the WEC task force on heat pumps, discusses the energy aspects of heat pumps and compares them to conventional heat generators. Energy savings, fuel flexibility, and reduction of pollution are a few of the benefits discussed which justify heat pump use. Economic competitiveness was identified as one of the determining factors for further heat pump market penetration. Current products and applications in the private, commercial and industrial sectors are also described. A review of the market development of heat pumps summarizes heat pump market information obtained form the Federal Republic of Germany, Finland, France, Japan, Norway, Romania, Sweden, United Kingdom, and the United States. Energy prices and the availability of information on heat pumps were identified as factors which will continue to strongly influence the market penetration of heat pumps.

Individual reports from the above mentioned countries as well as Austria, Canada, Denmark, the Netherlands, Norway, and China provide details on market situation, government policy, and future prospects for the use of heat pumps.

Proceedings of the Workshop on Ground Source Heat Pumps. Report Number HPC-WR-2, 1987, 245 pages, cost: DM 50 (US$ 30).

This workshop on ground source heat pumps was conducted to examine the status, benefits and opportunities for the use of such systems. The workshop was held in Albany, New York, from October 27-November 1, 1986. Participants at the workshop represented six European and North American countries; they included many internationally recognized leaders in the development and application of systems using the ground as a heat source for heating, and sink for air conditioning, via heat pumps. Some of the main topics addressed included system configuration, markets, utility benefits, soil properties, heat exchanger designs, and installation techniques. An extensive summary of the workshop appeared in the December 1986 (Volume 4, Number 4) edition of the IEA Heat Pump Center Newsletter.

Electric Heat Pumps for Retrofit in Small Residential Buildings (Hydronic Systems). Report Number HPC-WR-1/1-12, 1985, 506 pages, cost: DM 70 (US$ 36).

An experts' workshop was held in Graz, Austria, November 27-29, 1985. 35 experts representing utilities, manufacturers, consultants, and research organizations from IEA Heat Pump Center member countries discussed the technical and economic problems of hydronic heat pump retrofits. The workshop revealed that an expansion of the retrofit heat pump market in Europe will require either lower investment costs or a lower electricity-to-oil price ratio than currently exists. Since manufacturers are unable to significantly reduce the first costs of installed systems at present sales levels, additional governmental and utility programs are necessary to promote the use of such systems.

Background material in this document includes reviews of the national heat pump markets of Sweden, Germany, Austria, Italy, and Japan, as well as parametric study of heat pump economics, regarding variations of first cost, energy prices, climate, and heat pump efficiency. A study of the impact of heat pump utilization on the environment, a workshop guideline, and papers discussing retrofitting with air-water heat pumps and water (brine)-water heat pumps are also included.

Additional conference proceedings (contact the HPC for ordering information):

IEA Heat Pump Conference: Current Situation and Future Prospects. 1984, 645 pages

This conference was held in Graz, Austria, in May of 1984. 48 papers are included dealing with residential, industrial and district heating applications of heat pumps as well as the policies which affect them. European, Japanese and North American viewpoints are represented among the various authors.

Heat Pumps: Prospects in Heat Pump Technology and Marketing. 1987, 573 pages (hard cover)

This publication contains 42 papers presented at the April 1987 IEA Heat Pump Conference in Orlando, Florida. The topics discussed are operating experience with heat pumps in space conditioning; advances in electric heat pumps; industrial applications of heat pumps; thermally activated heat pumps; heat pumps for district heating; economics, marketing, and promotion; and governments' role in energy conservation. Authors come from private industries and government organizations in Europe, North America, and Japan.

First Announcement
The 3rd International Energy Agency Heat Pump Conference

Theme: Heat Pumps - Solving Energy and Environmental Challenges

Purpose: The purpose of this conference is to share between IEA member nations information that can lead to the increased use of heat pumps and to the attendant improvements in the efficiency of the utilization of our energy resources.

Location: Meiji Kinenkan (Meiji Memorial Hall), Tokyo, Japan

Dates: March 12-15, 1990

Speakers: Fifty invited speakers from North America, Europe, and Asia-Oceania will present papers in eight sessions.

Registration: Registration information will be issued in the second announcement.

Official Language: English (Japanese-English simultaneous interpretation is planned)

Session Descriptions:

I **Opening Plenary Session** -- Welcome and opening addresses by the Japan Organizing Committee and Japanese government. Overview presentations on IEA activities and keynote address.

II **Advances in Electric Heat Pumps** -- Prospects for electric heat pumps' technological improvements in performance, economy, and user satisfaction. Discussions on opportunities, costs, resource requirements, and IEA facilitation of such improvements.

III **Advances in Thermally Activated Heat Pumps** -- Progress report on TAHP development: absorption, internal combustion engine-driven, Stirling engine-driven, and chemical heat pumps. Completion dates for these systems will also be discussed.

