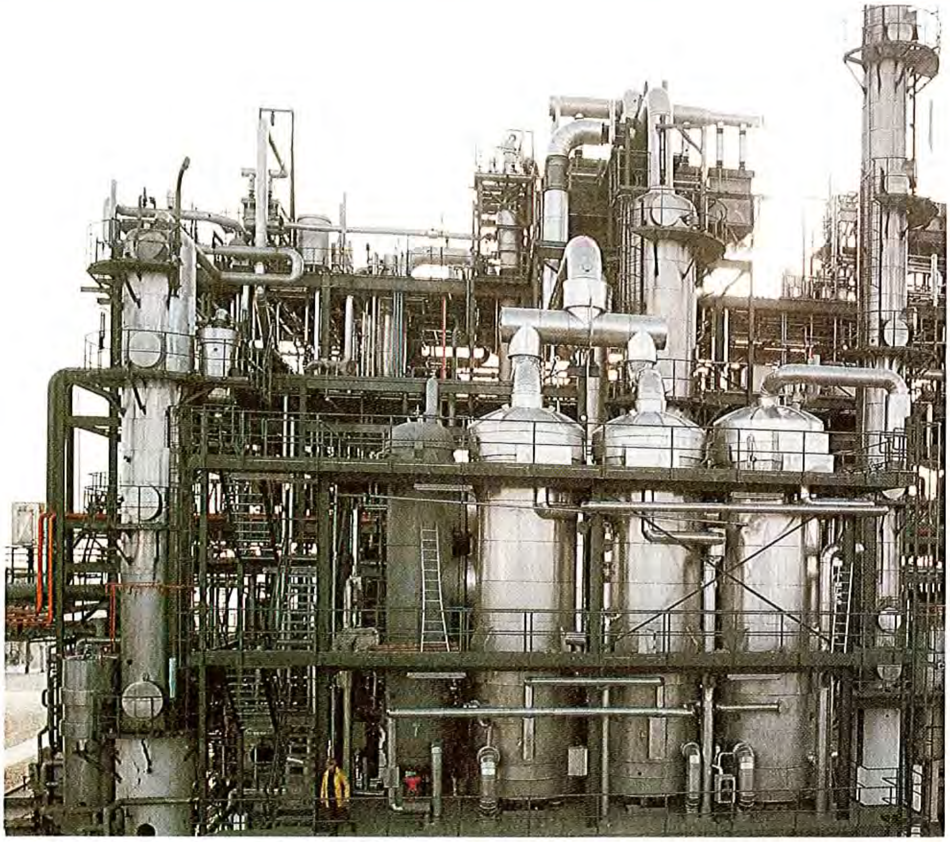
ISSN 0724-7028

NEWS LETTER

PERIODICAL OF THE
IEA HEAT PUMP CENTER

IEA heat pump center

VOL 4, NO. 2, JUNE '86



6.4 MW heat transformer in Delfzijl, the Netherlands (see page 20)

Contents **Page**

A. Lehmann*

The Industrial Heat Pump

In spring 1986, the IEA Heat Pump Center started an investigation on the status and future prospects of industrial heat pump applications. Previous investigations have shown that broad generalizations regarding industrial heat pump applications cannot be made at present. The reasons for this difficulty are several, the most important being:

- uncertainty about future energy prices,
- discussion about the future role of nuclear energy,
- differences in national energy programs,
- the broad spectrum of possible applications,
- the large number of different heat pump systems now available or under development.

At the same time, the potential for industrial heat pumps is promising. It is estimated that in highly industrialized countries up to 20% of industrial primary energy demand can be saved by the application of heat pumps (e.g. Japan) [1]. In several countries strong efforts are being made to assist the introduction of industrial heat pumps. The European Community and the governments of Japan, Sweden, the Netherlands, and the United States provide considerable funding for projects and demonstration plants.

The industrial heat pump has to compete with several alternative technologies, such as modern boilers, regenerators, recuperators, and heat pipes, with regard to profitability, primary energy savings, recovery of waste heat and reduction of environmental impacts. The following requirements must be met for the industrial heat pump to prevail against these alternatives:

1. manufacture of industrial heat pumps with lower first cost;
2. development of heat pumps with output temperatures in the range of 150-300°C, temperatures necessary for many industrial processes;
3. intensive and detailed analysis of different types of industrial heat pumps for specific branches of industry;
4. better adaptation of process technologies to heat pump applications;
5. increased cooperation among all persons involved in industrial heat pump applications, especially between process engineers and heating system engineers;
6. increased collection and dissemination of information about existing plants and operating experience.

Several techniques are now being used or are under development for high-temperature industrial heat pumps. For output temperatures above 150°C, only heat transformers, mechanical vapor compressors and steam jet compressors are currently available technologies. The search for suitable refrigerants, refrigerant mixtures and more effective compressors for compression heat pumps is continuing. In the case of sorption systems, work is now being done on new working fluid mixtures, improved component design and more effective system schematics.

To better adapt the heat pump to the boundary conditions of industrial processes, two-stage vapor compressors, vapor compressors for working media other than water vapor, and Brayton-cycle heat pumps for heat recovery from exhaust air containing harmful or recoverable substances are being developed. These and further development projects are discussed in detail in the articles that follow in this Newsletter.

Experience gained from demonstration projects and industrial heat pump installations represents an important contribution towards improved system design and therefore increased profitability of the industrial heat pump. The IEA Heat Pump Center is currently involved in several activities to make these experiences available to a large group of interested persons. The database "INSTAL" contains technical information for more than 300 installed heat pump plants, of which about 20% are industrial heat pumps.

The current version of the HPC's Research, Development and Demonstration database includes 91 industrial heat pump projects started between 1976 and 1985. These projects are in the following countries:

Country	Projects
Austria	2
Belgium	2
France	6
F.R. Germany	35
Great Britain	4
Ireland	3
Italy	4
Japan	6
The Netherlands	2
USA	27

Several additional RD&D projects are reported on in this issue.

Finally, the HPC staff has conducted extensive literature searches, to identify the most important and current developments in the field of industrial heat pumps. Based on these searches, the staff has put together a bibliography of the key publications concerning industrial heat pumps. (See page 28 for a brief excerpt; this literature review can be ordered using the card on the last page of this Newsletter.)

Over the next few years, all those involved in this field must make great efforts to take full advantage of the theoretical potential of the industrial heat pump, to increase primary energy savings, to improve industrial processes, and to reduce impacts on the environment. This includes making use of all opportunities to apply industrial heat pumps when considering new investments.

Reference

1. "The Development of the Super Heat Pump Energy Accumulation System." New Energy Development Organization, January 1986, Tokyo, Japan.

A. Lehmann, IEA Heat Pump Center, Karlsruhe, F.R. Germany

HPC Interview

Prospects for Heat Pumps in Industry

In conjunction with the focus of this Newsletter on industrial heat pumps and the ongoing study on industrial heat pump applications at the Heat Pump Center, HPC staff members Dr. Axel Lehmann and Margaret Meal recently met with Dr. Jan Berghmans, professor of Mechanical Engineering at the Katholieke Universiteit Leuven, Belgium, for discussions on his work on industrial heat pumps and for a tour of lab facilities. Prof. Berghmans, chairman of the IEA Executive Committee on Advanced Heat Pumps and lead researcher for the IEA Annex III on Industrial Heat Pumps, has done extensive research on both the technical and economic aspects of industrial heat pump applications. His findings and perspectives on the future of industrial heat pumps are summarized in this article.

Prof. Berghmans sees a positive future for industrial heat pump applications. In his view, the next steps for further penetration of presently available heat pumps in the industrial sector are a better understanding of those processes best suited to heat pump application, and broader dissemination of technical and economic results from actual installations to industrial decision makers. Wide application of heat pumps in industry will ultimately depend, of course, on economics, and on economics extending beyond energy prices. A strengthening of the economy in general, industrial renewal, and consideration of all the benefits of heat pumps in industry are all important factors that will contribute to the wide-spread installation of heat pumps in industry in the near future.

Experience to date

Prof. Berghmans has worked on several projects that have evaluated the success of heat pumps in actual installations. Experience from these case studies has shown that it is often the side benefits of the heat pump, not the energy savings, that make the installation a complete success. He cites, for example, a case in Belgium where an industrial heat pump is used to extract heat from cooling water. Before installation of the heat pump, cooling water was taken from groundwater wells, and new wells had to be drilled every few years. Ultimately, the water table would drop, preventing expansion of plant capacity. The savings resulting from reduced wellwater consumption with installation of the heat pump were as great as the energy savings themselves. Such side benefits exist in many industrial heat pump applications, but the only way to evaluate these added benefits is by studying existing installations in detail.

Processes best suited to heat pumps

Prof. Berghmans lists the following as the most promising applications for heat pumps in industry:

- drying processes (e.g. wood drying)
- heat recovery
- applications that require simultaneous heating and cooling

At present, it is impossible to estimate how many heat pumps of what capacity can be applied in specific industrial sectors. Such an estimation requires a detailed multi-year analysis of various industries. Currently, the only analysis that can be made is a comparison of heat pump applications for a specific industrial process across different countries. As an important first step in further analysis, Prof. Berghmans' research has developed correlations that can then be used to identify attractive opportunities for heat pumps. For example, his work has determined correlations for evaluating the economics of industrial heat pump applications. His theoretical studies showed the relationship between heat pump capacity and first cost to be less than linear, specifically

Heat pump first cost = A x $(\text{capacity})^{0.7}$,

where A is a constant (see Fig. 1).

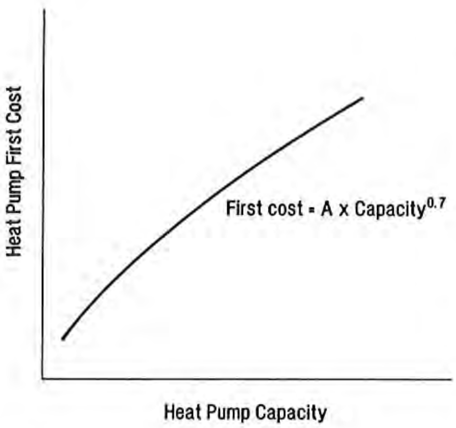


Fig. 1. Correlation between heat pump capacity and first cost

This relationship results in system sizing having a significant impact on project economics. Case studies have been in close agreement with this correlation.

Shared information

Perhaps most important, dissemination of results from case studies and demonstration projects is a key step towards building the confidence level for decision makers in industry. They are much more likely to make the decision to install an industrial heat pump if they know that a heat pump has worked in a similar application. Consulting engineers need to be provided with results from actual installations so they can better advise their clients in selecting the appropriate system.

High first costs

So far, the relatively high first costs of industrial heat pumps and the low payback periods required by industry have created a barrier to increased application of heat pumps. A large portion of heat pump system first cost is not related to the heat pump itself. Specifically, components (compressor, heat exchangers, etc.) are typically less than half the total system cost. The remainder is control equipment, assembly, and distribution costs. Prof. Berghmans sees a need for some "serious competition" among industrial heat pump manufacturers, which should follow as the number of installations increases. Governments can encourage this increase by doing all they can to finance demonstration projects, and to ensure that detailed follow-up investigations are carried out, and that results are distributed throughout the industrial community.

Technical considerations and future RD&D

Technically, many elements of industrial heat pumps can be improved upon, and these are all good areas of emphasis for future RD&D. First, achievement of higher temperatures is necessary to make heat pump systems applicable to a broader range of industrial processes. Compression systems are limited to output temperatures of 110°C, a level not high enough for many industrial applications. Particularly, Prof. Berghmans cites the heat transformer and the Super Heat Pump Energy Accumulation System (presently being developed in Japan to produce temperatures of up to 300°C) as important technologies for further development to achieve higher temperatures. Second, capacity control and microprocessors are "interesting ways to improve the performance of heat pumps," and third, improvements in heat transfer in condensers and evaporators can help to reduce the size of large heat pumps – often a problem in industrial applications.

Industrial renewal

Adaptation of industrial processes to integrate the heat pump can help the success of heat pump applications. This adaptation is easiest in new plants and installations, and this is one of the reasons that the economics of heat pumps when investments are being made in new industrial installations are often better than in retrofit applications. On the future evolution of industrial heat pump applications, Prof. Berghmans says that "industrial heat pumps will be seen and applied more and more, the speed of which will depend on industrial renewal." In the earlier part of this decade, industrial growth was limited due to low-growth economies. As economies strengthen, industry will have more opportunity to install heat pumps, as old facilities are modernized and new equipment is required for plant expansion. Economic growth is an excellent opportunity to take advantage of the benefits of industrial heat pumps.

A. Bratt*

Estimating the Profitability of Industrial Heat Pumps

The author presents a simple method for evaluating the profitability of an industrial heat pump application, given the investment cost, heat output, COP, and hours of operation of the project, as well as the prevailing prices of electricity and alternative fuel. This method (a static calculation) is useful for a preliminary analysis of project economics. A nomogram makes it easy fo identify how different factors affect profitability.

A large number of heat pumps are currently used in industry, and technical conditions for an increase in their use are favorable. If these prospects are to be fully realized, however, applications must be found where industrial demands on profitability can be satisfied. Decision makers require more extensive knowledge of specific heat pump characteristics and factors governing profitability.

This article provides a simple method for estimating profitability. The calculation excludes aspects of reliability, temperature limitations, handling of heat sources of different qualities, maintenance, service, etc. Nor does it take up the importance of careful planning for these types of projects.

Industrial profitability

A heat pump has to be profitable, otherwise industry will not be interested. From the industrial viewpoint, "profitable" often means "more profitable than any other competing investment" in, for example, production, marketing, and so on. One of the obstacles to heat pump projects competing on equal terms with other conceivable investments is the difficulty faced by decision makers in obtaining a clear view of calculated profitability and the financial risks involved in a proposed heat pump project. One reason for this is that engineers are specialists in their own processes and very seldom have expertise in heat pumps. Planners are also seldom specialists in heat pumps, since these represent in many ways a new technology lacking in long term traditions.

Determining factors

In the industrial economic environment, the shortest pay-off time is often the determining factor in choosing between alternative investment projects.

Pay-off time (T_{po}) for a heat pump can be calculated as

$$T_{po} = \frac{I}{Q\,(A - E/COP)}$$

where I = Investment (money)
Q = Heat energy from the heat pump (kWh/yr)
A = Price of alternative heat energy (money/kWh)
E = Price of electrical energy for driving the heat pump (money/kWh)
COP = Coefficient of performance of the heat pump plant

Note that if alternative investment is otherwise necessary in the heat energy system, I is the **increase** in investment with the heat pump. Second, the price of alternative energy is money per unit heat required, not per unit fuel, so already takes into account the efficiency of the alternative system. Also note that COP must be the **net COP**, including energy for driving fans, pumps, etc. necessary for running the heat pump plant.

Now, $Q = \dot{Q} \times T_{fe}$

where $\dot{Q}$ = heat pump capacity (kW)
T_{fe} = full load equivalent time (h/yr)

Substituting equation (2) into (1) gives the following equation for T_{po}:

$$T_{po} = \frac{I/\dot{Q}}{T_{fe}\,(A - E/COP)}$$

To obtain a short pay-off time, it is necessary to aim at:

- low specific investment (money/kW)
- long running time for the heat pump (h/yr)
- high COP

What does this mean in practice?

Low specific investment

It is easy to identify circumstances that may increase investment:

- long distance between heat source and location of heat demand (piping)
- corrosive heat source (material)
- dirty heat source (filter)
- availability of heat source and heat demand not simultaneous (accumulators)
- process sensitive to interruptions in heat distribution (advanced controls)

Conditions are more favorable, therefore, when these circumstances are avoided.

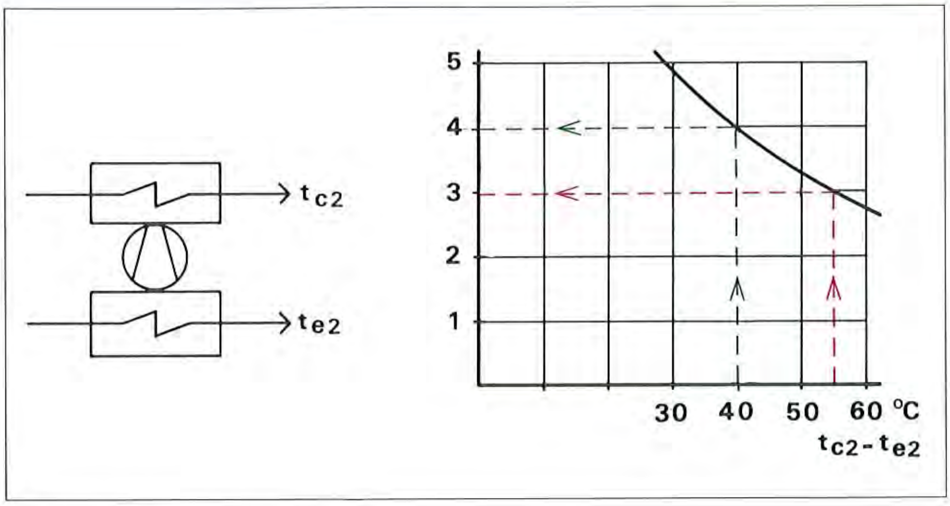


Fig. 1. COP versus temperature difference

Long running time

Conditions are favorable if heat is needed continuously during most of the year, preferably 8,760 hours per year. If the heat source is continuously available but the industrial need for heat is limited, connection of the heat pump to a district heating system or an integrated community energy system could be the most profitable alternative.

High COP

COP is approximately a function of the temperature difference between the heat carrier and cold carrier leaving the condenser and evaporator, respectively, as shown in Fig. 1. The COP in Fig. 1 includes energy for fans, pumps, etc., equal to about 10% of the energy to run the compressor motor. COP is higher if the heat source available has a high temperature

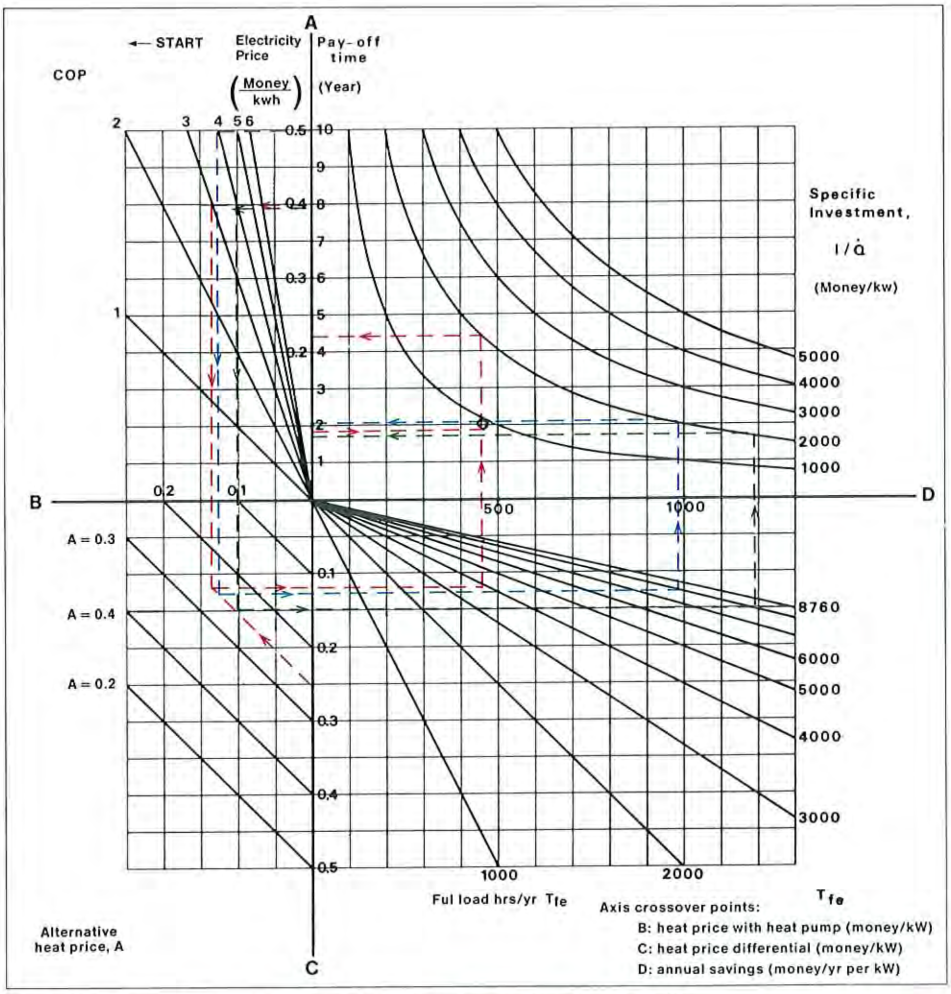


Fig. 2. Nomogram for calculating pay-off time based on system characteristics

and a high flow, and if the heat can be delivered at a reasonably low temperature. If the industrial process requires heat at a high temperature, connection of the heat pump to a district heating system or an integrated community energy system could again be the most profitable alternative.

Quantitative estimation

Equation 3 can be visualized in a nomogram, as shown in Fig. 2. This nomogram makes it easy to see how different factors affect pay-off time.

For example, assume

$E = 0.4$	(money/kWh)
$A = 0.25$	(money/kWh)
$t_{C2} = 70°C$	(process need)
$t_{e2} = 15°C$	(practically possible)
$T_{fe} = 4{,}000$	(h/yr, process limitation)

The temperature difference $t_{C2} - t_{e2} = 55°C$, and using Fig. 1 (red line) COP is 3.0. Assume further that the contractor can only offer the plant for 2000 money/kW. These five values, COP, electricity price E, alternative heat price A, operating hours T_{fe}, and specific investment $I/\dot{Q}$ are then used in the nomograph as follows (red line in Fig. 2):

1. Select electricity cost (axis A)
2. Move horizontally left to heat pump COP
3. Move down vertically (across axis B) to price of alternative heat
4. Move horizontally right (across axis C) to annual hours of operation
5. Move up vertically (across axis D) to specific investment
6. Move horizontally left to pay off time on axis A.

The path on the nomogram calculates intermediate values at the axis crossover points:

Axis B: price of heat supplied by the heat pump

Axis C: heat price differential between alternative and heat pump.

Axis D: annual savings in energy costs with heat pump

For this example, the pay off time is 4.3 years. Alternatively, one can impose a maximum acceptable pay-off time, for example two years, and then determine the maximum specific allowable investment. Following the red dashed line in Fig. 2, this becomes 900 money/kW.

Assuming that the energy from the heat pump can be delivered to a district heating system at a temperature of 55°C for 8,000 hours per year, that the price for energy delivered to the district heating system is the same as alternative energy used in the plant, and that the specific investment remains the same (2,000 money/kW), the COP increases to about 4 (green line in Fig. 1) and the pay-off time falls to about 1.7 years (green line in Fig. 2). According to the imposed pay-off requirement, this option is worth further investigation.

Sensitivity analysis

Equation (3) and the nomogram can be easily used for simple sensitivity analyses.

For example:

Assume that there is a risk that the price of electricity rises by 25% from 0.4 to 0.5 money/kWh in the example above. How does this affect the pay-off time? The blue line in Fig. 2 shows that the pay-off time increases from 1.7 to 2 years.

In practice

Several heat pump plants in Sweden have been built with cooperation between industry and the community, with industry supplying heat from a heat pump to a district heating system. Typical figures today are:

E	= 0.3	SKR/kWh
A	= 0.15 - 0.25	SKR/kWh
$I/\dot{Q}$	= 2,000	SKR/kW
T_{fe}	= 7,500 h/yr	
COP = 4		

The pay-off time is thus 1.5 to 3 years, with 2 years as a mean value.

In conclusion, I hope that this method of estimating profitability will contribute to simplifying the choice of the most economic alternative for heat pumps in industrial applications.

*A. Bratt, Heat Pump Office, Project Dept., STAL Refrigeration AB, Norrköping, Sweden

K. Narita*

Bridging the Gap: Heat Pumps for Industrial Use in Japan

The application of industrial heat pumps can reduce energy consumption in Japanese industry by 20%. The author reviews attractive applications for heat pumps in industry, and emphasizes that heat sources and heat sinks in industrial processes can and should be networked to maximize energy savings.

1. Introduction

Following the boom in heat pumps for residential and commercial uses in Japan, the use of heat pumps for industrial applications is increasing. Fig. 1 shows the trend of total energy consumption vs. gross national product in Japan. This ratio has decreased more than 30% over this ten-year period, showing Japan's great success in energy conservation. Planners and engineers have made their best efforts to save energy, and owners only approve suggestions that incorporate energy-saving measures. The application of heat pumps, especially in industry, has made a remarkable contribution, because energy consumption in industry is more than 60% of total energy consumption.

According to recent research, fuel consumption for processes at temperature levels below 100°C is more than 30% of industrial energy consumption [1], so a great potential for heat pumps in industry still exists. This article reviews the present status of industrial heat pump applications in Japan.

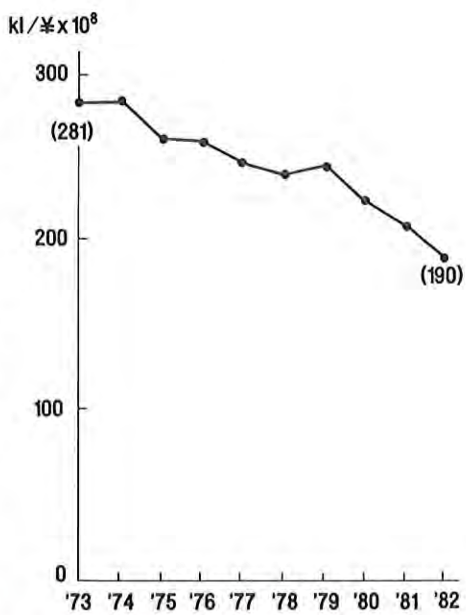


Fig. 1. Energy consumption vs. GNP in Japan

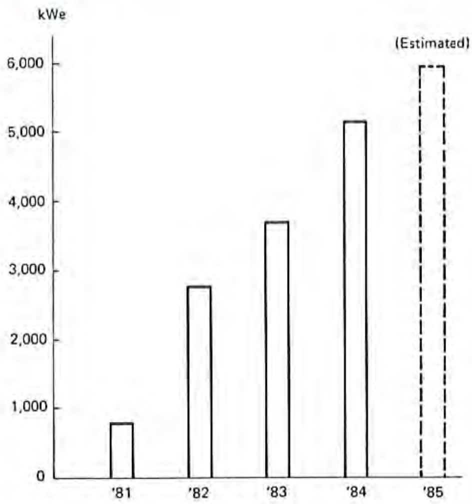


Fig. 2. Heat pump installations for industrial use in Japan

2. Industrial heat pump installations in Japan

Fig. 2 shows the steady increase in Japanese industrial heat pump installations. This trend is expected to continue, due to several favorable conditions for their use. As shown in Fig. 3, industrial heat pumps are used for several purposes. First applications included maintaining constant temperature and humidity for computer rooms, clean rooms for semi-conductor products, green rooms for farming and cultivation, and breeding tanks for fish.

More than 55% of cucumbers and tomatoes are farmed under artificial conditions, and new automated farming factories are being developed for rapid and year-round growing. The application of heat pumps for these purposes is fairly easy, due to experience in space conditioning for buildings, and the fact that the heat pump can be used for both heating and cooling.

Accumulation of experience has popularized the heat pump in terms of merit and reliability. The next step is to incorporate the heat pump into the industrial process itself. This integration is not easy, and requires close cooperation between process and heat pump engineers, as well as support from management. These three are often not familiar with each others' specialty. In general, owners are often quite timid in adopting new technologies, and are not willing to give out details about their industrial processes.

Electric utilities such as the Tokyo Electric Power Company (TEPCO) are often able to bridge this gap, through research and consultation on energy efficiency, and collection of information on various industrial processes. Suggestions are then made to owners, in cooperation with consultants in specialized areas. TEPCO has found that one success brings on the next and integrated heat pump applications are on the increase. The national "Super Heat Pump Project" will accelerate this increase, and heat pump promotion is expected to reduce industrial sector energy consumption by over 20% [2].

3. Classification of heat pump installations for industrial use

Fig. 3 shows the relative proportion (by number of installations) of heat pumps used in different industrial applications. The number of heat pumps used for farming and cultivating, which requires a moderate condensing temperature, is large, but these heat pumps generally have a small power demand, and are operated independently from the process. Heat pumps for integrated applications generally have a large power demand.

Different heat pump applications are shown schematically in Fig. 4. Type A applications are easiest due to abundant experience in space conditioning, with examples as stated above. The Japanese are said to consume the most raw vegetables and fish in the world, and the total area of greenhouses is close to 40,000 ha, where vegetables, mushrooms and fruits grow all year round. Automated artificial farms and ocean farms will be developed with the help of the heat pump in the near future. Reciprocating compressors are generally used in these applications. Constant temperature warehouses and storage installations are other examples

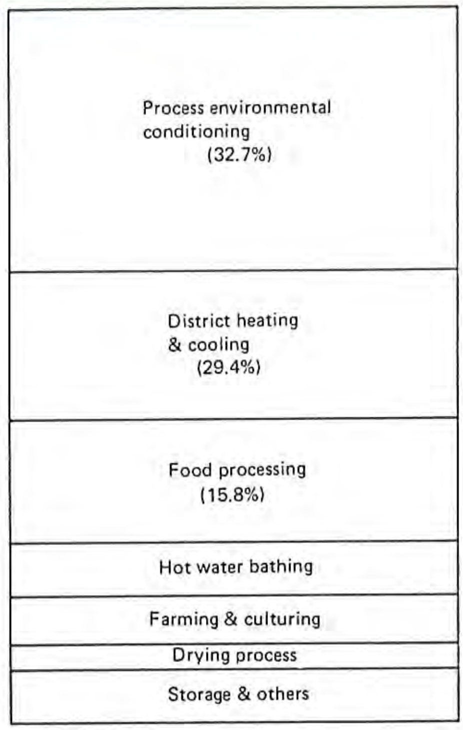


Fig. 3. Relative proportion of heat pump installations in various fields [3]

of Type A applications. Some products require certain conditions for maintaining quality, others for improving quality (such as curing).

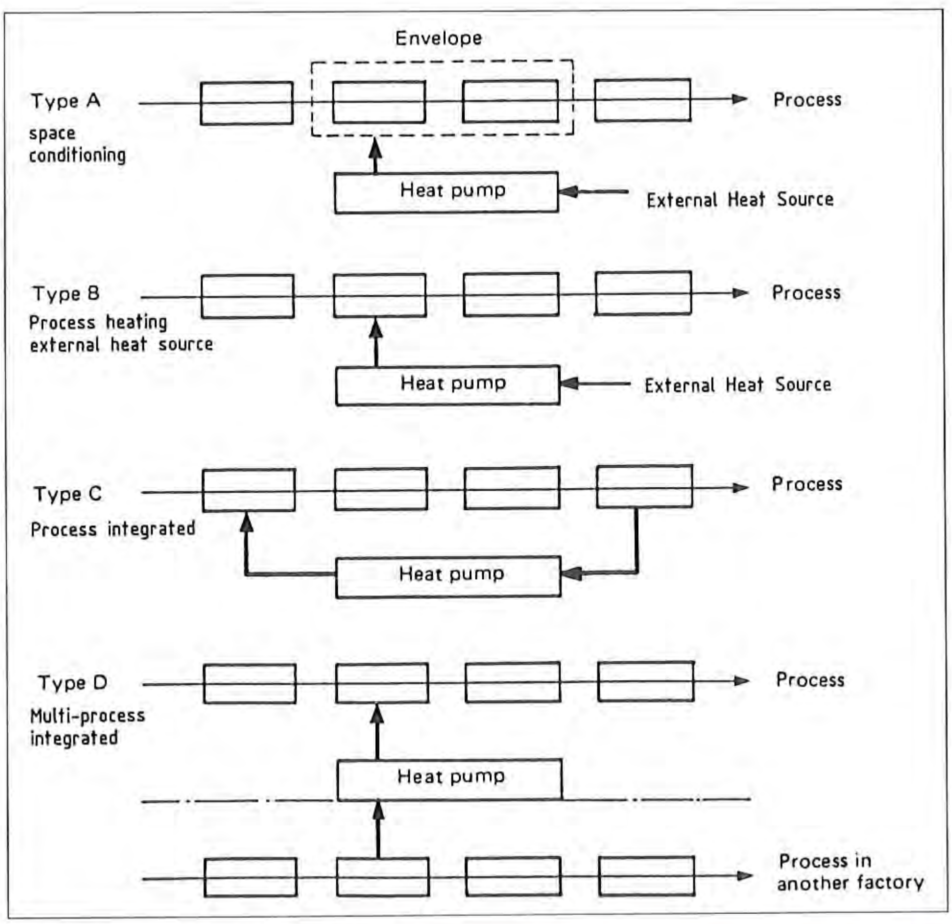


Fig. 4. Heat pump application classifications

Type B applications are also popular, using an external heat source to provide heat directly to the process itself. Typical examples are drying processes, additional heating for mineral spring baths, and some types of food processing. Drying processes might be classified as Type A at first glance, but these heat pumps work not only for conditioning but also extract moisture from the product in the drying process. Small heat pump package units for fish drying have recently been introduced in Japan, and installations for wood drying are also increasing. Heat pumps for boosting the temperature of mineral spring baths have been used since the thirties, but a lack of consideration for maintaining water quality often led to troubles and prevented increased use of heat pumps in this application.

Type C applications are Type B applications with heat recovery from other steps in the process. In these applications, the heat pump has been fully integrated into the process. Examples of Type C applications include integration of heat pumps into food processing, brewing, condensing, and evaporating processes. High condensing temperatures are often required and large screw or multi-stage turbo-compressors are generally used, along with a storage system. In cases where a good balance between heat recovered and process heating requirements is implemented, payback periods of 2 to 3 years can be expected.

In Type D applications, the heat source and the heat sink for the heat pump are steps in separate industrial processes. This is the most sophisticated industrial heat pump application, as the heat pump is integrated between two independent processes. One example of this application is heat recovery from sterilization processes in a dairy, and boosting the temperature of this heat with a heat pump for process drying (e.g. milk powder) in the same plant. Type D applications can also use a heat pump to link two separate plants, using waste heat from one plant as a heat source for process heating in another plant.

4. Conclusion

Although high-temperature waste heat is starting to be recovered and utilized, huge amounts of heat are still rejected. Building the bridge with a heat pump to processes that can utilize waste heat establishes a heat recovery system, resulting in a network for energy savings. In Japan, there is a huge quantity of low-grade waste heat resulting from energy consumption for various purposes, and heat pump technology can recover this heat and boost the temperature to a useful level. In addition, some facilities require heat, while some reject heat, and networks for linking these processes with a heat pump can and should be established. Industrial processes are one of the best opportunities for energy and environmental conservation. TEPCO will continue to promote heat pump technologies, and their penetration in all energy sectors.

5. References

1. UIE Japan, "The Research of Heat Sources in Industrial Fields and Utilization of Electric Heat," January 1986.
2. JRAIA, "A Working Group on Industrial Heat Pumps in Japan," February 1986.
3. JRAIA, as above.

K. Narita, Tokyo Electric Power Company, Japan

J. Bouma*

Industrial Heat Pump Stimulation Program in the Netherlands

In the Netherlands, commercialization of the industrial heat pump is encouraged through loans, grants and subsidies for promising new demonstration plants. NEOM (the Dutch Energy Development Company) provides support for several projects, including a large heat transformer (described in the following article) and mechanical vapor recompression systems for different industrial processes. Plans for supporting further projects are underway, including a high-temperature closed-cycle heat pump system for an electronics manufacturing plant.

The Energy Development Company NEOM focuses on diversification of primary energy sources used in the Netherlands, and on energy conservation in all sectors of the economy. The organization was commissioned by the Dutch Ministry of Economic Affairs to conduct demonstration and market introduction programs in 1976. NEOM support functions on behalf of the Ministry include market research, feasibility studies, and promotion of novel energy technologies and systems.

NEOM programs are aimed at two market sectors, residential and industrial. (Industrial greenhouse horticulture is handled through a separate program.) In the industrial field, several programs are now underway. Within the program "New Industrial Techniques" is the sub-program "Demonstration of Industrial Heat Pumps." This sub-program was set up to stimulate the use of heat pumps in industry by providing potential users with consulting and financial support. The aim of the program is to achieve acceptance of heat pumps by industry, by removing bottlenecks and impediments that block the use of industrial heat pumps, and by showing technical-economic applicability of various types of heat pumps on an industrial scale.

Demonstration project support includes grants and/or loans. After the demonstration phase, only loans are supplied for market introduction projects. Instead of a loan, a guarantee may be provided. In case of project failure, a loan may be converted partially or completely into a grant. For demonstration projects, a mandatory project evaluation is conducted by an independent third party on behalf of NEOM.

The market

In Dutch industry, there is still a large potential for energy saving techniques and sytems. On the basis of an exploratory market analysis, potential annual savings with heat pumps are as high as 600 million m^3 natural gas equivalent (nge), approximately 4% of total industrial fuel consumption.

The following promising options with immediate or short-range profitability have been identified, and incentive schemes for their promotion are underway.

1. Open heat pump systems for evaporation, crystallization and similar unit operations, with main applications in dairy, sugar, oil, fat, starch, inorganic chemical and petrochemial processing.

   Savings potential: 370 million m^3 nge.

Branch of industry	In operation	Process/application	Type	Heating capacity (MW)	Pressure ratio	COP	Expected savings nat. gas (10^6 m^3/yr)	Expected payback period without NEOM support (yr)	Status
Dairy	1983	Evaporation of whey concentrate	MVR	5	1.6	20	1.9	4.0	Completed
Oil and fat	1985	Evaporation of methanol-water	MVR	3	2.0	15	3.0	3.0	Measuring
Malting	1984	Drying kiln [1]	Electric heat pump	3.4	–	–	1.4	–	Reporting
Organic chemical	1985	Steam production	Heat transformer	6.4	–	0.45 [2]	6.0	2.5	Measuring

MVR: Mechanical vapor recompression · 1. Gas-engine cogeneration · 2. Heat ratio

Table 1: Completed and current demonstration projects in industry

2. Open heat pumps for distillation, rectification and similar unit operations, mainly in oil, fat, alcohol, organic chemical and petrochemical processing. **Savings potential: 110 million m^3 nge.**
3. Closed heat pump systems for drying and high temperature applications, particularly in the production of food and drink luxuries, textiles, paper, and in agriculture. **Savings Potential: 60 million m^3 nge.**
4. Closed heat pump systems for various operations and processes such as pasteurizing, blanching, sterilizing, heating, cooking, and particularly in the alimentary, textile, paper, chemical and metalware industries. **Savings potential: 70 million m^3 nge.**

Each field of application has its own product-market combinations, each with its own characteristics. Feasible techniques are those that employ mechanical vapor compressors (MVR, open cycle heat pumps), closed-cycle compression systems and sorption systems (including heat transformers). In addition to demonstration of new technologies, application of existing technologies in new areas of industry will be demonstrated.