IV **Industrial and District Heating Applications** -- Industrial and district heating applications, operating experience and economics, potential uses, market prospects and financing, and technological developments.

V **Environmental Aspects** -- Countermeasures for CFC problems and contribution to environmental protection by heat pumps will be discussed.

VI **Operating Experience, Economics, and Marketing** -- Thermal performance, seasonal efficiency, reliability, maintenance, user satisfaction, and marketing.

VII **National R&D Programs and the Government and Utility Role on Advanced Heat Pumps and Protection of Environment** -- Current and projected national R&D programs for advanced heat pumps. The government and utility role in protection of the environment will be discussed.

VIII **Closing Plenary Session** -- A movie on Japan's super heat pump system R&D. Then each session's chairman will discuss future heat pump prospects and the need for international cooperation. A general discussion of this issue will follow.

Pre- and Post-Conference Site Visits: Pre-conference site visit (5 days) and post-conference site visit (1 day) packages are options available to conference participants. These sites will include representative residential, commercial, and industrial heat pump installations, heat pump manufacturing plants, and heat pump laboratories.

Contact:

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Bibliographic Review

Listed below are excerpts from the results of a search in the ENERGY database of STN International. The search was limited to entries made in the database since the beginning of 1987. The terms used for this search included heat pumps and absorption refrigeration cycle. Individuals from member countries may contact the HPC to obtain the complete results of this search, or to request a search on a specific heat pump topic.

STN International, the Scientific & Technical Information Network, provides an on-line computer database service. This service is operated cooperatively by FIZ, Karlsruhe, Federal Republic of Germany; the American Chemical Society, Columbus, Ohio, USA; and the Japan Information Center of Science and Technology, Tokyo, Japan. STN offers over 30 separate databases on various subjects. The ENERGY database contains references of worldwide literature on energy research and technology for all kinds of energy sources. It contains more than 1.5 million citations from journals, reports, books, patents, and conference proceedings, and is updated bi-weekly. The database can be searched on subject terms, titles, authors' names, and other bibliographic information.

Condensing heat exchanger for an absorption-type heat pump. Muehlmann, H.P., W. Wessing, Ruhrgas AG, Essen, Fed. Republic of Germany. Proceedings of the 1987 international symposium on condensing heat exchangers, Columbus, Ohio, USA 14 April 1987, pp. 285-303 (English).

For gas-fueled, single-stage burner, air-to-water absorption-type heat pumps for residential applications (designed for ammonia/water operation), Ruhrgas investigated the use of condensing heat exchangers to improve the efficiency of the heat pump. Following laboratory work on a wide range of different heat exchanger designs, Ruhrgas field-tested a finned-tube aluminum (AlNgSi 0.5) heat exchanger which was installed in the flue systems of ten different heat pump installations for 35,000 hours. The average increase in useful heat output achieved by the condensing heat exchanger was 10%. The coefficient of fuel utilization correlating heat input and useful heat output was also improved by an average 10%. For continuous operation, the average coefficient of utilization was 1.124 for a space heating system operating at a flow temperature of 1580°F and a return temperature of 122 to 680°F and 1.237 for a space heating system operating at flow and return temperatures of 1130°F and 95 to 680°F, respectively. The space heating water passing through the countercurrent flow heat exchanger absorbed an average 68% of the heat carried by the flue gas. An increase in the size of the heat exchanger surfaces improved this ratio to more than 80%, but the improved heat transfer from flue gas to the space-heating water did not raise the coefficient of fuel utilization substantially, showing that the small increase in efficiency does not warrant the cost of the large heat exchanger. The optimum condensing heat exchanger size was 1.7 square feet for each kilowatt of heat pump rating.

Development of condensing type high-efficiency gas absorption chiller/heater. Kannoh, S., S. Kurosawa, S. Takemoto, S. Takabatake, Osaka Gas Co., Ltd., Japan. Proceedings of the 1987 international symposium on condensing heat exchanger, Columbus, Ohio, USA, 14 April 1987, pp. 269-283 (English).

In Japan, it has been more than 17 years since the double-effect type gas absorption chiller/heater was developed for building air-conditioning. This type of unit has been increasing in popularity year by year for the reason of low cost, energy saving and ease of operation, and it has occupied a large market share in central air-conditioning buildings. However, a highly efficient motor-driven chiller and heat pump have been put on the market, and competition is now becoming keener in an energy-saving aspect. Consequently, in order to save more energy than with the current absorption chiller/heater, a condensing type high-efficiency gas absorption chiller/heater is being developed for the purpose of recovering the latent heat in the exhaust gas to enhance the cooling/heating efficiency. This system makes it possible to achieve a cooling COP of 1.3 (for approx. 1.0 at the conventional double effect type), and heating COP 0.95 (for 0.85 at the conventional type). Further, in order to select the optimum corrosion-resistant material for a condensing type heat exchanger, long-term durability tests for different types of materials are being performed. This project started in 1984, a prototype of 100 RT was designed and manufactured in 1986, performance tests followed in 1987. This project will be completed early in 1988. The condensation heat recovery effect, and the interim evaluation of long-term durability tests for various materials which are being tested in Osaka Gas R&D center are discussed.

Construction and testing of an absorption heat transformer with new materials. Kernforschungsanlage Juelich GmbH, Projektleitung Biologie, Oekologie, Energie. Conference: Status seminar on the rational use of primary and environmental energy in building construction, Koblenz, 28 April 1987, pp. 467-474 (German).

Absorption heat transformers make it possible to raise waste heat to a higher temperature level without supplying expensive energy and therefore to make it possible to reuse it. The pairs of working materials previously used in such heat transformers led to some unfavorable properties. The aim of a study explained in detail was to find new materials for use in absorption heat transformers and to produce a pilot plant with an output of 100 kW for the pair of materials trifluoroethanol and tetra-ethylene glycol dimethyl ether. The phase equilibria (temperature-concentration diagram) were obtained for several pairs of materials with water as one material. Steam is used as the source of heat. The waste heat in the condenser is absorbed in the cooling water, which is heated from 15 to 20 deg C.

Popular heat pump in the sense of a particularly cheap absorption heat pump for detached houses and blocks of flats. Kernforschungsanlage Juelich GmbH, Projektleitung Biologie, Oekologie, Energie. Conference: Status seminar on the rational use of primary and environmental energy in building construction, Koblenz, 28 April 1987, pp. 451-459 (German).

Development work was done with the aim of producing a cheap gas absorption heat pump (GAWP) (cheaper than others on the market). Details of this "optimization development" are given, together with sketches and tables of technical data. Complete equipment for the heat sources water/brine and air was built and examined. A modular system was aimed at. The absorption circuit is secured by a safety pressure and a safety temperature limiter. The equipment costs are given for four variant models (material and total costs). Compared with the cost of 16,550 DM for a heat pump built in 1982, a GAWP with the same output of 22 kW of the L type could be manufactured for only 9,070 DM. This GAWP can make a considerable contribution to energy saving.

Performance analysis of ammonia-water vapor absorption heat transformer. Ertas, A., P. Gandhidasan, J.J. Luthan, Mechanical Engineering Dept., Texas Tech Univ., Lubbock, TX, USA. Technical economics, synfuels and coal energy - 1987. Dicks, J.B. New York, NY: American Society of Mechanical Engineers, 1987, pp. 51-58 (English).

Many industrial sectors reject heat to the atmosphere in the form of hot water with a temperature between 400 and 70 deg C. This low grade heat can be upgraded by using a vapor absorption heat transformer (AHT). The present study considers a single stage AHT with binary mixture of NH_3-H_2O as the working fluid. The performance characteristics of the system have been evaluated by solving the governing energy balance equations using a digital computer.

An ammonia/water transformer absorption refrigeration cycle for low temperature solar applications. Kouremenos, D.A., National Technical Univ. of Athens, Athens, Greece. Solar engineering - 1987, New York, NY: American Society of Mechanical Engineers, 1987, pp. 835-840 (English).

Although many pairs of working fluids have been proposed, investigated and tested for potential use in heat-driven absorption refrigeration units, only the binary mixtures of lithium bromide/water and of ammonia/water have been successfully proven and have found a wide commercial application. Solar heat-driven absorption refrigeration units must accordingly use one of these two pairs. If, in addition, refrigeration temperatures lower than 0 deg C are required, the only pair available is the binary mixture of ammonia/water. To run an air-cooled ammonia/water absorption refrigeration unit, a high pressure of 20 to 25 bar is usually required. Further, a weak solution mass fraction of about 10% is needed if the refrigeration has to start at or to remain at the -30 deg C temperature level. To achieve these values, the heat input required to drive the unit must be available at temperature levels close to 180 deg C. Since the heat delivered by the commercially available solar collectors is usually of a lower temperature level, it is proposed to use a heat-driven heat transformer to boost the temperature of part of the solar heat available, in conjunction with an absorption refrigeration cycle.

Theoretical analysis of an absorption heat pump with continuous regeneration of working fluids by solvent extraction. Cheng, C.-S., and Y.S. Shih. Chem. Eng. Res. Des., Sep 1987, v. 65(5), p. 415-420 (English).