NEOM support normally results from requests by potential users or from NEOM initiatives in the field. Financial support is subject to the following conditions:

1. The project meets certain specified criteria for profitability without support from NEOM.
2. The project involves technical risks.
3. The heat pump system involves one or more novelties.
4. The heat pump technique is applicable on a wider scale in the Netherlands.

The following are examples of technical risk when applying an open-type heat pump:

- reliability/operability
- control
- effect on process
- product quality
- fouling of equipment (heat exchangers, compressor, etc.)

Examples of novelties are:

- dehumidification of drying air with an electric heat pump driven by a cogeneration unit
- multi-effect MVR systems
- MVR systems operating with solvents other than water
- process integrated heat transformer
- Lorenz principle
- absorption heat pump driven by gas engine waste heat, etc.

Open-type heat pumps are linked to the process in a specific way and therefore operational conditions and characteristics are often not fully known. Less specific uncertainties occur with closed-type heat pumps because they operate with known refrigerants in a closed system. By applying heat exchangers in process streams, however, problems may occur with respect to fouling, control, etc., while specific lubricant/refrigerant problems may occur in high temperature applications (e.g. R114).

State of the art

Table 1 summarizes technical and economic data of completed and current demonstration projects.

In the Netherlands, a number of MVR water-vapor systems are now operating in the starch, chemical, dairy and offal industries. One demonstration project has been completed in the dairy industry. In the chemical industry, two systems are currently under demonstration, an MVR system with a solvent-water vapor mixture for separation of fatty acid and a 6.4 MW heat transformer that produces low pressure steam of 145°C and uses waste steam of 100°C as driving energy (see Fig. 1 and the article about the heat transformer later in this Newsletter). Monitoring programs are in progress for both projects. MVR installations for distillation and rectification are rarely used in the Netherlands.

Since MVR systems using water vapor are now widely known and accepted by industry, and the market introduction phase has been reached, NEOM will focus its grant support on non-water-vapor MVR applications. For example, an installation for evaporation of a gelatine solution in the chemical industry is being built without NEOM support. The starting point for market introduction is the knowledge and experience gained from preceeding demonstration projects in that branch of industry.

Experience with closed-cycle compression heat pumps in industry is still limited. For the drying of timber, however, a number of heat pumps have been running for several years already. Moreover, closed-cycle heat pumps are used in the chemical, food and metal industry. At present, a demonstration project in the malt industry is underway.

Planned demonstration projects

In 1986, four new demonstration projects will be started, specifically, three MVR systems and one high-temperature closed-cycle heat pump system in an electrical components manufacturing plant. Technical and economic data are summarized in Table 2.

The MVR installation in the starch industry is used in a multi-effect evaporation process and incorporates a thermo-compressor. The MVR installation in the beer industry, the first in the Netherlands, will be equipped with a roots blower.

Selection of a suitable solvent vapor compressor for the MVR-unit in the chemical industry was a laborious process. The chosen compressor is a special type. The high temperature heat pump (condensing temperature 110°C) is used for both cooling and heating of process fluids. The behavior of the refrigerant (R114) and lubricant (chemical stability) is of special interest due to the limited experience so far available.

Only electric motors are used as compressor drives in current and planned demonstration projects, apart from the heat transformer project. The main reasons for this are inexpensive cogenerated electricity, high reliability and low main-

Branch of industry	In operation	Process/application	Type	Heating capacity (MW)	Pressure ratio	COP	Expected savings nat. gas (10^6 m^3/yr)	Expected payback period without NEOM support (yr)	Status
Starch	1986	Evaporation of corn process water [1]	MVR	21.7	1.6	16.2	3.0	1.7	Construction
Beer	1986	Evaporation of wort [2]	MVR	2.2	1.5	22.0	0.5	5.0	Engineering
Inorganic chemical	1987	Evaporation of acetone	MVR	0.28	1.4	14.2	0.14	4.0	Engineering
Electro-technical	1986/ 1987	Heating/cooling of process fluids	Electric heat pump (R II4)	0.17	–	5.6	0.17	3.4	Engineering

MVR: Mechanical vapor recompression · 1. Combined with thermo-compressor · 2. Part of total installation; extension if successful
Table 2: Demonstration projects in preparation

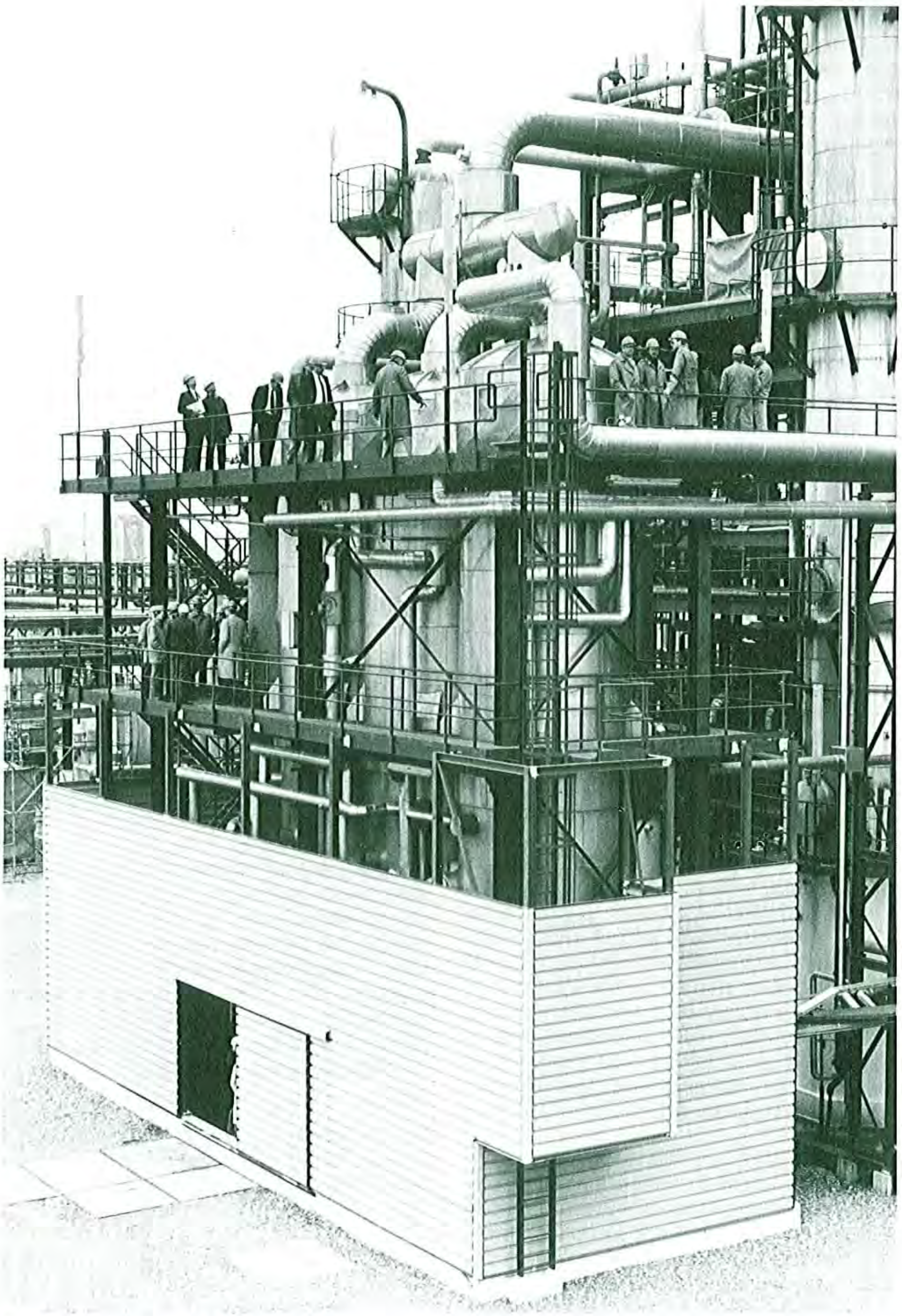


Fig. 1. Heat transformer, the Netherlands

tenance. If cogenerated electricity is not available, gas engines as prime movers are preferable from an energetic point of view, and are reliable as well. NEOM has emphasized to industry that hesitation towards the use of gas engines is not justifiable in many cases. Plans now exist to demonstrate a gas-engine-driven two-stage heat pump based on the Lorenz principle in a dehumidification application.

Studies

Feasibility studies for heat pumps have been supported in various applications, for example, for an alcohol distillery (MVR), cellulose production (MVR), and starch drying.

A feasibility study on the use of fiber-loaded waste process water as a heat source in a paper mill is currently in progess. Support has also been granted for a feasibility study into the use of low-grade waste heat as the drive energy for a heat transformer for production of low-pressure steam in the heavy metal industry. The support NEOM can give for feasibility studies depends on the heat pump system and on total costs.

In the Dutch food industry, a market study has been conducted on the use of heat pumps for industrial drying. It was concluded that there are no significant technical bottlenecks, 40 million m^3 nge can be saved annually, and a capacity of about 60 MW$_{th}$ can be installed. NEOM has also given consulting support to a market study on absorption heat pumps for industry, ordered by the Management Office for Energy Research, PEO. This study will be published shortly.

In the near future, a market study on the use of high temperature heat pumps in industry will be started. The aims of this study are to examine possible applications of various types of heat pumps and to estimate potential and penetration through 1990.

*J. Bouma, NEOM BV, Sittard, the Netherlands

D.L. Hodgett*

Research on High Temperature Industrial Heat Pumps at ECRC

At the Electricity Council Research Centre (ECRC) in Great Britain, research into high-temperature heat pump technology is being carried out to help minimize the use of energy in industry. In this article, several completed and on-going projects are described, including basic research on working fluids to achieve high condensing temperatures, compressor development, and applications research for drying and distillation. Future plans for further research are also described.

In 1974 the Electrical Council Research Centre (ECRC) identified the need to develop high temperature heat pump technology to provide a means of minimizing the use of energy in industrial processes. In particular, research has focused on working fluids, components and systems, initially for temperatures up to 100°C and subsequently for 150°C and beyond. Application research concentrated on drying, seen as the area most amenable to inclusion of heat pump technology [1]. Initial research concentrated on convective drying, and particularly timber drying [2], since timber drying temperatures of up to 80°C in fossil-fuel fired chambers are used within the UK, and at that time heat pumps were limited to 50°C output by refrigeration equipment and working fluid. Between 1974 and 1979 a heat pump that uses R114 as its working fluid and operates with a condensing temperature up to 100°C was developed, and a licensing agreement for its manufacture made with a supplier of low temperature heat pumps. This unit is now in full commercial use in the timber, ceramics and latex goods industries [3].

More recently, research has concentrated on other types of drying, on the search for working fluids for operation at up to 150°C, and on compressor development for these working fluids, including steam. Application studies have concentrated on identifying processes that could use this technology, such as drying, evaporation, and distillation.

Working fluids for 150°C condensing temperature

A survey of the physical and thermodynamic properties of available working fluids for use at temperatures up to 150°C ruled out conventional halocarbon refrigerants. Operating within the constraints of non-flammability, stability, non-toxicity and moderate working pressures, a fully fluorinated heat transfer fluid (perfluoro-n-hexane or PP1) was chosen for further study [4]. The solubilty of the working fluid in various compressor lubricants and its effect on their viscosities and chemical and thermal stabilities were measured. A synthetic hydrocarbon lubricant was eventually chosen. Tests were carried out at evaporating temperatures of 75-105°C and condensing temperatures of 130-155°C; coefficients of performance of between 2 and 4 were obtained, somewhat less than anticipated. An economic analysis showed that systems using PP1 were unlikely to be economically viable because of their low performance and high capital cost.

A wider range of compounds was then considered, including some specially-synthesized fluorine compounds, few of whose properties were known. This forced ECRC to develop a method of estimating the thermodynamic performance parameters of any fluid from the sparsest of basic data [5].

The theoretical performances of some 250 potential working fluids in vapor compression heat pumps condensing at 150°C and evaporating at 100°C have been predicted. Expected correlations were found between COP and critical temperature, between specific compressor displacement and normal boiling point (T_{bp}), and between condensing pressure and T_{bp}. Correlations were also found between minimum superheat and both molecular weight and critical pressure. From these correlations the desirable basic properties of any high temperature heat pump fluid were deduced. A numer of interesting fluids have been identified and these are currently being investigated for toxicity by our industrial collaborator.

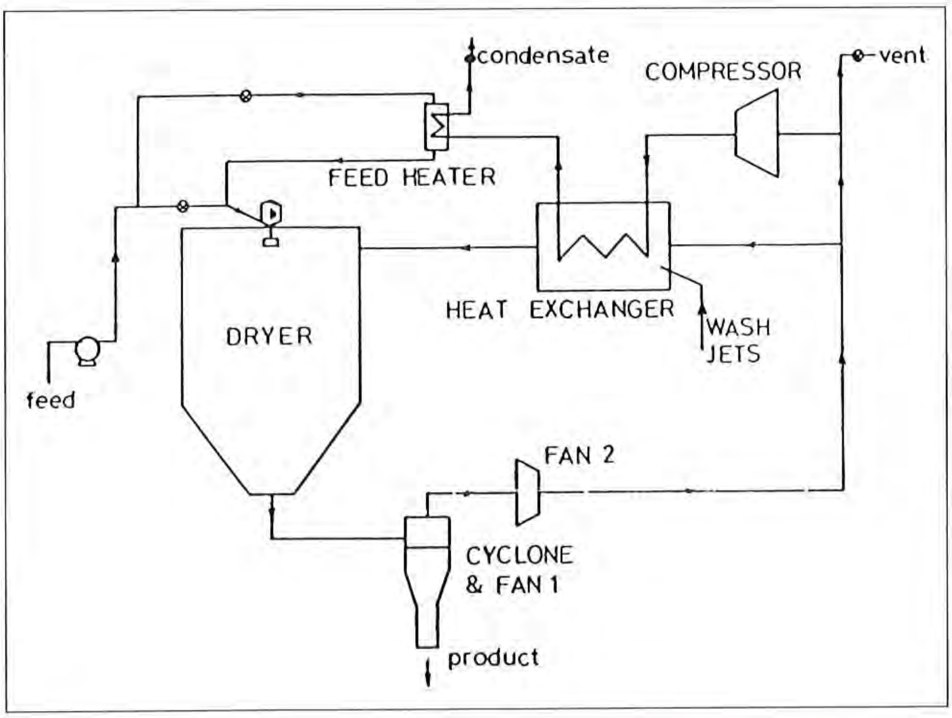


Fig. 1. Steam recompression pilot plant

Compressor development

Semi-hermetic reciprocating compressors have been evaluated for performance and reliability for many thousands of hours on non-condensing gas cooling rigs, operated first on refrigerants R114 up to 120°C condensing temperature and later on PP1 up to 150°C condensing temperature.

More recent work has concentrated on steam compression. Pilot plant "open" (or direct) and "closed" (indirect) steam heat pumps have been evaluated with a small rotary compressor. Further work has extended the range of steam compressors while reducing the capital cost and increasing reliability. A facility now exists for testing larger-scale steam compressors.

The fundamental principles of internal flows in rotary compressors in two-phase flow are under study to ultimately increase efficiency through better design.

Drying

Two basic dryer types have been investigated: Convective dryers, where a gas or

Fig. 2. Pilot-scale rotary contact dryer (with open-cycle heat pump compressor bottom right)

vapor transfers heat to the solid, and contact dryers, where the solid is heated by contact with a heated surface.

Convective dryers

Convective dryers using air as the heat transfer medium are very common in industry [1]. Generally, ambient air is heated first by heat recovery from the exhaust and then by burning fossil fuels before being admitted to the dryer. After cooling in the heat recovery unit, air is exhausted to the atmosphere. Further heat recovery is possible using a heat pump between the exhaust air and the inlet air after the heat exchanger. The use of non-azeotropic mixtures to improve matching temperatures in the evaporator and condenser to the temperatures of the streams flowing across them has received a great deal of attention in the last few years. An alternative approach to the matching of varying stream temperatures, the use of 'horizontal' multistage heat pumps, has been proposed by ECRC [6].

This system uses a number of heat pumps in series, and is optimized for performance and capital cost with a mathematical model that selects optimum intermediate stream temperatures and the switch-over temperature for heating by burning with fossil fuel.

For a typical malt kiln, minimum running cost was obtained with a four-stage heat pump with a switch-over temperature in the condenser stream of 65°C, the full heating load met by the heat pumps. The COP of the system was 4.35, comparing favorably to a COP of 3.85 for a non-azeotropic mixture cycle with the same relative efficiency and temperature differences across the heat exchangers. Several malt drying heat pumps have been installed following this principle.

Superheated steam is an alternative to air as the heating medium. The vapor produced in drying the solid is separated from the main saturated steam flow after the dryer and compressor before being condensed in a heat exchanger to reheat the main steam flow at the dryer inlet. Work at ECRC [7] concentrated first on system optimization and then on a pilot plant based on a spray dryer (Fig. 1). Drying tests were successfully carried out on several products and results matched well with the theoretical predictions. A pilot-scale dryer with an evaporation rate of 0.25 ton/h is soon to be put on trial.

Contact dryers

A similar exercise has been carried out for contact dryers. A pilot-plant rotary-contact dryer (Fig. 2) in which the heat pump working fluid condenses in the dryer shell has been operated in conjunction with three different heat pump systems. A 'closed cycle' heat pump with a refrigerant as working fluid has its evaporator in the dryer exhaust and condenses in the shell [8]. An 'open cycle' heat pump recompresses the dryer exhaust (from which air has been excluded) and condenses in the shell. A 'semi-open cycle' condenses the dryer exhaust to reboil clean steam that is compressed and then condensed in the shell. Results from these tests showed that the last two systems had the greatest economic return for a full scale plant, the open cycle system being the best (if the dryer exhaust is clean enough to be used). A heat pump dryer using the semi-closed cycle now being designed for a 4 ton/h evaporation rate rotary-dryer will be installed in the near future.

Distillation

Distillation, like drying, involves heating and cooling process streams with a relatively small (usually 50K) temperature difference, and should be an ideal application for heat pumps. Only a few recorded installations exist worldwide; however, since many distillation processes form part of process networks the heating/cooling requirements of the distillation column can be integrated with the heat flows to or from other adjacent processes. The heating/cooling requirements for distillation are often greatly in excess of those for the other processes, and/or distillation cannot easily be adapted for integration with them (particularly in batch distillation systems and steam strippers).

An analysis of the effect of thermodynamic properties of the fluids being separated on heat pump design and performance has been undertaken at ECRC [9]. A theoretical model for optimizing heat-pump-assisted distillation is being developed.

The production of malt whisky is an important part of the Scottish economy. Although the production process involves relatively large temperature differences, a heat pump system has been successfully developed, based on a theoretical and experimental study of the process, in particular the condenser for the ethanol-water mixture [10]. A full scale heat pump is being installed in a malt whisky distillery (Fig. 3) and is due to start operation within the next few months. The unit uses a twin-screw compressor to compress 2.7 tons/h of steam from 0.5 to 2 bar and should reduce process energy costs by more than 50%.