A new type of absorption heat pump is proposed by using a second liquid to extract the refrigerant from the dilute absorbent solution in the absorber. The proposed system gives a better thermodynamic efficiency eta than the traditional absorption heat pump. The calculated eta value reaches as high as 0.73 which is about 50% higher than the conventional one. Using LiBr/H_2O/acetophenone as an example, this paper presents the thermodynamic feasibility, the concept design and the operation analysis of the proposed plant.

Energy storing absorption heat pump process. Lourdudoss, S. and H. Stymne. Int. J. Energy Res., Apr-Jun 1987, v. 11(2) p. 263-274 (English).

A novel process, named the super solution field absorption process, for storing and pumping heat is described. This makes use of a solid-salt-solution transformation through the absorption of a suitable fluid. Six working pairs are considered and are analyzed using their enthalpy-concentration diagrams. Although their heat pumping COPs are slightly lower than those of the corresponding conventional systems making use of an (unsaturated) solution 1-solution 2 transformation (through fluid absorption), their storage densities are high enough to be compared to those of the systems using solid 1-solid 2 transformation (through fluid absorption). The operation parameters of the pairs considered suggest that four of them can pump heat from natural thermal sources of a cold climate for space heating, although all six can be regenerated by means of solar collectors.

Errata: In Volume 6, Number 3, September 1988, on page 35, the ordering information for **IEA Heat Pump Conference: Current Situation and Future Prospects, Proceedings and Conclusions**, was incorrectly listed. The correct information is as follows: Mr. W. Hochegger, Energiesparhaus Graz, Petersgasse 45, A-8010 Graz, Austria.

Feedback

Environmental Aspects of Absorption Technology

A remarkable change of interest in the energy saving community can be noted. If you meet heat pump researchers, they do not talk much about heat pumps any more but now about refrigerators. Energy saving is still considered to be very important, but more important is the environmental aspect of human activity in using energy. Particular concerns such as the depletion of the ozone layer (the green-house effect), caused mainly by CO_2 but also by other infrared absorbing gases like NO_x, CH_4 or chlorofluorocarbons; the pollution of the oceans, rivers, and lakes by industrial waste water and acid rain; and the pollution of drinking water by chemicals of different sorts, e.g., pesticides, have finally been brought to the attention of the public and of government authorities.

Some people think that refrigeration technology is presently experiencing the largest change in its history. The situation about replacements for refrigerants like R12 by new fluids or mixtures of fluids is rather unclear. Also unclear is the future use of R22, and whether replacements or mixtures of fluids will make it. Therefore, traditional fluids like NH_3 or absorber systems are experiencing renewed interest. Indeed, H_2O/LiBr can be used very effectively for air-conditioning and water chilling as it is demonstrated in Japan. NH_3/H_2O is usable for deep freezing. Other fluid combinations are under test for absorption applications.

The recently developed know-how about absorption technology may even have additional impact on environmental protection and pollution reduction besides refrigeration. Some of the advanced absorption cycles are now maturing to be ready for commercial and industrial use. Advanced heat transformers (heat pump, type II) with high temperature lift or the family of heat pump transformers (heat pump, type III) are examples.

Some of the following application areas should serve to demonstrate the potential for energy saving and environmental protection involved in this technology.

District heating

Supply of high-pressure steam (e.g., 5 bar, 150°C) to industrial and commercial enterprises, hospitals, etc., by installing heat transformers into conventional district heating systems (100-120°C) -- Cogeneration is one of the best techniques for energy saving and pollution reduction. With respect to primary energy use, the supply of heat with 80°C to 120°C extracted from a condensing power station is equivalent to the operation of an electrically driven heat pump with a COP from 8 to 5.

Many cities, particularly in the Scandinavian countries, in Russia, Hungary, Czechoslovakia, Poland, Romania, but also in Germany and Austria, already have such networks. By heat transformers, the application of this technology can be expanded without installing expensive high temperature steam networks.

Air conditioning of office buildings, schools, hospitals, etc., by using district heating networks in combination with advanced absorption air conditioners -- Compared to electrically driven compressor systems, this combination needs about 35 to 40% less primary energy. Furthermore, no fluorocarbons are required. With engine-driven power stations, the waste heat can be used to operate chillers or refrigeration machines.

Chemical engineering

Concentrating of industrial waste water or corrosive solutions, like sulfuric acid, using an energy saving heat supply system as, for example, the heat pump transformer (heat pump, type III) -- COPs up to 4.0 are expected. By this method the efficiency is as good as for a multi-stage system, but the corrosive or dirty material comes into contact with only a small number of heat transfer surfaces, perhaps only one.

Water desalination by using efficient absorption devices as heat supply systems -- The actual separation process can be limited to a small number of stages and shifted into a favorable temperature regime without loss in efficiency.

Heat recovery and upgrading by heat transformers.

Power and incineration plants

- Stackgas purification of waste incineration plants by absorption cooling (example, Uppsala)
- Condensation of sulfuric acid from stack gases by absorption cooling
- Preheating of water in power stations or for steam generators

Refrigeration and heating

Advanced double-effect absorption chillers, as they are widely used in Japan today, can be switched into a heat pump mode for providing hot water for hotels, restaurants, etc., or for heating purposes. Absorption or combined absorption-compression technology can be used for reduction of CFC emissions.

These examples serve to demonstrate that absorption technology not only bears the potential to contribute to energy saving but also, and presently more important, to environmental protection.

G. Alefeld, Technische Universitaet Muenchen, Muenchen, FR Germany

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We invite you to send your Feedback (comments, ideas, criticisms, opinions) on this issue, or any heat pump-related topic, to the Editor. See HPC address on back cover.

News Briefs

Absorption Technology Workshop

The first working meeting of Annex XIV "Working Fluids and Transport Phenomena in Advanced Absorption Heat Pumps" of the IEA Implementing Agreement for Advanced Heat Pumps was held at the Institute of Gas Technology (IGT) in Chicago, Illinois, USA, September 19-20, 1988. Sixteen specialists participated in this meeting from Denmark, Germany, Sweden, and the United States. Japan is acting as the operating agent for this project.

On the first day, Professor Takamoto Saito from the University of Tokyo, Japan, chaired the workshop. The literature survey in progress, absorption fluids data, advanced cycles, and transport phenomena were discussed. After the workshop, the participants visited the research facilities of the IGT.

The second day focused on the current situation of R&D of absorption technology. Mr. R.C. DeVault of Oak Ridge National Laboratory and Mr. R.C. Macriss of IGT chaired this seminar. Topics covered were R&D on working fluids, transport phenomena in absorbers, solar absorption refrigeration, air-cooled absorption chiller heaters, absorption heat pumps, resorption heat pumps, and absorption heat transformers.

The next meeting is scheduled for May 28-29, 1989, to be held in Sweden. The final meeting will be held in Japan in the fall of 1989.

The official starting date for this Annex was December 1, 1987, and the initial term was 18 months. The participants expect to conclude this Annex in December 1989.

IEA Activities on the CFC Problem in Heat Pump, Refrigeration, and Air Conditioning Equipment

The following is a summary of IEA activities on the CFC problem including the seminar which was held in Rome, Italy, May 30-31, 1988. This report was prepared by Prof. Thore Berntsson, Chalmers University of Technology, Sweden.

Introduction

In the IEA Advanced Heat Pumps Executive Committee meeting held in Paris, October 16, 1987, it was decided to start activities to cope with the CFC problem. Sweden should take the lead in these activities. The author of this article was appointed to be in charge of this work, and the funds for it have been provided by the Swedish Council for Building Research. The activities have been carried out in accordance with the decisions made in Paris. The main tasks were to distribute questionnaires to IEA countries, to put together a report on the questionnaires, and to organize an IEA seminar.

The questionnaires to the IEA countries were distributed to government authorities and agencies as well as research organizations. The aims were to collect information concerning ongoing and planned R&D activities and illustrate attitudes towards various measures. The final report will be distributed to all delegates of the IEA Advanced Heat Pumps Executive Committee for further distribution in their countries.

The aims of the seminar were:

-- To discuss advantages and drawbacks for various future solutions

-- To define needs for further R&D activities

-- To propose R&D projects suitable for international cooperation within IEA

The seminar covered a whole range of subjects: present and planned situation concerning regulations, norms, recommendations, etc.; presentations and discussions on future possible measures; ongoing and planned R&D activities; and need for further R&D activities as well as possible new IEA annexes.

The proceedings from the seminar consist of all overheads shown in the various presentations, summaries of the discussions in the four main sessions, general conclusions and suggestions for further activities. They have been distributed to all participants and Executive Committee delegates.

In addition to these activities, several new annexes dealing with the CFC issue are now ongoing or planned. Some results from the questionnaires and the seminar are presented below.

Results from the questionnaires

An important part of the questionnaires was to collect attitudes towards various short- and long-term measures to deal with the CFC problem. The results are summarized below.

Measures in existing plants (measures for service, maintenance, and special measures during repair) -- In most answers, constructive measures of this kind are given the highest priority. Several point out the need for well-educated maintenance personnel. Codes of good practice and guidelines must be revised and used. Also pointed out is the need for periodical inspections, tightness control, and the establishment of an information channel in which experiences concerning component and material choices can be exchanged across company and country borders. Recycling possibilities of used refrigerants as well as an appropriate refunding or other economic system for this must be developed.

In one response, the attitude towards constructive measures is very pessimistic. Due to poorly educated personnel, this will never work worldwide and the only possibility to cope with the problem is to forbid R12 quickly.