Future work

Apart from promoting the use of steam in drying, distillation and other unit operations, future work is planned to extend the economic range of steam compressors to smaller unit sizes. Further work on non-steam based systems awaits the

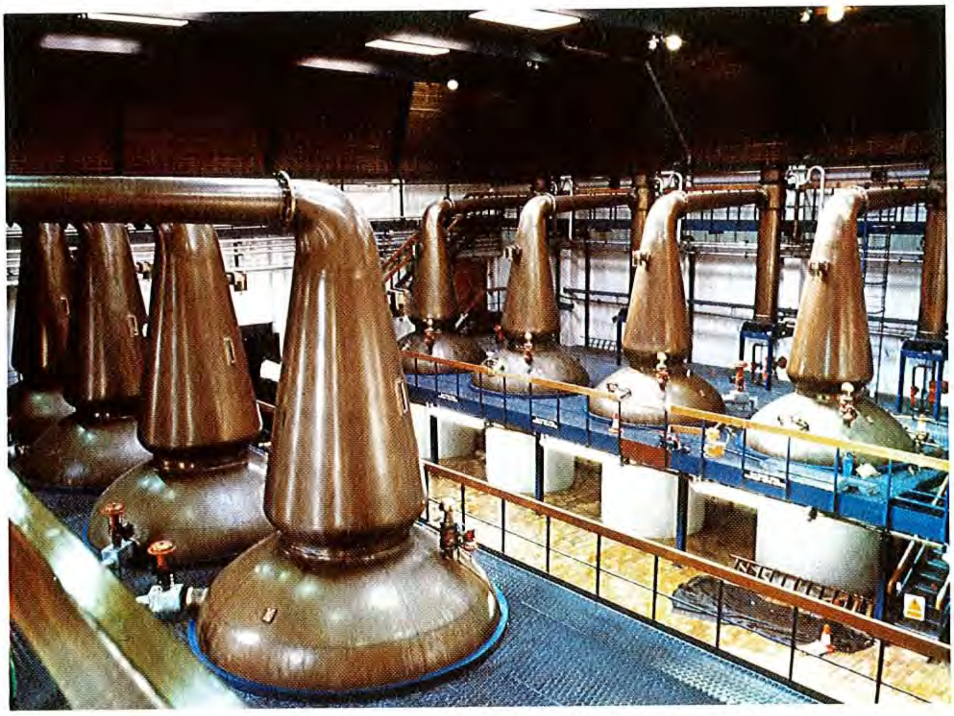


Fig. 3. The Scotch malt whisky distillery where the heat pump is being installed

conclusion of toxicity tests and identification of applications where steam is not a viable option. Theoretical work on the optimization of the integration of heat pumps into complete industrial operations is intended to lead to a powerful tool for identifying future application areas. A collaborative project with Chalmers Technical University in Sweden is aimed at finding heat pump systems based on a combined compression and absorption process that will match many industrial areas where heat pumps have not yet found use.

References

1. Hodgett, D.L., "Efficient drying using heat pumps," The Chemical Engineer, July/August 1976
2. Kolbusz, P., "Heat pumps and their contribution to energy conservation," Ed. Camantini and Kester, Nordhoff 1976
3. Anon., "High temperature dryer cuts costs," Timber Trades Journal (UK), 25 July 1981, "High Temperature Kilning on Trial," ibid, 8 August 1981
4. Taylor, B.J., Bertinat, M.P., "The design and evaluation of 150 °C heat pump," Proc. 2nd BHRA Int. Symp. on the Large Scale Application of Heat Pumps, York, England, 25-27 September 1984, ISBN 0 906086 97 7
5. Bertinat, M.P., "Fluids for high temperature heat pumps," Int. J. Refrig. 1986, Vol.9, January, pp 43-50
6. Benstead, R., "The Optimization of multistage heat pump systems," Proc. Meeting of Commission E2, Int. Inst. of Refrigeration, Trondheim, Norway, 19-20 June 1985
7. Heaton, A.V., Benstead, R., "Steam recompression drying," Proc. 2nd BHRA Int. Symp. on the Large Scale Application of Heat Pumps, York, England, 25-27 September 1984, ISBN 0 906085 97 7
8. Green, R.H., "Energy performance of heat pumps and continuous dryers," Proc. of the 3rd Int. Drying Symposium, ED J.C. Ashworth, 1982, ISBN 0 946 224 00 5
9. Hogdett, D.L., "The assessment of heat pump assisted distillation using thermodynamic criteria," 2nd BHRA Int. Symp. on the Large Scale Applications of Heat Pumps, York, England, 25-27 September 1984, ISBN 0 906085 97 7
10. Hodgett, D.L., "A heat pump for batch distillation," ibid.

D.L. Hodgett, Electricity Council Research Centre, Capenhurst, England

Industrial Heat Pump Demonstration Projects in the European Community

The goal of the European Community's demonstration program is to accelerate the uptake of rational use of energy technologies as they successfully pass through the research and development phase in the technology innovation process. Several industrial heat pump projects have been or are now being demonstrated with the help of European Community support. The following is a brief description of eight of these projects. Several additional industrial heat pump projects that were proposed in 1985 are now in the contract-signing stage.

MECHANICAL VAPOR RECOMPRESSION

Waste steam compression by a gas-engine-driven screw compressor in a brewery, F.R. Germany. The aim of this project is to show that steam compression with a gas-engine-driven screw compressor can considerably reduce energy consumption in the brewing process. Waste steam (5,650 kg/hr, 1.1 bar, 99°C) normally exhausted to the air from the wort copper is recompressed by the screw compressor (to 1.6 bar, 114°C) to be reused in the copper. Hot condensate (100°C) is extracted from the copper and used with waste heat from the gas motor to heat hot water (90°C) used by the brewery.

Primary energy input (gas) of 493 kW produces 4,269 kW of useful energy, resulting in a primary energy ratio of 8.6. Construction was completed in June 1985, and monitoring is scheduled for completion in August 1986.

Heat pumps using steam generated by a thermomechanical pulp process, France (see Fig. 1). This project recovers energy from the steam (water vapor) generated in thermomechanical pulp production, recycling waste steam from the pressurized preheater. The steam generated is first fed into a cyclone washer where impurities are removed, and then to a heat exchanger that acts as the evaporator for the heat pumps. Fresh steam is generated and sent to two compressors, one at 132 kW_e, compressing 1,500-2,500 kg/hr steam, and one at 55 kW_e, compressing 700-1,300 kg/hr steam. The steam then passes to the steam network. During the first six months of 1982, this project was quite successful, with a payback period of 19 months. Similar heat pump plants can be applied in several other processes that generate large amounts of waste steam, including paper and sugar plants, and breweries.

Heat recovery from sugar production, France. This project, still in the design stages, is a mechanical recompressor of steam in the crystallization and syrup condensation units of a sugar processing plant. Exhaust steam will be recompressed and pumped back into the crystallization heating system. The steam compressor in the syrup condensation unit will require a preconcentration (pre-evaporation) stage using recycled steam.

Full operation and measurement is expected to begin in September 1987 and to continue through January 1988. Results will be analyzed jointly by Electricite de France (EDF) and the Sugar Industry Research Institute of France (IRIS).

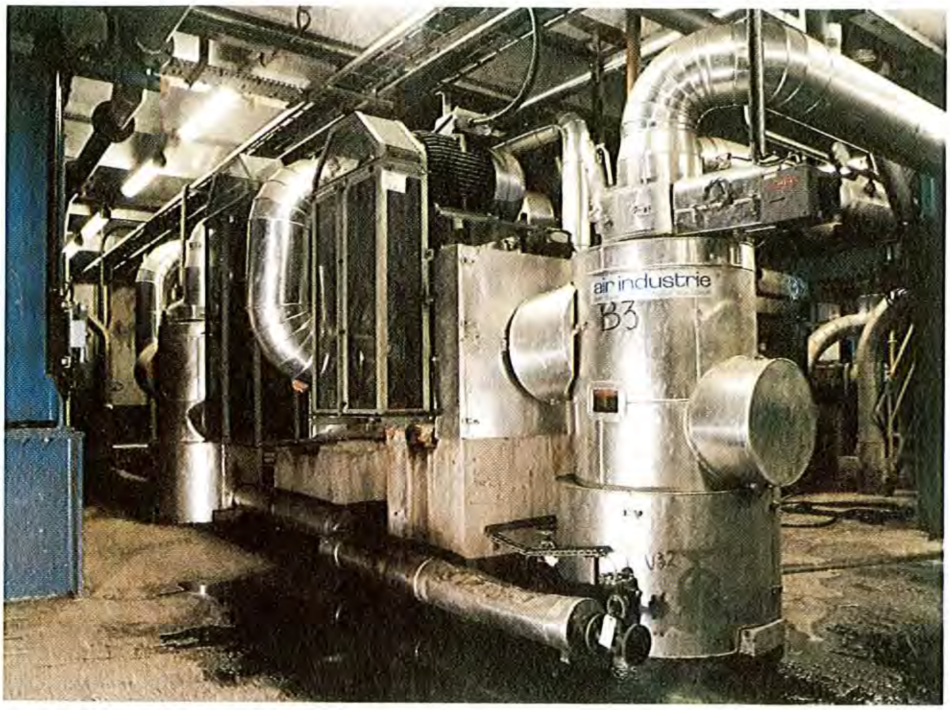


Fig. 1. Heat pump system for recovery of steam generated by thermomechanical pulp production, France

HEAT RECOVERY

Recovery of energy through heat pumps in a malt works, France. Low temperature exhaust gases generated during the drying process are recycled to heat the air used to dry malt. A two-stage electric heat pump is used, stage one operating with R12, heating the air to 60-65°C, and stage two operating with R114, heating the air to 85°C if required. The design capacity of the heat pump is 5,000 therms/hr, with an average COP of 3.7. Annual savings are estimated to be 73% of the total energy requirement for heating air during a full malting cycle, or 1,000 tons of oil equivalent per year. Mechanical installation and first start-up has been completed, and initial measurements have produced excellent results in terms of COP.

Heat pump system for waste heat recovery from malt drying processes, F.R. Germany. Two heat pumps, with inputs of 330 and 420 kW, were designed to use harbor water next to the plant as a heat source. Emissions into the harbor from industrial processes nearby raised the temperature of the heat source. Using R12 and R22, water heat is exchanged to an air heater, used to dry malt in malt kilns.

During the winter of 1982-83, system output reached 3.3 MW, and the coefficient of performance was 4.5. Evaporator corrosion problems, however, resulted in converting the heat pump to use waste heat from the refrigerating system. In the new mode, the system can only operate 200-220 days per year, instead of 330, and the system is more sensitive to climatic changes, reducing the savings.

Large gas motor driven heat pump with integrated alternator for drying processes, Great Britain. A heat regeneration plant that simultaneously produces electrical energy is estimated to save 52% of the energy required for heating hot air for industrial malt production, or 2,700,000 m^3 of natural gas per year with additional electricity savings. The system includes two heat pumps in parallel with a gas motor, screw compressor and alternator mounted on the same shaft. Heat is recovered from hot air exhausted from the kiln, from gas motor cooling, and from exhaust gases. Thermal and electric loads are controlled by a microprocessor to maintain constant motor speed. If no electrical energy is produced, a maximum COP of 3.25 is estimated. Installation of the project is complete and monitoring is underway.

Energy savings in a dairy with integration of a heat pump, Belgium. Goals of this project were to gain experience in heat pump installation techniques in the food industry, to improve integration of different components, to examine problems specific to the food sector (e.g. use of water polluted by various residues as the heat source for a heat pump), and to evaluate the economic viability of such projects. Residual heat from cleaning water and super heat from refrigerating plants is recovered with a heat pump, and heat from cooling whey is used to heat milk for cheese production. A microprocessor will be used to control the various heat recovery systems. Technically, the project proved to be very efficient.

HEAT TRANSFORMER

Steam production by a heat transformer, F.R. Germany. This heat transformer will be installed in a chemical firm, fed by process waste steam from a dehydration unit at about 100°C. A part of this energy is transformed to a higher temperature of about 130°C and constitutes the fraction that is recovered. The remaining part is exhausted at a lower temperature of about 40°C. Operating for 8,000 hours per year, steam production is estimated at 31,600 tons/yr at 2.5 bar, or 2,046 tons of equivalent petroleum per year. The estimated payback is 4.2 years. The working fluid is water mixed with lithium bromide, allowing operation under vacuum or slight overpressure in internal circuits, avoiding the high pressures seen when using ammonia. The efficiency of the transformer is 48% (the ratio of high-temperature energy produced to the waste energy supplied).

(Based on information provided by the Commission of the European Communities, Directorate General for Energy Demonstration Projects, Brussels, Belgium)

K. Krenn, W. Ritter, M. Schneeberger*

The World's First Industrial Heat Pump

The world's first industrial heat pump system was constructed in 1856/57 in the salt works in Ebensee, Upper Austria. This system was first introduced at the 1984 IEA Heat Pump Conference in Graz, Austria. The history and technical details of this project and the development of thermocompression for salt production are summarized in this article.

Today, a thermocompression system requiring 8 MW of electric power input for a thermal output of 66 MW is operating at the new salt works in Ebensee, Upper Austria. Since 1979, 2,500,000 tons of salt have been produced through this economical and environmentally beneficial process. This system is the result of 130 years of experience that started when the Austrian Peter Ritter von Rittinger first tested his invention of a new evaporation process in 1856. His invention was Austria's first heat pump and the first industrial heat pump world wide.

The inventor

Peter Ritter von Rittinger (Fig. 1) was born on January 23, 1811, in Neutitschein, Austria. He attended high school in Olmütz, and continued on to study law, mathematics and physics at the university in Vienna. Ritter von Rittinger devoted himself to his research work in mining and ore-processing at the beginning of his career. In 1850, he was nominated to a leading position at the Ministry of Mining in Vienna. In 1853, he applied for a patent for a new method of evaporation that he had developed, and in 1855, his article, "Theoretical and practical treatise on a new method of evaporating all kinds of liquids, based on a hydromechanical power system applied to a continuous vapor circulation with special application to the salt-brine evaporating process," was published (Fig. 2).

Ritter von Rittinger's treatise introduction begins with, "Steam can generate mechanical work. Most of today's industrial advances are based on this fact. Physicists have no objections to also accepting that mechanical work can generate steam. As far as I know, however, nobody has tried to take advantage of this fact for the benefit of industry on a large scale. This treatise explores this opportunity." The introduction concludes with, "By presenting this scientific work to the public, I have a personal hope that industry accepts and takes advantage of this process as soon as possible. Energy savings of at least 80% of combustion fuel are a strong incentive to utilize this new evaporation process." The inventor's words of 130 years ago are still relevant today, as we are in a period of new innovations for industrial heat pump systems.

Fig. 1. Portrait of Peter Ritter von Rittinger (1811-1872), Lithography by Josef Kriehuber, 1856

Theoretisch-praktische Abhandlung
über ein
für alle Gattungen von Flüssigkeiten
anwendbares
neues Abdampfverfahren
mittelst einer und derselben Wärmemenge,
welche zu diesem Behufe
durch Wasserkraft
in ununterbrochenen Kreislauf versetzt wird.
Mit specieller Rücksicht auf den Salzsiedeproceß dargestellt
von
Peter Rittinger,
k. k. Sectionsrath (Oberbergrath) in Wien
Mit einer Figurentafel.
Wien, 1855.
Verlag von Friedrich Manz.

Fig. 2. "Theoretical and Practical Treatise on a New Method of Evaporating All Kinds of Liquids," 1855, published by Fr. Manz, Vienna

The invention

Ritter von Rittinger's evaporation process was tested in 1856-1857 at the salt works in Ebensee. Salt production in the upper Austrian "Salzkammergut" has been economically important for several hundred years. The salt resources are located in the Dachstein geological area. The classical method for salt production using large salt pans required large amounts of wood for combustion. In the beginning of the 17th century, a 40 km brine pipeline was built from the salt resources in Hallstatt to the well-wooded region of Ebensee. In the 19th century, the forest resources in the Ebensee region ran out due to the use of wood for salt production. New energy resources (coal) and new energy saving technologies became increasingly important. This prompted Ritter von Rittinger to test his new idea for thermocompression on an industrial scale (Fig. 3). Technical details for his experimental facility for salt evaporation are as follows:

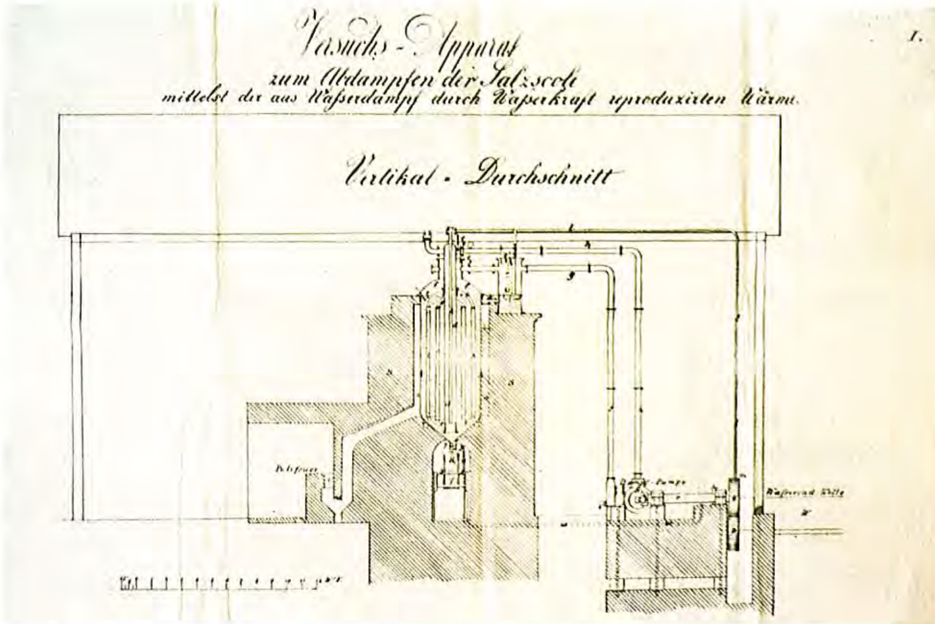


Fig. 3. Vertical cross-section of the experimental apparatus used for the evaporation of the salt-brine by reproducing heat from water vapor (driven by hydropower)

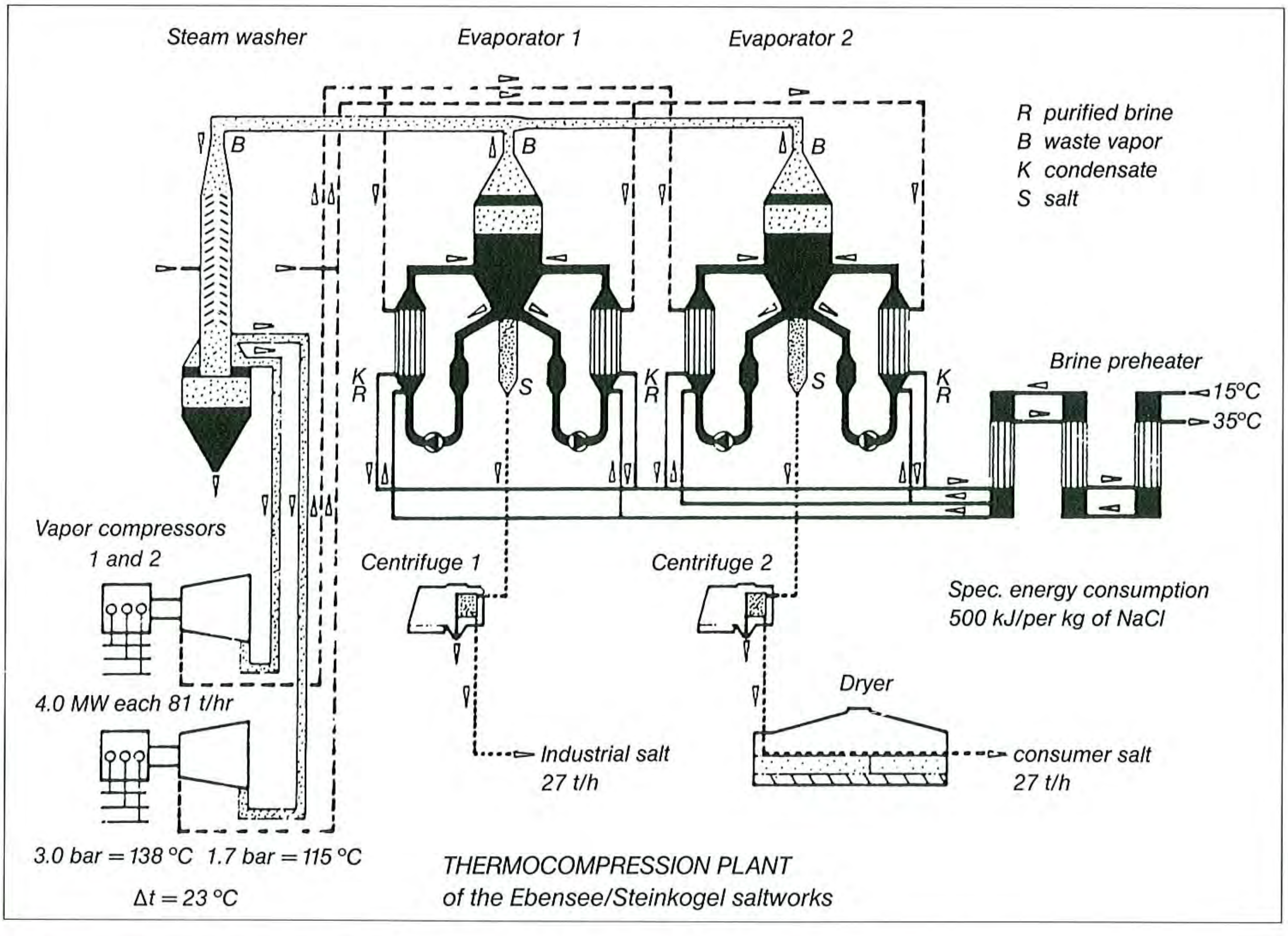


Fig. 4. Thermocompression plant (2 units at 4 MW_e) in the salt-works of Ebensee/Steinkogel, system schematic

Location:	Ebensee, Upper Austria
Start of operation:	1856-1857
Method:	Thermocompression
Designer:	Peter Ritter von Rittinger
Auxiliary Heat:	Biomass (wood)

Thermocompressor:

– driving energy:	Hydro power
– power input:	11 kW
– fuel savings:	80%

First experiments were performed with fresh water with excellent results. Further experiments with salt brine showed complications due to crust formations caused by gypsum. Experiments continued in 1858, however, technical problems with crusts could not be solved.