It has commonly been considered practical and economic to put in an extra tank for the refrigerant during repair. In small systems, portable units can be used. The leakage during repair is considered to be a major source of leakage.

Exchange of R12 (R500, etc., flammables, and nonazeotropic mixtures) -- Exchange of R12 to, for example, R500, is thought to be technically possible in several types of plants, especially larger ones, but a general view seems to be that the improvement of the ozone depletion factor is so small that the potential for this measure is very small, even in a transition stage.

The future potential of flammable fluids in plants not designed for them is believed to be negligible.

The views on nonazeotropic mixtures in existing plants diverge somewhat. Some believe that there is a potential in certain applications although effects on capacity, heat transfer, lubrication and the need for modification of, for example, the control device, must be taken into account. General knowledge and experience with these mixtures must also be increased. Others believe that the changes necessary in existing plants will be too many which, together with leakage problems, results in a negligible potential. A general consensus seems to be that it is better to modify the newer plants and phase out the older plants.

Measures in new plants, a few years' sight -- Here, too, construction measures, improved mechanical construction and design are given high priority. There is a general feeling that today's systems can be improved considerably in these respects. Among the measures for improved mechanical construction, the use of more soldered and welded connections is mentioned. For improved design the use of indirect systems and direct expansion are suggested. However, there is also one critical view about this which says that such solutions lead to less efficient plants.

Another measure is to increase the operating pressure so that R22 can be used. The views on this measure diverge. Some see this as one of the most important ways of reducing the use of R12. The critics see such a development as having the same time perspective as the introduction of new fluids. There is also a risk that R22 might be prohibited and that it, therefore, is a short-term solution. The problem is mainly economic, not technical. High-pressure compressors must be developed (today only large turbo compressors exist) and, at least for larger capacities, the production figures are too small to interest any manufacturer.

The views on the future potential for ammonia also diverge. Several are of the opinion that due to its acute toxicity, high pressures, and high compressor outlet temperature, the use of ammonia can be of future interest only in larger industrial, refrigeration and freezing plants. Some see that it is an important measure in several types of future applications. There is also a need for education on practices with ammonia since ammonia needs very well-educated personnel. There is also a need for component R,D&D and experimental/demonstration (exp/demo) plants.

Even if the system is designed for a flammable fluid, there seems to be a relatively strong resistance towards such fluids in most types of applications except industrial ones. This is somewhat surprising when one considers the large quantities of, for example, hydrocarbons, handled in society in other circumstances. There is mention of a possible potential in small hermetic systems if R134a fails to enter the market.

For nonazeotropic mixtures in new plants, more R&D work seems to be needed as well as exp/demo plants.

The general attitude towards mixtures, also in this rather short time perspective, is positive. Some believe them to be one of the most interesting possibilities in new plants, at least in some types of applications, to replace R12. The other view is that mixtures will be of general interest only if R134a fails to enter the market. Problems with leakage/refill, heat transfer, and control are mentioned.

Measures in new plants, 5-10 years' sight -- It is clear from the answers that the most interesting single fluid over the long term is R134a. However, in several answers there is a concern about the actual time of availability. Due to the need for basic R&D, education of personnel, time for implementation, experience from experimental plants, etc., there is a concern that large-scale introduction may take at least ten years or more. The known or suspected problems with R134a concerning performance, capacity, heat transfer, and oil miscibility mean that the competition with alternative solutions, such as the ones discussed above, might be unfavorable for some applications. An important aspect is if manufacturers and users, from both a technical and economic point of view, can accept a larger variety of fluids on the future market so that the best fluids for each application can be selected, or if we must concentrate on finding one or two fluids as a universal replacement for R12.

It is also pointed out that over the long term, new nonazeotropic mixtures, including hy-drocarbons (where the mixture is nonflammable) and without R22 probably can be available.

In a long-term perspective, there seems to be a generally positive attitude towards alternative processes at least in some types of applications. Especially solution cycles (compression/absorption) are mentioned. Also the Joule and Stirling cycles may be of interest if R134a fails to enter the market.

Results from the seminar

In the seminar, thirty-five specially invited experts from twelve countries participated. The general conclusions from the discussions are summarized below.

The restrictions on the use of some CFCs already imposed internationally (Montreal Protocol), nationally, or those being discussed will mean changes in refrigeration and heat pump equipment, which will have an enormous worldwide impact both technically and economically.

There exists a large variety of possible solutions to cope with the CFC problem over the short and long term. However, today no single long-term solution can be seen with such large technical and economic advantages that it will rule out all other solutions. Due to the reductions of CFCs needed and the decisions taken on the time frames for this, different possible solutions must be evaluated quickly in a period of a few years. Decisions made without proper knowledge of the various alternatives can lead to serious economic and technical impacts.

Government agencies and authorities must play an important role in this work due to the fact that the necessary changes will have a large impact on society. For this reason, experimental and demonstration (exp/demo) plants will be crucial in this work. An important part of that must be made in an independent way, i.e., by government actions of various kinds.

For the necessary work, international cooperation is crucial. It is important that duplication of work be avoided and that exchange of information between countries be done at an early stage of R&D work. Cooperative efforts also mean that results can be made available early. The International Energy Agency (IEA) is the appropriate organization for such international cooperation activities.

International cooperation is needed on the software (R&D on fluids, components, cycles) side and on the hardware (exp/demo) side.

The need for exp/demo plants is urgent. This is one of the best ways of evaluating various possible solutions. There is a need for such plants to demonstrate the use of: new fluids, azeotropes and "near"-azeotropes; nonazeotropic mixtures; ammonia and flammable fluids; and alternative compression cycles.

Exp/demo plants are needed in both small-, medium-, and large-scale applications. They can be placed either in the field or in a laboratory, in which the behavior of the whole system can be tested.

The purpose of exp/demo plants is:

-- To investigate all types of practical problems in real plants

-- To demonstrate that the type of plant in question can be used in practice

-- To identify possible applications

-- To compare experimental results with theoretically calculated results

Due to the importance of exp/demo plants, projects for initiation of such plants must have high priority. Such projects can be done as IEA annexes that are working on the CFC issue.

The following further activities were identified by the seminar participants as having the highest priority:

-- A written statement from the Executive Committee of IEA Advanced Heat Pumps shall be made in which the severity of the situation is pointed out. The need for government activities in R&D and exp/demo plants, as well as international cooperation, shall be stressed.

-- Establishment of a task force for initiation of international cooperation in the exp/demo plants area. The task force shall compile a list of known existing and planned exp/demo plants worldwide, make a priority list on the need for further plants, investigate possible, practical, and economic ways for international cooperation in this area, and suggest in detail the approach to be used in the annex(es) for exp/demo plants.

Suggestions for new annexes -- Several areas were suggested for new annexes, such as:

-- Data base for new fluids. Aspects to discuss further are types of properties to be included, types of fluids to be included (pure fluids, mixtures, etc.), means and amount of work for critical evaluation of data format (document, computer based).

-- Flammability aspects for new fluids and mixtures, theoretical calculations, methods and experimental results.

-- The compression/absorption (solution) cycle. An investigation of the state of the art and task sharing on important research areas.

-- Systems with ammonia and flammable fluids. Safety aspects and identification of the possible applications. One of the goals of this annex would be to initiate exp/demo plants using these fluids.

Schedule of Conferences and Trade Fairs

January 16-18, 1989

Gothenburg (Sweden); **Third Workshop on Solar Assisted Heat Pumps with Ground Coupled Storage.** Contact: Jan-Olof Dalenbaeck, CTH/Installationsteknik, S-412 96 Gothenburg, Sweden.

January 28-February 1, 1989

Chicago, Illinois (USA); **1989 ASHRAE Winter Meeting**. Sponsored by ASHRAE. Contact: Judy Marshall or Judith Breese, ASHRAE International Headquarters, 1791 Tullie Circle, N.E., Atlanta, Georgia 30329, USA, telephone 01-404-636-8400, telex 705343.

January 30-February 2, 1989

Chicago, Illinois (USA); **International Air-Conditioning, Heating and Refrigerating Exposition.** Sponsored by ASHRAE and ARI. Contact: International Exposition Company, 200 Park Avenue, New York, New York 10166, USA, telephone 01-212-986-4232.

March 7-9, 1989

San Francisco, California (USA); **Energy Utilization Symposium.** Sponsored by Electric Power Research Institute, Palo Alto, CA, USA. Contact: EPRI, Attn: D. Rigney, P.O. Box 10412, Palo Alto, CA 94303, USA.

March 13-15, 1989

Gembloux (Belgium); **Internationales Seminar ueber die Abwaermenutzung in Kernkraftwerken.** (International seminar on utilization of waste heat from power stations.) Sponsored by the Commission of the European Communities, Directorate General for Energy, and the Food and Agriculture Organization of the United Nations. Contact: Faculte des Sciences Agronomiques et de l'Etat, Attn: Prof. J. Deltour, 8, Ave. de la Faculte, B-5800 Gembloux, Belgique.

April 17-21, 1989

Hobart (Australia); **Federal Conference and Exhibition of the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH).** Sponsored by AIRAH. Contact: Australian Institute of Refrig., Air Conditioning and Heating (Inc.), P.O. Box 1533R, G.P.O., Hobart, Tasmania 7001, Australia.