After Ritter von Rittinger's death in 1872, Prof. Piccard followed up on his work in Lausanne, in cooperation with the mechanical engineer Weibl. A thermocompression plant was constructed between 1870 and 1880 in the salt works of Bex, Switzerland. The final breakthrough occurred at the end of World War II when the Swiss Josef Wirth developed turbocompressors directly coupled to electric motors.

The salt works in Ebensee

Peter Ritter von Rittinger's thermocompression process has become increasingly important in Austria since World War II. In the years following the war, the salt works in Ebensee produced about 50,000 tons of salt per year, and production has risen to about 400,000 tons per year today. This rise in salt production is closely linked to the step-by-step introduction of thermocompression for salt-brine evaporation. In the fifties, the first vapor-compression unit was put into operation, with a power input of 650 kW_e (later increased to 1 MW_e). In 1979, a completely new facility was built at the periphery of the Ebensee. Two 4 MW_e salt-brine thermocompression units were installed, allowing for production of 1,350 tons of salt per day with more than 7,500 hours of operation per year (Fig. 4).

Most of Austrian salt is produced in Ebensee. The use of vapor compression in place of conventional salt production processes is the main reason for the independence of salt production costs from crude oil price fluctuations, since most of Austrian electricity generation comes from hydro-electric plants. Aside from the special legal conditions for salt production in Austria, this price decoupling is the primary reason for the excellent economic health of the Austrian salt industry. The Oberösterreichische Kraftwerke Aktiengesellschaft (OKA) has been supplying the salt works at Ebensee with electricity for more than 50 years. The electric load of the thermocompression units (8 MW_e) and the additional demand from production facilities represent an important part of the power company's industrial sector consumption, due to the large number of operating hours per year.

Fig. 5. Thermocompression units today, with monument to Peter Ritter von Rittinger on the back wall

The electric thermocompression process both saves energy and provides considerable environmental benefits for salt production in alpine regions. The success of SALINEN AG, a company with 500 employees and AS 780 million yearly sales, is based in its future-oriented investment decisions, from an economic as well as environmental point of view.

Fig. 5 shows a view of the thermocompression units at the salt works in Ebensee today. On the far wall, a monument to Peter Ritter von Rittinger is signed with the words, "Dedicated to the man who invented the heat pump."

References

1. M.F. Schneeberger, "The impact of an Austrian Utility's heat pump initiatives," Proceedings, IEA Heat Pump Conference, "Current situation and future prospects," Graz, Austria, May 22-25, 1984, pp 507-513.

2. M.F. Schneeberger, „Heat Pump Activities of an Austrian Electric Utility Company," IEA Heat Pump Center Newsletter, Vol. 3, No. 3, pp 2-6.

K. Krenn, Österreichische Salinen AG, Ebensee, Austria

W. Ritter, M. F. Schneeberger, Energy Consulting Department, Oberösterreichische Kraftwerke AG (OKA), Linz, Austria

Brayton Cycle Solvent Recovery Heat Pump

In 1978, the United States Department of Energy (DOE) initiated, within the Office of Industrial Programs, the design and development of a Brayton cycle high temperature heat pump system for use in milk drying applications. Garrett AiResearch of Torrance, California is the contractor for this project, with responsibility for design, fabrication and testing of the system. Technical monitoring of this project was conducted by EG&G Idaho, Inc. at the Idaho National Engineering Laboratory.

During the early part of the work it became evident that, due to decreasing natural gas costs, milk drying heat pump applications were economically viable only where low-cost electrical power was available. The contract was consequently redirected, on the basis of findings made during an initial market survey, to development of a Brayton cycle heat pump system designed to recover solvents entrained in drying air streams such as those emitted from magnetic tape drying ovens. Fig. 1 shows a

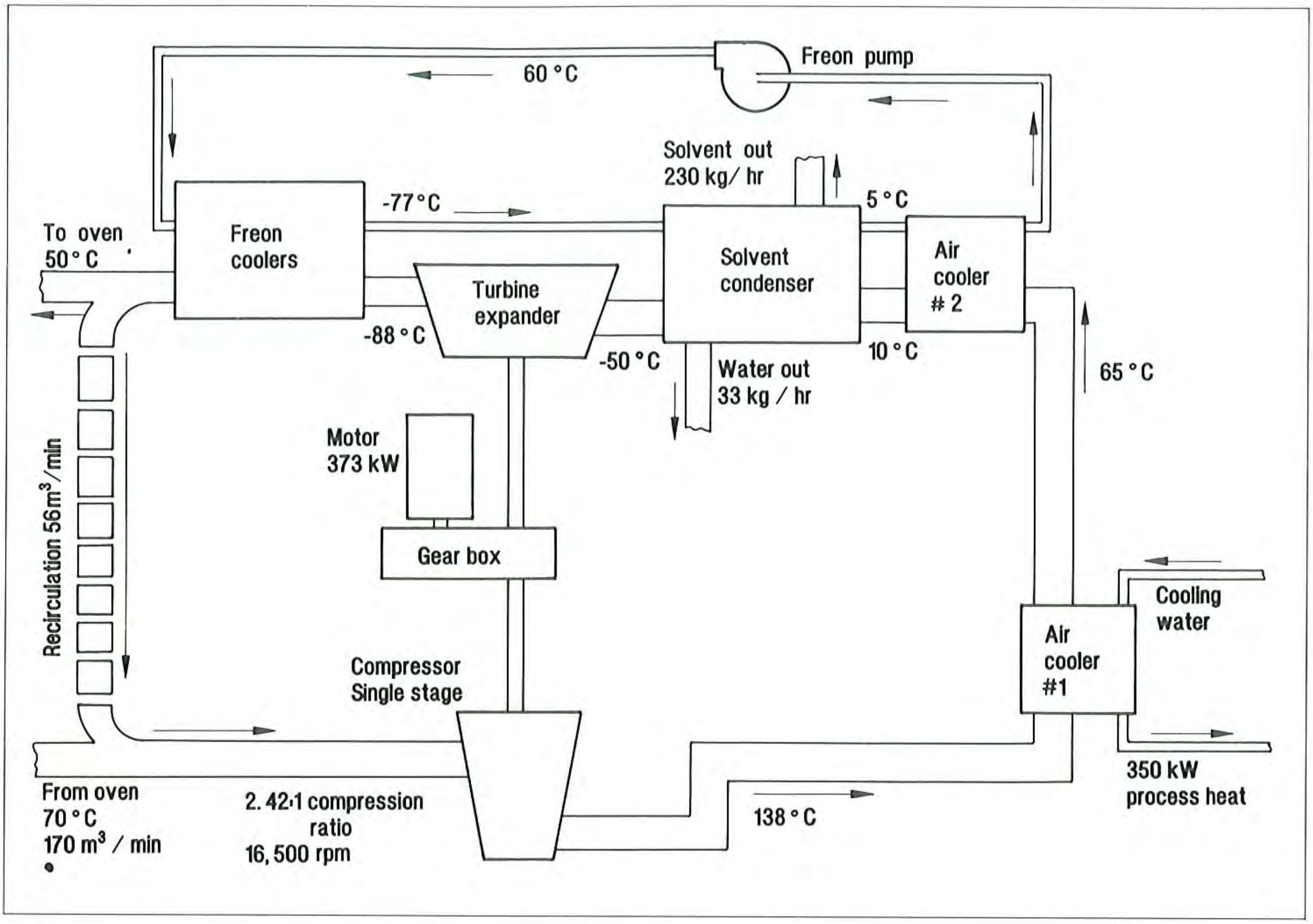


Fig. 1. Heat pump system schematic, open loop Brayton cycle

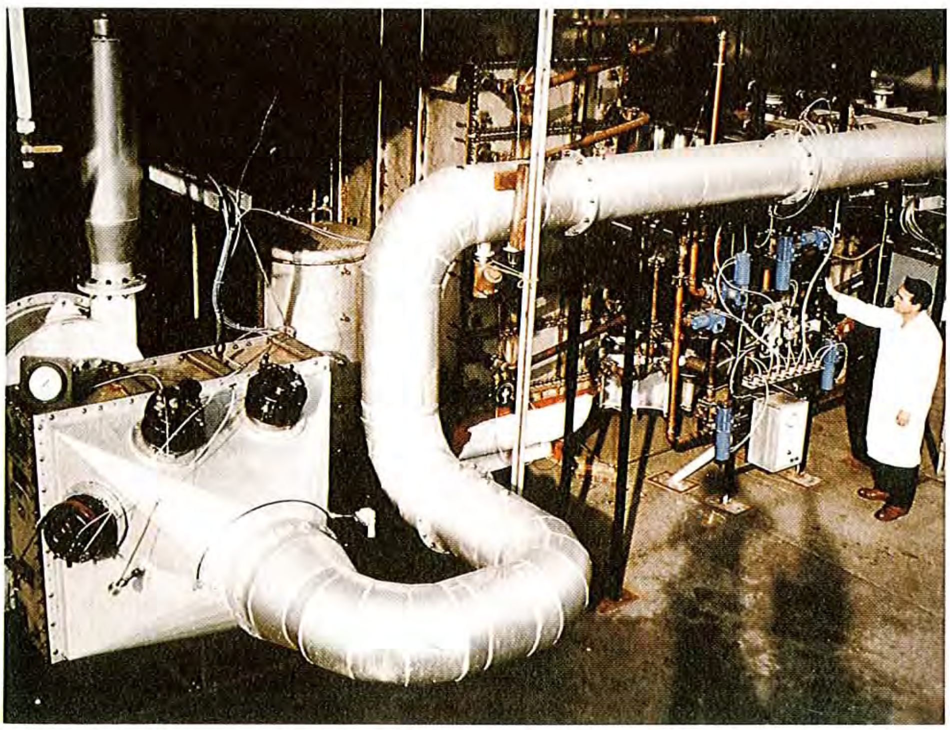


Fig. 2. Brayton cycle solvent recovery heat pump

schematic of the system design completed in November 1982. This system was fabricated and successfully tested, and solvent recovery efficiencies of approximately 90% were demonstrated (see Fig. 2).

Following completion of testing in February 1985, the turbo-compressor components were disassembled for inspection. Minor problems, such as an oil leak, were corrected at this time. The system is presently being prepared for service in a magnetic tape facility with system start-up scheduled for August 1986.

A first evolution of the technology featuring free-spindle rather than gear-driven turbo-compressors has been designed to desorb drying oven charcoal beds. Installation of this system is also expected to occur in the summer or early fall of 1986. Other potentially attractive applications for the technology include flash freezing of foods, removal of flammable vapors at storage terminals, or other processes that emit vapors that are either environmentally damaging or commercially valuable.

Additional information can be obtained from R. N. Chappell, Idaho National Engineering Laboratory, U.S. Department of Energy, Idaho Operations Office, 785 DOE Place, Idaho Falls, ID 83402 (USA), or phone 208/526-0085.

S. Taki*

Energy Savings in Beer-Brewing Process with a Vapor Recompression System

Energy-intensive wort boiling for beer brewing is an excellent application for a mechanical vapor recompression heat pump system. At the Suntory Tonegawa Brewery in Japan, such a heat pump has reduced energy consumption by 68%, and product quality has been maintained. The operation of this installation is described here in detail.

Wort boiling, part of the beer brewing process, requires a great deal of energy, up to as much as 35% of total plant energy consumption. To save energy in this process, we have developed a screw steam-compression system, and have constructed a full-scale test plant at the Suntory Tonegawa Brewery, in cooperation with Mayekawa Mfg. Co., Ltd.

The completed system has a driving-energy requirement that is only 31% of the conventional system. The system controls the heat exchanger outlet temperature to within 1 K and the inner pressure of the kettle to within 200 Pa. The quality of both the wort and the beer produced is maintained compared to that produced conventionally. This system can be applied in many industrial processes, resulting in significant energy savings.

The beer-brewing process

The beer-brewing process is separated into five main stages: wort production, fermentation, storage, filtration and bottling. The wort production stage consumes by far the most energy. The primary purposes of the wort boiling process are to extract and isomerize the substances in the hops, and to stabilize the composition of the wort. With nearly 10% water evaporation in the wort kettle, energy consumption reaches as much as 35% of total-plant energy requirements.

In a conventional plant, the vapor from the copper that results from wort boiling is used for hot water production. This heat recovery method is not effective, however, because too much hot water is produced and it is difficult to match production with hot water demand. The vapor from the copper can be used as the heat source for an absorption refrigerator; this has proven to be unsuccessful due to high capital costs and therefore long payback period. The preferred application for energy recovery is a simultaneous need for process heat and production of waste heat. A mechanical vapor recompression (MVR) system has recently been introduced in some industries to satisfy these conditions.

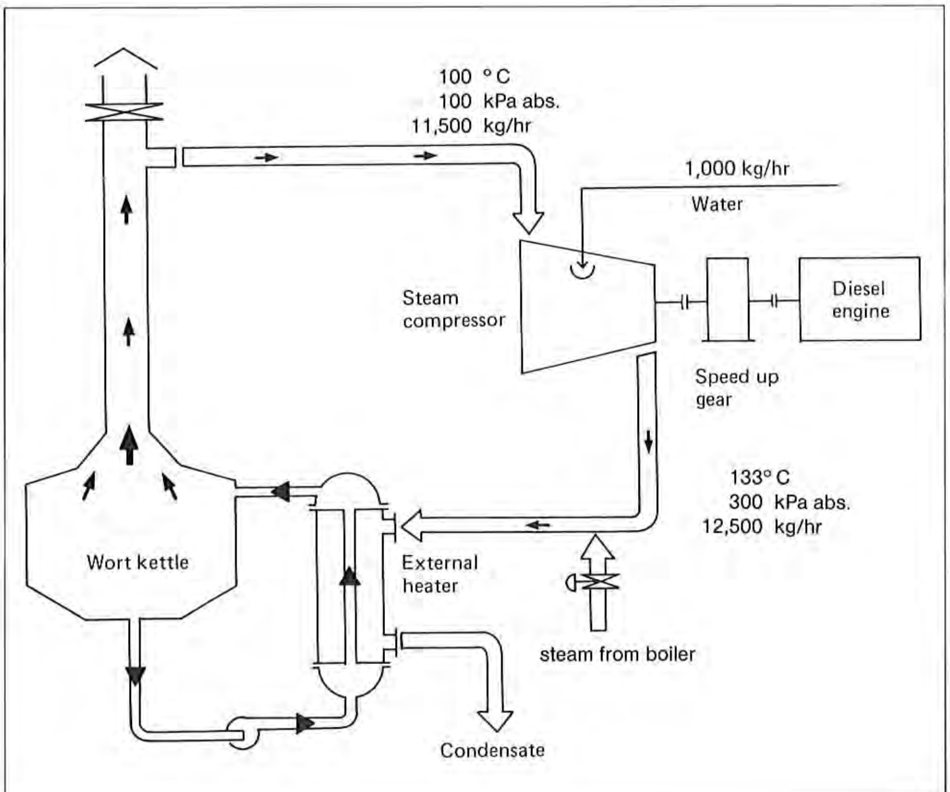


Fig. 1. Schematic of mechanical vapor recompression system

Wort volume out of kettle	140 kl/brew
Boiling time	75 minutes
External heater outlet temperature	106° C
Compressed steam temperature	133° C (300 kPa abs.)
Compressor displacement	19,200 m^3/hr at 3,800 rpm
Diesel engine maximum output	1,000 kW at 1,750 rpm

Table 1. Test conditions and compressor specifications

The heat pump system

In 1982, we started our development of an MVR system for the wort boiling process, and constructed a full-size test plant at the Suntory Tonegawa Brewery. Fig. 1 shows a schematic of the system; Figs. 2-4 are photographs of the completed plant.

At the start, the wort is heated to boiling temperature with steam from a boiler. After evaporation has begun, the wort copper vapor, at about 100°C and almost atmospheric pressure, is compressed by the steam compressor to a sufficient temperature level for reuse (130-140°C). Wort boiling continues using the heat of compressed vapor, and no additional feed of steam from the boiler is required.

In a conventional MVR system, a turbo or roots compressor is normally used, but these kinds of compressors have limitations in practical applications due to, for example, small compression ratios and vulnerability to mist. In wort boiling, the vapor from the copper needs to be compressed to 250-350 kPa absolute to operate under the same conditions in a conventional system. We designed a high-efficiency screw compressor to meet the needs of this system.

System operation and performance results

After the screw compressor was completed in March 1984, we tested our MVR system for one year at the Suntory Tonegawa Brewery. Test conditions and system specifications are summarized in Table 1.

	Conventional		Mechanical Vapor Recompression	
	Actual Value	Equivalent Fuel Consump.	Actual Value	Equivalent Fuel Consump.
Steam consumption during boiling	16.8 ton	1,379 l	1.45 ton	119 l
Engine fuel consumption	–	–	273 l	273 l
Electricity consumption	–	–	154 kWh	40 l
TOTAL		1,379 l		432 l
ENERGY SAVINGS				69 %

Assumptions:	
Steam production of boiler:	14 kg-steam/kg-fuel
Specific gravity of fuel:	0.87 kg/l
Efficiency of electric generation:	35 %
Net heating value of fuel:	39 MJ/l

Table 2. Comparison of energy consumption per brew, conventional and heat pump system

Fig. 2. Steam screw compressor

Wort kettles are usually of open construction, and there is a risk of swelling and caving with little change in inner pressure. The inner pressure of the kettle must be strictly controlled. We have successfully controlled this pressure to within 200 Pa.

When hops are added, a large volume of air flows into the kettle abruptly, resulting in a large pressure disturbance. Even at this moment pressure control was maintained. The most influential factor on wort quality is the heat exchanger outlet temperature, which was successfully controlled to within 1 K.

As for energy savings, the energy required to drive our MVR system was about 31% of the requirement for a conventional system (as shown in Table 2). In addition to this large reduction in energy consumption, wort and beer quality were maintained, based on results from chemical analysis and taste testing.

This screw-compressor system is an ideal and practical technique for heat recovery, especially in existing plants. We expect this system to be applied in many kinds of industry, including distillation and other evaporation processes, resulting in significant energy savings.

*S. Taki, Engineering Department, Suntory Limited, Osaka, Japan

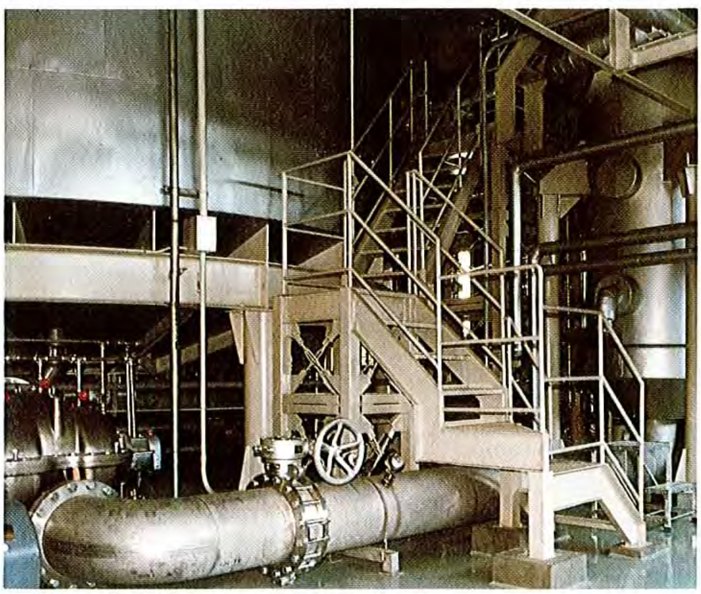


Fig. 3. Wort kettle (lower part) and external heater

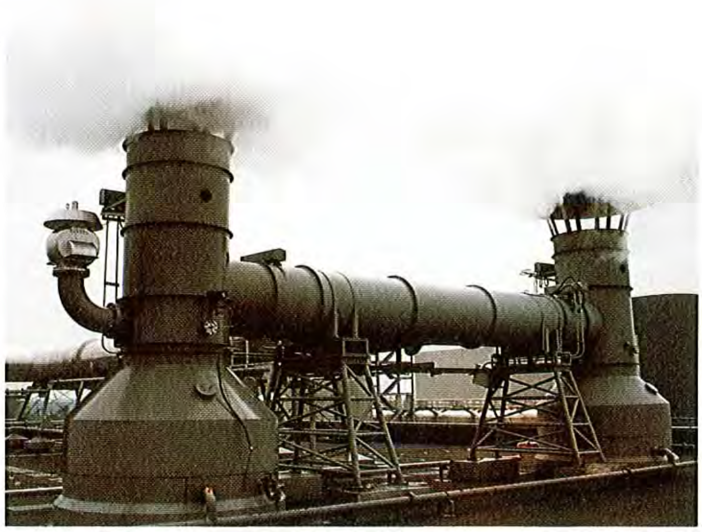


Fig. 4. Wort kettles (upper part)

Heat Transformer
Demonstration Project in the Netherlands

In Delfzijl, the Netherlands, Delamine B.V. operates a plant for production of ethylene amines. The production process requires 4.7 bar steam, 150 °C. At the same time, water vapor is condensed in air coolers at the same facility. A heat transformer has been installed to use this energy effectively, and the project has a projected payback period of two years.

The heat transformer is an absorption heat pump; it releases about 50% of the waste heat supplied to it at a higher temperature level, and requires electricity only to run a few pumps. The heat transformer operates on the principle that the temperature at which water vapor condenses (is absorbed) in a salt solution is above the temperature at which water evaporates, provided both processes are at the same pressure. At reduced pressure, a salt solution circulates through special heat exchangers. Absorption of water vapor releases heat, and this heat is used to generate steam (10 tons/hr) for the production process.

A flow sheet of the system is shown in Fig. 1. Waste heat is used to evaporate the condensate, and to evaporate the water in the salt solution at reduced pressure. This latter vapor is condensed using cooling water, the condensate pressurized and evaporated. This water vapor is absorbed in the salt solution, releasing the heat of absorption at an elevated temperature.

Waste heat is used in two heat exchangers, the regenerator and the evaporator, where the same quantity of water is evaporated. Only the waste heat used in the evaporator is retained; this is about 50% of the waste heat supplied. The only expensive energy required is electricity to run circulation pumps.

The heat transformer can be used with waste heat temperatures above 60°C. The temperature level attainable in the absorber is determined by the temperature of the waste heat and the temperature of the condenser. Technical specifications are given in Table 1. The heat transformer went into operation in October 1985. The heat pump was made by Hitachi Zosen, the plant was designed and built by Akzo Engineering B.V. (Arnhem, the Netherlands), and the project received a subsidy from NEOM as a demonstration project beneficial to other industries. The initial investment for the plant was six million Dutch guilders, and the projected savings are six million m^3 of natural gas annually.

(Information provided by Delamine B.V., Delfzijl, and NEOM, Sittard, the Netherlands)

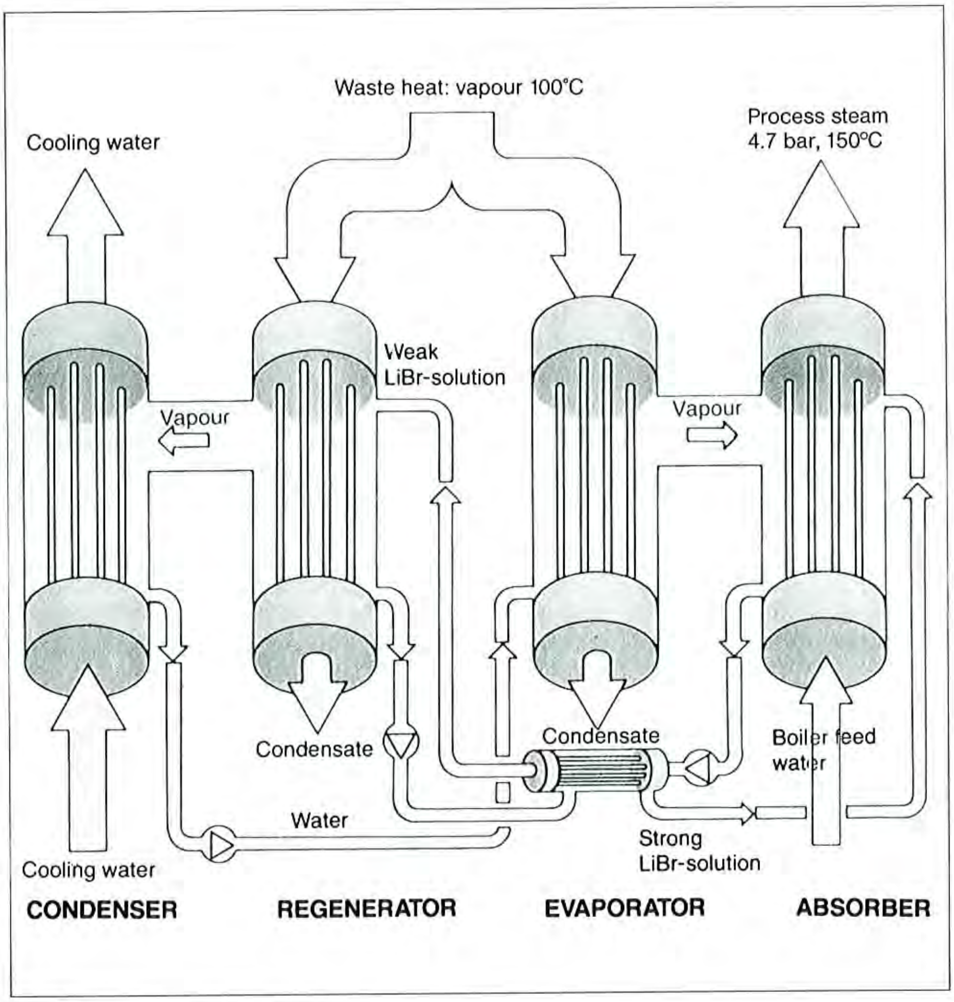


Fig. 1. Flow sheet: heat transformer

Output (Steam)	Heat Quantity	6.42 MW
	Flow Rate	10.46 tons/h
	Feed Water Inlet Temp.	127° C
	Steam Outlet Temp.	150 ° C
	Pressure	4.7 bar
Waste Heat (Vapor)	Heat Quantity	13.78 MW
	Flow Rate	22 tons/h
	Inlet/Outlet Temp.	100/100° C
Cooling Water	Flow Rate	389 tons/h
	Inlet/Outlet Temp.	24/40° C
Power Consumption		43.5 kW

Table 1. Technical Specifications

S. Takizawa*

Development and Application Examples of a Horticultural Heat Pump

Tokyo Electric Power Company and Mitsubishi Electric Corporation have developed an air-source heat pump that provides heating, cooling, and dehumidifying for horticultural facilities. This unit combines high energy efficiency at low outdoor temperatures with low cost and small size, providing better growing conditions year round, and higher product quality.

1. Background and objectives of development

Japan's area of horticultural houses is continuing to grow, and now totals 39,000 hectares (ha) across the country. Of this total, about 14,000 ha require heating in winter, and most use a boiler system.

Since the oil crisis, horticulturists have experienced soaring oil prices and reduced economic growth, pressing them to improve productivity through energy conservation, year-round use of facilities, and reduced production costs. One step in that direction is the introduction of a heat pump with a high energy efficiency, and with heating, cooling and dehumidifying functions.

At present, most of the heat pumps utilized in horticultural facilities use ground water as the heat source, and cannot be used in regions where ground water pumping is restricted. Air-source systems, on the other hand, have had their own problems, such as a reduced efficiency in frigid regions.

To overcome these difficulties, Tokyo Electric Power Co., Ltd. (TEPCO) and Mitsubishi Electric Corporation have collaborated since 1983 to develop a "horticultural air source heat pump" that:

1. is an "air source system" whose use is not limited to specific regions;
2. has a high energy efficiency even at low outdoor air temperatures;
3. has heating, cooling and dehumidifying functions that are required for higher quality and year-round availability;
4. has a low first cost and requires little space.

In June 1984, two test units were installed in a glassed hothouse at the Agaki Experimental Center of the Central Research Institute of the Electric Power Industry (Figs. 1 and 2). Field experiments with tomato cultivation verified expected performance levels.

2. Structure and features

System specifications are given in Table 1. The indoor and outdoor units are of one-piece construction, and have heating, cooling and dehumidifying functions. A „reverse cycle defrosting system" with a built-in cold draft stopping function is used. The compact air-source heat pump unit developed has the following features, satisfying all essential horticultural requirements:

1. the one-piece construction of indoor and outdoor units reduces weight and simplifies installation, reducing cost;
2. the air-source system allows for utilization in any region;
3. increased efficiency of indoor heat exchangers improves efficiency in the heating mode by about 20% compared to the conventional system, even at low outdoor air temperatures (-10°C);
4. the cooling, heating and dehumidifying functions improve the quality of farm produce, prevent diseases, and allow for year-round cultivation;
5. the reverse cycle defrosting system prevents the house temperature from dropping during defrosting, and nearly halves the defrosting time compared to conventional systems.

3. Operational patterns

The refrigerant circuit and operating modes of the system are given in Fig. 3.

In the heating mode, the first and second indoor heat exchangers are connected in series for counter-flow heat exchange, improving efficiency and raising discharge temperature.

If the indoor fan runs during the defrosting mode, a cold draft blows out, dropping the house temperature. Therefore, this fan is stopped (cold draft stopping mechanism). In this state, however, the refrigerant pressure on the intake side drops. Using the No. 1 solenoid valve circuit that bypasses the compressor outlet and accumulator inlet, some hot gas flows into the accumulator, shortening the defrosting time (high generation circuit).

For dehumidification, air in the house is cooled and dehumidified by the first indoor heat exchanger, then heated by the second heat exchanger and blown out. The system operates just like a heater-dehumidifier (at this time, the outdoor fan stops).

For cooling, the first and second indoor heat exchangers are connected in parallel to shorten the heat conducting pipe length per pass, and pressure loss of refrigerant in the evaporation side is reduced, increasing efficiency.

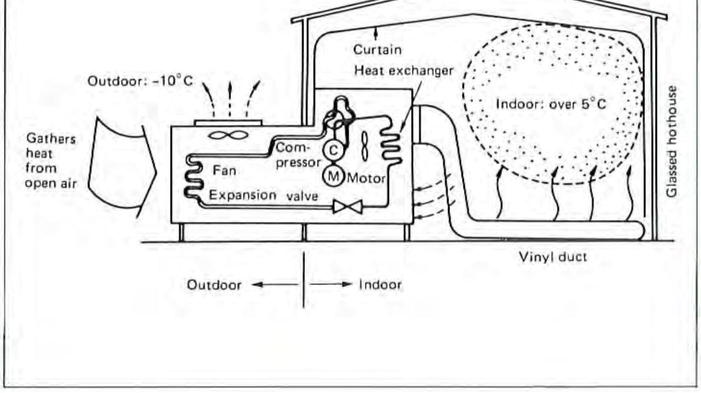


Fig. 1. The principle of the horticultural heat pump (when heating)

Fig. 2. Field experiment with tomato culture

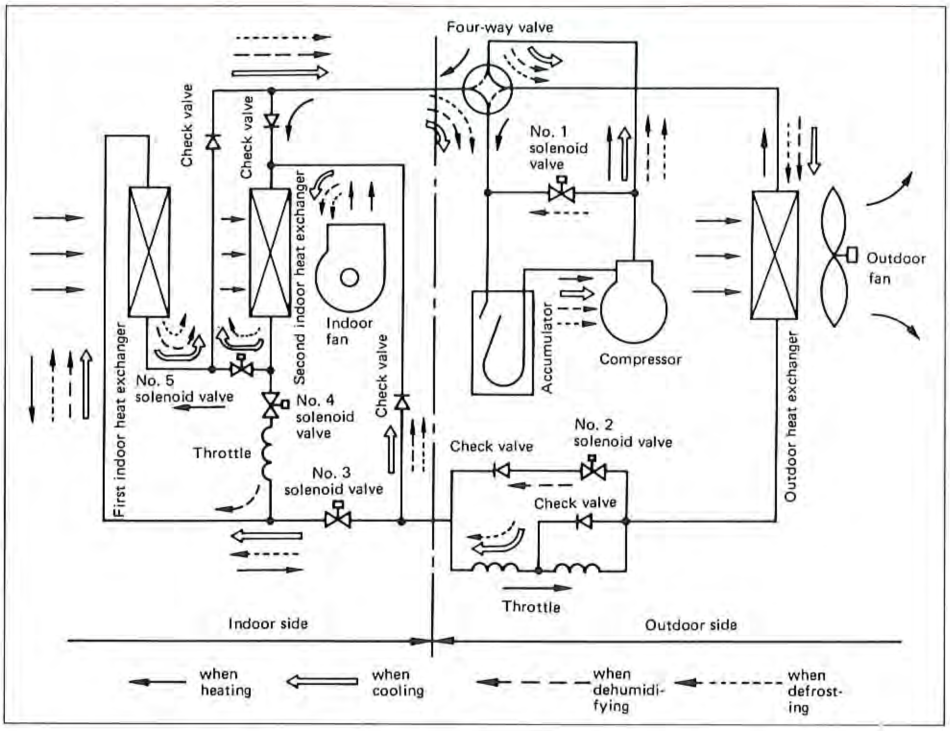


Fig. 3. Schematic of horticultural heat pump system

4. Advantages of heat pump introduction

The heat pump is a new „environmental control unit" in the field of horticulture, maintaining an optimal environment for cultivation of farm produce.

When a boiler system is used, a cooler and dehumidifier must be installed in some cases. Since the heat pump unit has all these functions, however, its installation results in reduced first costs, reduced running costs, and an improved rate of yearly utilization.

Favorable results have been achieved when the heat pump has been installed for horticulture. Benefits of cooling and dehumidifying, among others, are outlined below.

Cooling effect

Cooling during tropical summer nights allows for growth of healthy seedlings, prevents farm produce from aging, and improves productivity. For the cultivation of flowering plants, such as roses and carnations, good plant shape, long flower life and vivid colors can result. For melons etc., sugar content is increased due to the widened temperature difference from day to night.

In the traditional cultivation of orchids, begonias, strawberries, etc., transport high above sea level is required for bud branching. With a heat pump, a similar effect results from cooling, and flowering/shipment adjustments can be made according to demand, while eliminating uphill transport for dramatic labor savings.

Dehumidifying effect

During the rainy season or winter heating, high humidity frequently causes diseases. Dehumidification on humid days effectively prevents diseases and reduces disinfection requirements, saving both labor and material costs.

During melon cultivation, formation of net-like patterns on the melon surface requires delicate humidity adjustments. The heat pump simplifies these adjustments, improving quality and increasing profitability.

Mushroom cultivation (champignon, maitake, etc.) has required difficult temperature and humidity adjustments. Use of the heat pump has led to stable cultivation.

Item \ Operation model		Heating	Cooling	Dehumidifying
Power source		Three-phase 200V 50/60 Hz		
Capacity (kW)		30/33*1	29/32*2	17/18l/h*3
Power consumption (kW)		9.9/11.4*1	11.3/13.4*2	10.5/12.4*3
Type of compressor		Hermetic reciprocating type		
Fan (indoor side)	Air flow rate [m³/min.]	85 (static pressure outside the machine: 17 mmAq) 105 (static pressure outside the machine: 0 mmAq)		
	Type	Sirocco fan		
	Rated output (kW)	1.0		
Fan (outdoor side)	Air flow rate [m³/min.]	160		
	Type	Propeller fan		
	Rated output (kW)	1.1		
External dimensions	Height (mm)	1,071		
	Width (mm)	970		
	Depth (mm)	1,504		
Product weight (kg)		340		
Defrosting system		Reverse cycle (high generation circuit + cold draft stopping mechanism)		
Heat exchanger	First indoor Second indoor Outdoor	Cross fin (louver & stair)		
	Surface treatment	Allonaclear treatment		
Appearance		Acrylic coat (color: Munsell 5 GY 5.5/4.5 . . . . . green)		
Option		Blowout duct flange (track-type)		

< Conditions > *1. Outdoor side inhaled air temp. 7°CDB, 6°CWB; indoor side inhaled air temp. 21°CDB.
*2. Outdoor side inhaled air temp. 35°CDB, 24°CWB; indoor side inhaled air temp. 27°CDB, 19.5°CWB.
*3. Indoor side inhaled air temp. 25°CDB, relative humidity 80%.