May 1989

London (UK); **Industrial Energy Management Conference.** Sponsored by the Institute of Energy, London. Contact: Institute of Energy, Conf. Dept., 18 Devonshire St., London W1N 2AU, UK.

May 1989

Prague (Czechoslovakia); **Symposium on the Optimum Use of Primary Energy Resources in Final Heat Consumption.** Sponsored by the United Nations, Geneva, Switzerland, and the Economic Commission for Europe. Contact: UN ECE Energy Division, Palais des Nations, Attn: F. Romig, CH-1212 Geneva 10, Switzerland.

June 7-8, 1989

Essen (FRG); **Tagung ueber Blockheizkraftwerke und Waermepumpen: Betriebserfahrungen unter aktuellen Umweltschutz- und Wirtschaftlichkeitsaspekten.** (Seminar on Cogeneration and Heat Pump Systems: Operating Experience in Light of Environmental Protection and Economics.) Sponsored by Verein Deutscher Ingenieure (VDI) - Gesellschaft Energietechnik, Duesseldorf. Contact: Verein Deutscher Ingenieure, Abt. Tagungen, Graf-Recke-Str. 84, Postfach 1139, 4000 Duesseldorf 1, FR Germany.

June 24-28, 1989

Vancouver (Canada); **1989 ASHRAE Annual Meeting.** Sponsored by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Contact: ASHRAE International Headquarters, 1791 Tullie Circle, N.E., Atlanta, Georgia 30329, USA, telephone 01-404-636-8400, telex 705343.

August 6-9, 1989

Philadelphia, Pennsylvania (USA); **National Heat Transfer Conference and Exhibition.** Contact: American Society of Mechanical Engineers, United Engineering Center, 345 East 47th St., New York, NY 10017 USA.

August 28-September 1, 1989

Sarajevo (Yugoslavia); **CLIMA 2000 (The 2nd World Congress on Heating, Ventilating, Refrigerating and Air Conditioning).** Sponsored by the Federation of Representatives of European Heating and Ventilating Associations (REHVA), ASHRAE, and IIR. Contact: Organizing Committee of CLIMA 2000, Masinski fakultet, Prof. Dr. Emin Kulic, 71000 Sarajevo, Omladinsko setaliste bb, Yugoslavia, telephone 071/642071, telex 41 529 IPES YU.

September 18-21, 1989

Seoul (Republic of Korea); **International Conference and Exhibition on Energy Sources Management and Energy Saving Technology and Equipment (KORENERGY '89).** Contact: SHK International Services Ltd., 22/F, 151 Gloucester Road, Hong Kong.

October 18-22, 1989

Saarbruecken (Fed. Rep. of Germany); **Internationale Messe fuer Energietechnologie, Energieeinsparung, Umweltschutztechnik und Umweltfreundliches Bauen (Energie und Umwelt '89).** (International trade fair of energy savings, technology, environmental protection and construction kind to the environment.) Contact: Saarmesse GmbH, Messegelaende, 6600 Saarbruecken, FR Germany.

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HPC-WR2*	Proceedings of the Workshop on Ground-Source Heat Pumps (1987), 245 pages	DM 50,--/U.S. $30
HPC-WR3	National Reports on the Status of Heat Pumps (1987), 105 pages	DM 40,--/U.S. $25
HPC-R2-1*	Heat Pump RD&D Projects Summary Report, Edition 2 (Dec. 1986), 514 pages	DM 50,--/U.S. $26
HPC-R3-1*	Comparison of National Standards Testing and Rating Procedures for Heat Pumps (December 1986), 162 pages	DM 50,--/U.S. $30
HPC-R-4*	Inverter-Driven Heat Pumps (September 1988), 109 pages	DM 50,--/U.S. $30
HPC-LR-3*	HPC Bibliography - Sorption Heat Pump Systems (Oct. 1986), 372 pages	DM 20,--/U.S. $11
HPC-LR-2*	HPC Bibliography - Industrial Heat Pumps (July 1986), 378 pages	DM 20,--/U.S. $11
HPC-WR-1/1-12*	Workshop: Electric Heat Pumps for Retrofit in Existing Small Residential Buildings (1985), 13 separate reports, 506 pages	DM 70,--/U.S. $36

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Vol/No	Topic	Deadline for Contributions
7/1	Prospects in industrial heat pumps - process integration	January 7, 1989
7/2	Heat pumps and the environment	April 7, 1989
7/3	Heat pumps - heating and cooling	July 7, 1989
7/4	Planning for the future: national R,D&D programs, incentives, codes, and standards	October 7, 1989

If you would like to contribute an article on any of these topics, please contact the Heat Pump Center to obtain a copy of our author guidelines. Our regular features (feedback, bibliographic review, news briefs, and schedule of conferences and trade fairs) will also be included.

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