Table 1. Specifications for horticultural air source heat pump

5. Current problems and future trends

In addition to cooling and heating, the heat pump is also used for hot water supply, temperature boosting, chilling, drying, dehumidifying, etc. Fields of application include cultivation of vegetables, flowering plants, mushrooms, fish, and marine life, livestock raising, storage of vegetables and fruits, preservation of seedlings, budding control, drying of farm and marine produce, and hot water supply to various other processes. The heat pump has responded to the requirements of a new agricultural age.

At present, international oil circumstances have taken a favorable turn, and oil prices are showing a downturn. Under current oil prices, if the air source heat pump system is used only for heating, running costs are roughly the same as those for a boiler system. Meanwhile, initial costs are somewhat high. It is important to achieve further price decreases and increases in efficiency, and to effectively utilize the cooling and dehumidifying functions of the heat pump.

The heat pump is rapidly penetrating industry in general, including horticulture. Along with the steady development of software for heat pump utilization, and effective utilization of the heat pump's diverse functions, it is expected that the heat pump will be seen in wide range of uses.

*S. Takizawa, Marketing Development and Engineering Division, Tokyo Electric Power Co., Ltd., Japan

F. Trombetti*

Energy Conservation in an Electrical Substation

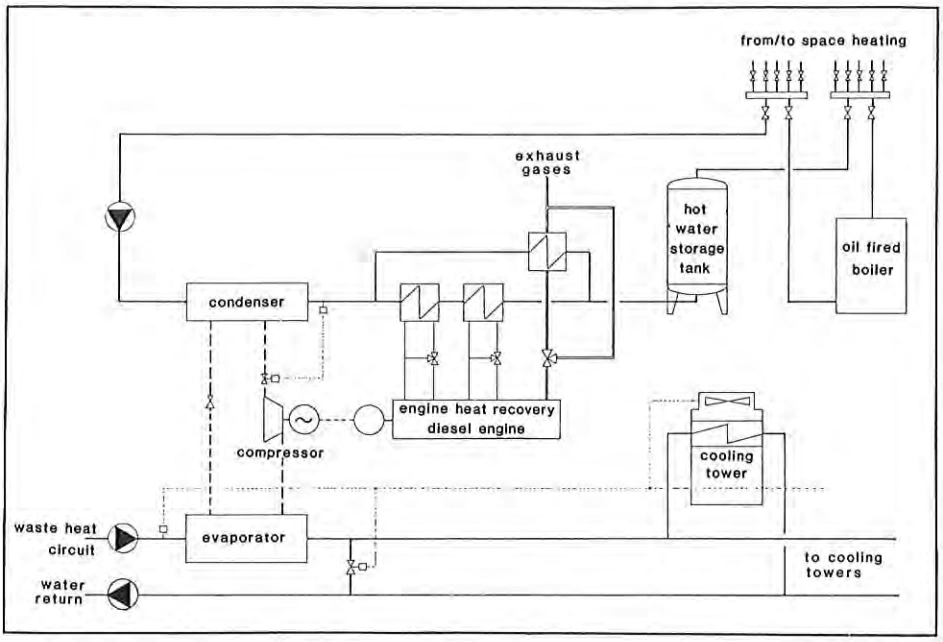


Fig. 1. Heat pump system flow diagram

Evaporator	Type Recoverable waste heat Water temperature, in/out	shell and tube 700 kW 38/30° C
Condenser	Type Heating capacity supplied Water temperature, in/out	shell and tube 900 kW 60/67° C
Compressor	Type Working medium Shaft power Motor power	centrifugal R-12 232 kW 257 kW

Table 1. Characteristics of major plant components

An interesting experiment with a heat pump uses the heat rejected from an electric substation for building heating during the winter. Electrical machinery is cooled with closed-loop water, which is in turn cooled by cooling towers. The amount of heat released into the atmosphere by the cooling towers, the amount of heat required for office space heating and the similar behavior of the thermal loads in time suggested the possibility of using a heat pump to take advantage of the heat generated by the electrical machinery. The heat pump uses cooling water as a heat source and supplies the heating circuit of the buildings with upgraded heat. The overall heating load is about 1,160 kW.

A feasibility study determined that a diesel engine driven heat pump with heat recovery from oil, motor cooling and exhaust gases was the best choice from an energy and economic viewpoint. In case of heat pump malfunction, the heating load is met by an oil-fired boiler.

The diesel motor and the heat pump are connected by a generator-electric motor unit. Compared to direct coupling with the diesel engine, overall plant efficiency at reduced loads is improved, and connection to the main electrical grid may be possible for both the sale and purchase of electricity.

Fig. 1 shows a flow diagram of the heat pump system. Table 1 gives the characteristics of the major components of the plant. The plant started operation in the first months of 1982. Results from these first years of operation have confirmed performance, consumption and yield predictions (within fixed allowable limits). The plant has been running smoothly and reliably.

F. Trombetti, HPC National Team, CISE spa, Milan, Italy

Y. Hayashi*

Application of Heat Pump System to Propylene Distillation Column

Using a heat pump for mechanical vapor recompression in distillation processes has resulted in significant steam and cooling water savings in a propylene-propane fractionation plant in Japan. Operating with a coefficient of performance of 10.3, first-year savings in operating costs were slightly higher than the increase in investment costs compared to a conventional system, resulting in a less than one year payback period.

One of the most promising industrial processes for the integration of heat pump technology is fractional distillation. Fractional distillation is a process used to separate the components of a chemical mixture. Using a heat pump to generate heat to drive this process recovers waste heat, reduces cooling water consumption, and eliminates boiler fuel consumption to produce process steam. In this article, the application of a heat pump to a distillation column for the separation of propylene and propane at the Marifu Refinery in Japan is described (Fig. 1).

In the distillation process, a mixture of liquids with different boiling points is heated (with a "reboiler"), vaporizing one or more of the mixture components. These vapors rise through a distillation column, and are separated out through condensation at various temperatures. In conventional distillation systems, the latent heat of condensation in these vapors is lost to the atmosphere through a cooling tower. With the application of a heat pump using mechanical vapor recompression, these vapors are recycled through a compressor, boosting the temperature, and the latent heat is delivered back to the reboiler.

Fig. 1. Propylene splitter at Marifu Refinery, KOA Oil Co., Ltd., Yamaguchi, Japan

Feed	
Flow-rate	12,906 kg/hr (297.55 kg-mol/hr)
Composition	
- ethane	0.03 mol %
- propylene	61.36 mol %
- propane	34.92 mol %
- butane+	3.69 mol %
Product propylene	99.7 mol % and above
Percent recovery of propylene	97.6 % and above
Flow rate, product propylene	178.77 kg-mol/hr
Flow rate, propane	118.78 kg-mol/hr
Utility costs	
Electric power	18 Y/KWH
Steam	1,600 Y/ton
Cooling water	5 Y/ton
Operating hours	8,000 hr/year

Table 1. Operating conditions, propylene fractionation

	Conventional System		Heat Pump System	
	Pressure kPa	Temperature °C	Pressure kPa	Temperature °C
Top of Column B	1,960	47.4	1,100	27.3
Bottom of Column A	2,150	63.6	1,300	39.5
Reflux Returned to Column B	1,910	41.2	1,950	46.2

Table 2. Comparison of operating pressures and temperatures

Benefits of heat pumps in distillation processes

Application of a heat pump to a distillation process is particularly suitable when the components to be separated have boiling points that are close to each other, meaning that the temperature difference between the top and the bottom of the column is small. Examples of this are separation of propylene from propane and ethylene from ethane. Through slight compression of the vapors coming out of the top of the column, the temperature is increased enough so the heat can be used as a heat source for the reboiler, eliminating process steam requirements.

In the distillation process, a portion of the condensed vapors are sent back to the column in order to enrich the mixture. In conventional systems, the amount of product sent back to the column (reflux ratio) is determined by the ambient air temperature (air-cooled condensers) or by the cooling water temperature (water-cooled condensers). A heat pump system for distillation is free from such constraints, allowing for lower operating pressures. This results in easier separation, higher relative volatility, and a lower reflux ratio, and an excellent opportunity for energy savings.

In conventional systems that use cooling towers, application of a heat pump significantly reduces cooling water consumption, since the greater part of the heat of condensation of vapors from the column are used as a heat source.

System design and economics

Operating conditions for the system at the Marifu refinery and energy prices used for cost comparisons are given in Table 1. The details of both the conventional and the heat pump system are described below.

Conventional propylene fractionation

A schematic for for conventional propylene fractionation is shown in Fig. 2. This system requires two columns (A and B), since as many as 254 distillation trays are used. Steam from a boiler heats the feed that enters at the bottom of column A. The vapors rise to the top of column A and then enter the bottom of column B. After rising to the top of column B, vapor is completely condensed by two water-cooled condensers. Part of this condensate is withdrawn as product propylene, and part is returned to the distillation column via a reflux drum. While in contact with the vapors in column B, the reflux liquid flows down across the trays in the column. Liquid that arrives at the bottom of column B is pumped back up to the top of column A. After contact with vapors in column A, the reflux is withdrawn as a propane-rich liquid from the bottom of the column.

The temperature of the cooling water supplied to the condensers determines the pressure at which all vapors coming out from the top of the column can be condensed. The operating pressures and temperatures of this particular system are summarized in Table 2.

Heat pump system for propylene fractionation

The heat pump system for propylene fractionation is shown in Fig. 3. In this system, the vapors coming out of the top of column B are pressurized by a compressor to increase the temperature of condensation. Before being returned as reflux to column B, a portion of the vapor from column B goes directly to the reboiler where it is condensed and is used as a heat source. After the reboiler, condensate is returned to the top of column B via the reflux drum.

The compression ratio required is determined by system operating pressures and temperatures (summarized in Table 2). The operating pressure and temperature at which all product propylene can be condensed were set at 1,900 kPa absolute and 46°C. To set the temperature at the bottom at about 40°C, about 6°C lower than the temperature of the heat source, the operating pressure at the bottom of column A was set at 1,300 kPa absolute. Considering the tray pressure drop, the effective operating pressure at the top of column B was calculated to be 1,100 kPa absolute. As a result, a compressor with a compression ratio of 1.76 (1,900/1,100) was installed.

The reflux ratio at the top of column B (R/D_{COLD}) is 16.1, compared to 16.5 in the conventional system. Since the operating pressure at the top of the column is lower than that in the conventional process, the reflux ratio at the bottom of column A (R/D_{HOT}) is considerably reduced, from 17.6 to 12.9. An even smaller reflux ratio value would result if a cooling medium with a temperature lower than that of the cooling water was used.

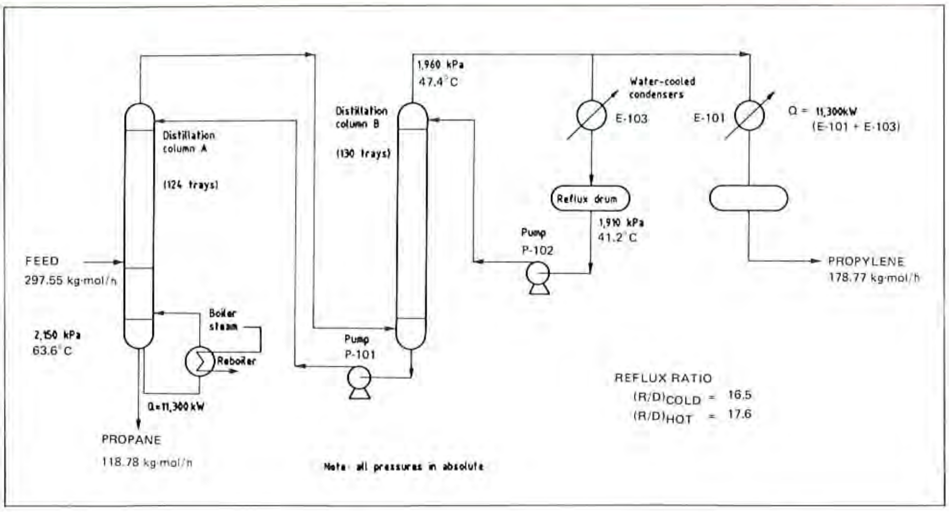


Fig. 2. Conventional propylene fractionation system

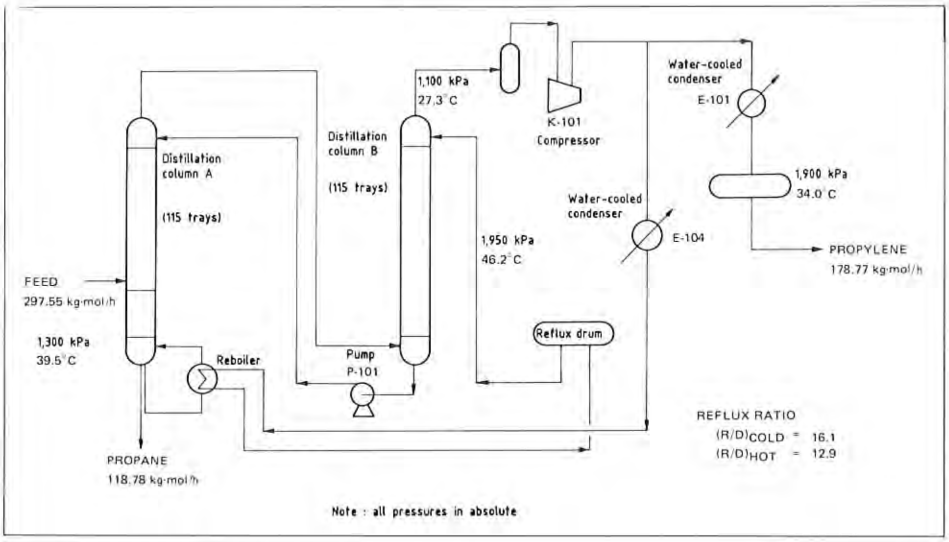


Fig. 3. Heat pump system for propylene fractionation

	Conventional System			Heat Pump System		
	Elec kW	4 bar Stm. Ton/hr	Clg. Wtr. Ton/hr	Elec kW	4 bar Stm. Ton/hr	Clg. Wtr. Ton/hr
Compressor K-101	–	–	–	1490	–	–
Reboiler E-102	–	19.2	–	–	–	–
Condenser E-104	–	–	–	–	–	69
Condenser E-101	–	–	91	–	–	91
Condenser E-103	–	–	1148	–	–	–
Pump P-101	50	–	–	38	–	–
Pump P-102	46	–	–	–	–	–
TOTAL	96	19.2	1239	1528	0	160

Table 3. Comparison of energy and cooling water consumption

Comparison of energy and water consumption

The plant at the Marifu Refinery, owned by KOA Oil Co., Ltd., went on line in December, 1981, and has been producing polymer-grade propylene with a coefficient of performance of 10.3, as expected. A detailed comparison of energy and water consumption is shown in Table 3. Compared to the conventional process, electric power consumption has increased, steam consumption is zero, and cooling water consumption has decreased drastically. A cost comparison for the two processes is given in Table 4. Annual savings of Y83,000,000 are possible with the heat pump system.

A comparison of investment and operating costs is shown in Table 5. The heat pump process required an initial investment cost of Y64,000,000 above that for the conventional process. The heat pump process saves, however, as much as Y67,000,000 in annual operating and investment recovery costs, making the process far more economical than conventional distillation.

Item	Unit	Conventional	Heat Pump
Electricity			
- Capacity	kW	96	1528
- Annual Consumption	kWh	0.768x10⁶	12.22x10⁶
- Unit Cost	Y/kWh	18	18
- Annual Cost	Yx10⁶	13.8	220.0
4 bar Steam			
- Input	Ton/h	19.2	-
- Annual Consumption	Ton	0.154x10⁶	-
- Unit Cost	Y/Ton	1600	-
- Annual Cost	Yx10⁶	246.4	0
Cooling Water			
- Consumption rate	Ton/h	1239	160
- Annual Consumption	Ton	9.91x10⁶	1.28x10⁶
- Unit Cost	Y/Ton	5	5
- Annual Cost	Yx10⁶	49.6	6.4
Total	Yx10⁶	309.8	226.4
Note: annual consumption based on 8000 h/yr operation			

Table 4. Comparison of annual utility costs

Item	Conventional x 10⁶ Yen	Heat Pump x 10⁶ Yen
Investment		
- Process Equipment (excl. comp.)	275.3	176.3
- Compressor and driver	-	170.8
- Material, engineering, construction	500.5	493.1
Total investment	775.8	840.2
Annual Utility Costs		
- Electricity	13.8	220.0
- 4 bar steam	246.4	-
- Cooling water	49.6	6.4
Total	309.8	226.4
Annual cost to cover capital investment	25 %	25 %
Annual capital cost	193.9	210.1
Annual utility cost	309.8	226.4
Annual operating cost	503.7	436.5
Material, engineering and construction: 180 % of process equipment costs, 100 % of compressor and driver costs, plus 5 million Yen		

Table 5. Project economics

Y. Hayashi, JPC Corporation, Yokohama, Japan

E. G. Bacigalupo*

Heat Pump in an Italian Pasta Factory for Producing High Temperature Water

This example of a heat pump-cogeneration system in a pasta factory in Italy has a system efficiency of 1.32 at full load--using a gas-engine drive to provide both heat and electricity to the factory. The project has operated successfully since September 1985, and a payback period of 3.2 years is projected.

This system uses heat recovery wherever possible. Heat is recovered from gas engine exhaust, from oil and water cooling and from air compressors feeding air to the engine. In addition, heat is recovered from the compressor oil separator and oil cooler. Exhaust air from the process is used as a heat source for the heat pump.

The pasta factory Molini e Pastifici Corticella, in Bologna, was exhausting warm and humid air from the production process. This process must be fed by hot water (from a boiler) and electricity (from ENEL, the national company). A gas engine to drive a heat pump and to generate electricity was installed, and the savings in operating costs (fuel and electricity) result in a projected payback of only 3.2 years. Using refrigerant R114, it is possible to produce high-temperature hot water (above 100°C) with the condenser of a heat pump operating at a moderate pressure. Such a heat pump is unusual, but not exceptional, as the market offers screw and reciprocating compressors with suitable design and construction characteristics.

System description

The plant, shown in Fig. 1, operates for 100 hours at full load each working week, or 5,000 hours per year. A flow sheet of the system is shown in Fig. 2. The gas engine drives the generator and the screw compressor on the same shaft.

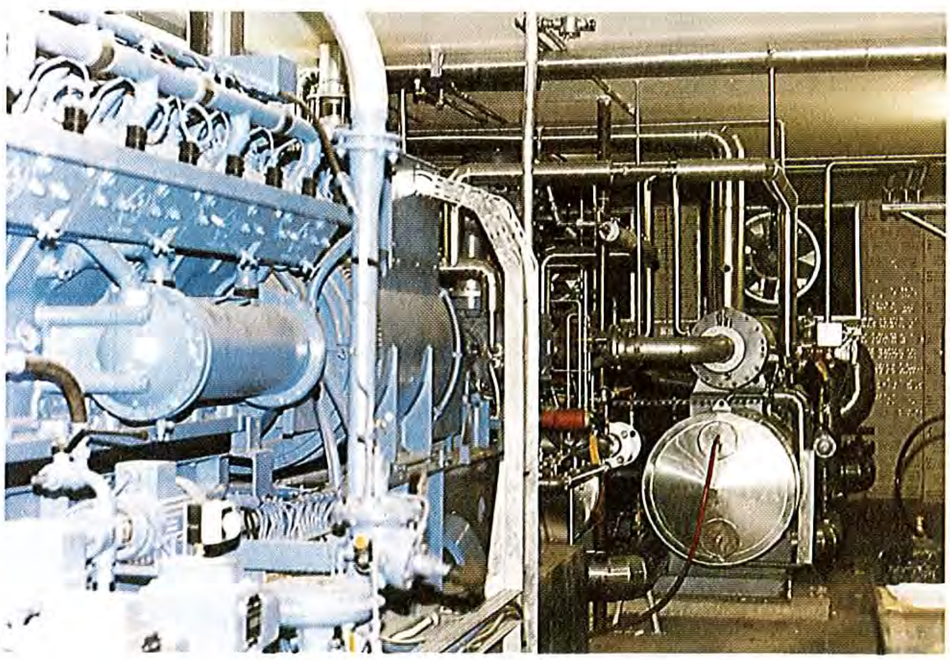


Fig. 1. Heat pump-cogenerator system

Performance results

The gas engine can operate at full load, generating both heat with the heat pump and electricity with the generator, or can run only to drive the heat pump or only the generator (see Table 1). At full power, the gas engine requires 130 m^3/hr of natural gas with a specific heating value of 9.767 kWh/m^3, or 1,272 kW. Combined heat pump and engine heat generation capacity is 1,403 kW (978 kW process load and 425 kW to radiators), disregarding 54 kW of heat recovery from air compressors and oil cooling for sanitary heating needs. The output of the generator, operating at the same time, is 224 electrical kW.

Fig. 2 shows all temperature levels. Without oil cooling, the heat pump COP is 3.52 on the shaft. Motor efficiency is 37% mechanical and 54.4% thermal (total 91.4%) when heat is recovered from engine exhaust, oil and water cooling, and air compression (ACHR).

The COP of the system – the ratio of thermal capacity to fuel consumption – is 1.21 when the gas motor gives only 216 kW shaft power at 46% of full load. The system efficiency is increased to 1.32 under full load, when the customer is producing electricity and utilizing all cooling water flows.

As of May 1986, the system has operated for more than 3,000 hours – almost continuously from start up in September 1985 – with the thermal load as the guide load and the electrical load making up the difference. In the case of gas motor shut down for maintenance (with the coupling shut off), the screw compressor is driven by the generator, operated as an electric motor supplied by the electric utility.

	Full load operation	Heat pump only
Fuel input to engine	1,272 kW	706 kW
Shaft power	470 kW	216 kW
Generator output	224 kW_e	0
Generator output, compressor decoupled	440 kW_e	–

Table 1. Operating capacities

Operating hours per year	5,000
Heating capacity	1,403 kW_{th}
Fuel price (natural gas)	240 lira/m^3
Fuel heating value	9.767 kW/m^3
Boiler efficiency	85 %
Electric capacity	224 kW_e
Electricity price	110 lira/kWh

Table 2. Economic assumptions

	Boiler Alternative	Heat pump/ Cogenerator	Difference
First cost	30 ML	820 ML	
Heat pump subsidy	–	(246 ML)	
Net first cost	30 ML	574 ML	544 ML
Annual operating cost			
Fuel (natural gas)	40,560 lira/h	31,200 lira/h	
Electricity	24,640 lira/h	0	
Total	65,200 lira/h	31,200 lira/h	
Annual	326 ML/yr	156 ML/yr	170 ML/yr
Simple payback period			3.2 yr

Table 3. Summary of economic results Note: ML = million lira

Project economics

Assumptions used in the following economic calculations are summarized in Table 2. Economic results are summarized in Table 3.

First costs

The engineering design, completed in August 1984, estimated the following project costs: total cost, 820 million lira; 300 million lira for the gas motor and alternator; 270 million lira for the heat pump; 250 million lira for cooling coil with air system and for installation of the entire plant.

Italian law No. 308 (incentive for energy savings) provided sunk capital of 30% of the project cost, or 246 million lira, reducing the financial burden to 574 million lira. Additionally, the user received financing of 350 million lira from BEI (European Investments Bank), which offers a lower rate than that given by Italian banks.

The first cost of an equivalent-size gas boiler is estimated to be 30 million lira.

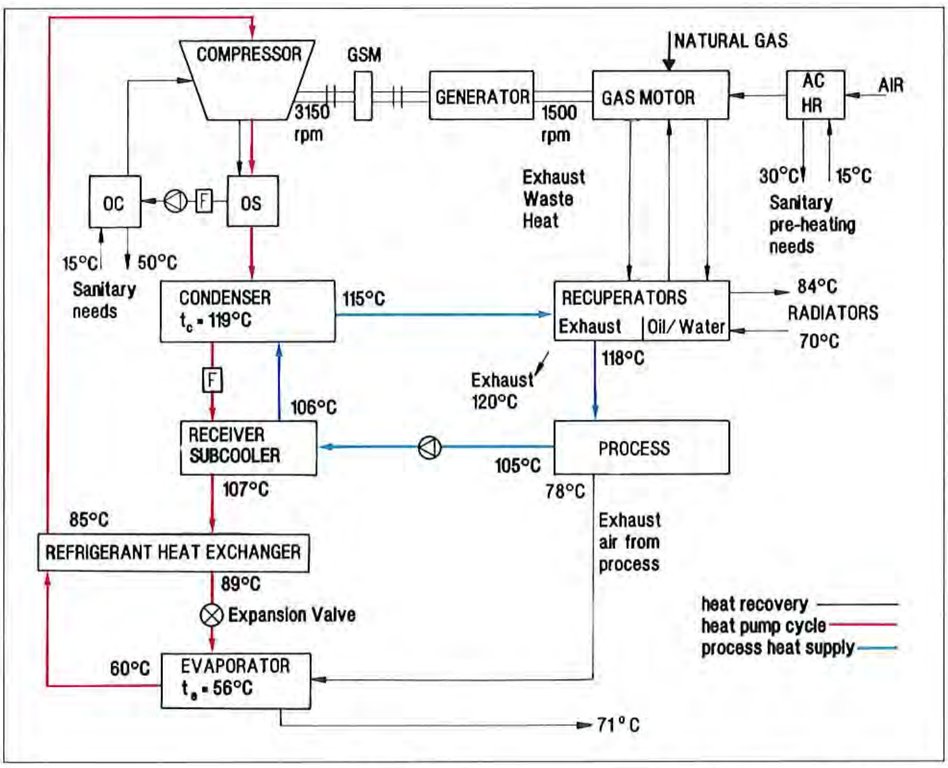


Fig. 2. System flow diagram

OC: Oil cooler
OS: Oil separator
F: Filter
GSM: Gear speed multiplier

ACHR: Air compression heat recovery
t_c - t_e: condensing and evaporating saturation temperatures corresponding to operating pressure

Annual operating costs

The annual operating cost for the heat pump/cogenerator is the annual fuel consumption times the fuel price. At a cost of 240 lira/m^3, the fuel cost is 31,200 lira/h, or 156 million lira/yr.

Fuel cost for the boiler alternative is calculated as:

$$\text{Fuel requirement } (m^3/h) = \frac{\text{Heat output (kW)}}{\text{Boiler Efficiency x Fuel Htg Value } (kWh/m^3)}$$

or 169 m^3/hr, 40,560 lira/h at 240 lira/m^3.

Electricity costs must be included in the operating costs of the boiler alternative. These are 224 kW x 110 lira/kWh = 24,640 lira/h. Total hourly operating costs are then 65,200 lira/h, or 326 million lira/yr.

Payback period

The difference in first cost is 574 million lira - 30 million lira = 544 million lira. The annual savings in operating costs are 326 million lira - 156 million lira = 170 million lira/yr. The payback period, first cost divided by annual savings, is 3.2 years.

E.G. Bacigalupo, DIRECO Spa, York Italia, Milan, Italy

LITERATURE REVIEW: INDUSTRIAL HEAT PUMP APPLICATIONS

Now Available from the Heat Pump Center

The Heat Pump Center staff has compiled a world-wide review of publications concerning industrial heat pump applications, in conjunction with the focus topic of this issue of the Newsletter. The complete review, with bibliographic citations and abstracts, is now available from the Heat Pump Center for DM 40.- to readers in HPC member countries (use the order form on the last page of the Newsletter). This review is a valuable resource for anyone interested in pursuing industrial heat pump applications in more detail. The following is a brief excerpt from the review, with condensed abstracts.

General

"The heat pump in industry," Energy Technology, 1985, No 2, pp 3-16 (in English). The use of heat pumps in the industrial sector of Sweden is explored. Processes in which steam is used as a heating medium are natural applications for such equipment. Heat pump utilization in several industries is discussed; possible applications for heat pumps are cited.

Reay, D.A., "The large scale applications of heat pumps," York, England, 25-27 September 1984, J. of Heat Recovery Systems, 1985, Vol 5, No 3, pp 251-265 (in English). A conference focusing on the large scale applications of heat pumps in the U.K. for domestic and industrial uses was held in York. Highlights of papers presented are compiled. Heat pump systems commonly used for space and process heating applications are discussed. Topics covered include new design developments, absorption heat pumps, and steam generation and compression.

Schnitzer, H., "High temperature heat pumps for steam generation in industries," Kerm. Ind., 1985, Vol 34, No 2, pp 99-102 (in English). Compression heat pumps, absorption heat pumps, heat transformers, and cogeneration are discussed with respect to steam generation in industry.

Bencheroun, N., "Heat pumps in industry," Rev. Inst. Fr. Pet., 1985, Vol 40, No 1, pp 113-123 (in French). This report discusses heat pump utilization for the heating of industrial premises, industrial processes, agriculture, and food and dairy industries.

RD&D

Mills, J.I.; Plaster, D.S.; Chappell, R.N., "Advanced mechanical heat pump technologies for industrial applications," DE85-014613; EGG-M-28384; CONF-850515-2, Presented at the 7th Ann. Ind. Energy Technol. Conf., Houston, Tex., 13 May 1985 (in English). Five advanced mechanical heat pump systems are described (a waste-heat-powered steam compression system, a high-temperature reverse-Rankine-cycle heat pump with methanol working fluid, a Brayton-cycle solvent recovery system, magnetic cycle heat pumps, and Stirling cycle heat pumps), as well as how development strategy allows efficient progression from concept to technology transfer to the private sector. Results are beneficial for determining how various steps of a product development plan should proceed.

Eustace, V.A., "Testing and applications of a high temperature gas engine driven heat pump," J. of Heat Recovery Syst., 1984, Vol 4, No 4, pp 257-263 (in English). This paper presents the results of work to identify specific industrial applications, test the high-temperature gas-engine-driven heat pump at off-design and part load conditions, and monitor the performance of the main components, i.e. compressor, gas engine and heat exchangers.

Mucic, V.; Schenermann, B., "Dual-agent compression heat pump with solution circulation (Principle, construction and test results)," Fernwärme International, 1984, Vol 13, No 2, pp 79-81 (in German). The principle, type of construction and trial results of a new pilot heat pump are described. This is a dual-agent heat pump that uses an ammonia-water mixture as a working fluid instead of a single agent. Energy savings achieved with a dual-agent heat pump, compared to a single-agent type, can be quite considerable, especially when the temperature reduction of the cooled medium and/or the temperature increase of the warmed medium is of sufficient magnitude. The trial results have fully confirmed theoretical calculations.

Kruse, H., "Improving industrial heat pumps by applying refrigerant mixtures," J. of Heat Recovery Syst., 1984, Vol 4, No 5, pp 359-363 (in English). By combining a high pressure (R12, R22, R502) and a low pressure (R11, R113, R114) refrigerant in a mixture, different pressures and temperatures can be achieved in order to adapt a special heat pump to the limits of the application. Pressure differences and discharge temperatures, heating capacity, power and performance coefficient for mixtures are given. Continuous adjustment of heating capacity can be achieved.

Moehring, U.; Fleischmann, R., "Chemical heat transformers," Chem.-Anlagen Verfahren, 1984, No 12, pp 72, 76, 78 (in German). Industrial waste heat utilization based on absorption with small energy requirements is discussed. Chemical heat transformers work according to H_2SO_4-H_2O absorption. The system transfers approximately 50% of the waste heat received to a useable temperature. The experimental and calculated temperature shifts are enough for the corresponding heat pump temperature levels to bring several practical application advantages to industry.

Heppenstall, T., "A theoretical and experimental investigation into the performance of absorption cycle heat pumps applied to industrial processes," Comm. Eur. Communities, [Rep.] EUR 9236, Energy Conserv. Ind., 1984, Vol 1, pp 243-252 (in English). The development of the design of a 300 kW industrial absorption cycle heat pump based on LiBr and water, and the construction and operation of its 10 kW experimental version are described. Results from a theoretical model that predicts the behavior of the heat pump are presented. The absorber is the most difficult component to design, and requirements and design problems are discussed.

Industrial applications

Wright, J.R.; Steward, F.R., "Three industrial heat pump installations operating in Canada," J. of Heat Recovery Syst., 1985, Vol 5, No 2, pp 81-88 (in English). Three waste heat recovery systems have been installed and operated in three different process industries for more than one year. These include an edible oils plant, a milk processing plant, and a lead smelter. Operating characteristics, difficulties, and economic details are presented.

Sakashita, S., "Heat recovery with screw type steam compression system in industry," IEA Heat Pump Conference, Graz, Austria, May 22-25, pp 261-272 (in English). This report describes the fundamental concept of the Screw Type Steam Compression Heat Pump (S.S.H.P.), the performance of the screw steam compressor, and case studies of practical applications on batch type evaporation process in a brewery plant, beet sugar multi-effect evaporator, and continuous distillation of ethyl alcohol.

Davidson, W.F.; Erickson, D.C., "AHP gives NGL fractionation energy savings," Oil & Gas J., Aug 5, 1985, Vol 83, No 31, pp 107ff (in English). Absorption heat pumps (AHP) offer a highly economic avenue to process heat integration and heat recovery in natural gas liquid fractionation plants. The AHP has significantly higher output than mechanical compression heat pumps.

Niess, R.C., "Reducing energy costs in vapor degreasing systems," Plant Eng. (Barrington Ill.), 1985, Vol 39, No 6, pp 66-67 (in English). Vapor degreasing is commonly used to remove wax, oil, and grease from metal parts, subassemblies, and completed products prior to plating, painting, or finishing. Process heating and cooling operations often consume and waste large amounts of energy. The addition of an industrial heat pump to a conventional vapor degreasing system can cut energy costs almost in half.

Harris, G.E., "Heat pumps in distillation processes," EPRI EM-3656, Research project 1201-23, Final Report, August 1984 (in English). This report documents the methodology and results of an investigation of the range of economical applicability for electric-driven heat pump retrofits to existing distillation columns. It also includes a survey of heat pump manufacturers, case histories of existing units, a review of novel applications, an investigation of emission offset potentials, and a distillation heat pump bibliography.

NEWS BRIEFS

Seminar held in Kansas City "Meeting Customer Needs with Heat Pumps"

Nearly 400 participants involved in selling heat pumps to electric utility residential and commercial customers recently attended the first national seminar on "Meeting Customer Needs with Heat Pumps." The seminar, held in Kansas City, Missouri, April 7 - 9, 1986, was jointly sponsored by the American Public Power Association, the Edison Electric Institute, the Electric Power Research Institute, and the National Rural Electric Cooperative Association.

The seminar was designed by the sponsors to meet the information needs of electric utility customer service organizations in marketing heat pumps. The seminar agenda was divided into parallel sessions, each addressing a different aspect of heat pump marketing information. The three sessions were: "Meeting the Needs of Residential Customers with Heat Pumps," "Meeting the Needs of Commercial Customers with Heat Pumps," and "Heat Pump Technologies and Applications." An important feature of the seminar was the discussion of utility experience with heat pump marketing, advertising, dealer certification, assuring quality installation, and customer service. Presentations were also given by leading builders, design professionals, and heat pump dealers on the realities of marketing heat pumps.

The seminar also featured an exposition of heat pumps and associated software and hardware where manufacturers and other vendors displayed the latest heat pump technology.

Many of the speakers emphasized the need for direct electric utility involvement in marketing activities in order to assure that customers have enough information upon which to base intelligent equipment choices, and to ensure that the installation is done to assure the efficient and effective performance of the heat pump. Jim Watson, Sales Manager for Ohio Edison, said, "As many utilities have found out the hard way, customers buy their heat pumps from dealers, but hold the utility responsible for the results of the system. With this knowledge, Ohio Edison's program was designed to provide homeowners with heat pumps that will provide them with satisfaction." Bob Stephens of S&S Air Conditioning, a dealer in Dallas, Texas, pointed out that, "The heat pump industry (manufacturers, distributors, dealers, contractors) and the electric utilities both profit from the increased sale of heat pumps, but the utilities have more to gain than does the industry." He went on to add, "Industry and the electric utilities need a marketing program that will make the buying public aware of this exciting product... Electric utilities should coordinate the overall effort and lead the way." Jerry Shaw of Kansas City Power and Light Company pointed out that some utilities are finding that the heat pump association is a way for the utility to become involved in marketing, education, and training activities to assist their trade allies in assuring quality installations.

The technical sessions included overviews of currently available products and new technology. Product areas included heat pump water heaters, water-loop heat pumps, groundwater source heat pumps and dual-fuel heat pumps. New technologies discussed included advanced refrigerants and future compressor improvements.

(Contributed by the Electric Power Research Institute, Palo Alto, California, USA)

Four Heat Pump Installations Win 1986 ASHRAE Energy Awards

Of the thirteen 1986 Energy Awards given by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), four went to projects that include heat pump installations – two commercial and two industrial applications.

The ASHRAE Energy Awards program is designed to recognize innovative design and engineering to save energy in buildings, and to share award-winning technologies with others. The four winners that include heat pump installations are:

New Commercial Building: The Comstock Center, a 10-story office building in Pittsburgh, Pennsylvania, has annual energy costs of only $7.21 per gross square meter, less than 60% of the average office building in Pittsburgh. In addition to several innovations used in the building envelope, the building has a tri-water incremental heat pump system.

Sprinkler lines are used to distribute 15-32°C water to the heat pumps, and only those heat pumps serving occupied zones are allowed to operate. Six to eight independent heat pumps serve each floor, increasing system reliability. The heat pump/HVAC system first cost was less than $54/m^2.

New Public Assembly Building: The Ridgeview Elementary School, in Oregon, integrates daylighting, passive solar and thermal mass storage, heat recovery and low-temperature geothermal energy to keep energy consumption to one-third of that of other schools in the district. A ground water well produces 760 liters of water per minute at 11°C and serves as the heat source for the heat pump. The heat pump (reciprocating chiller) produces heating water at 45°C with a COP of over 4. The 11°C well water is used directly for cooling. Heat recovered by the heat pump is used to preheat domestic hot water.

Existing Industrial Facility: The McCord manufacturing plant, South Dakota, uses water-source heat pumps to recover heat from water that was previously sent to an open cooling tower. The system has a payback period of less than two years. 35°C water is sent to water-to-air coils, piped in series with water-source heat pumps. The heat produced is used to heat a 1,900 m^2 warehouse.

New Industrial Facility: The H.B. Fuller Company's Willow Lake Laboratory, Minnesota, uses well-water-source heat pumps for heating and cooling, in addition to several other equipment and envelope innovations. The building, housing offices and laboratories for chemical product research and development, is located in a wildlife preserve, so that protection of the surrounding environment was critical. Well-water discharge is used to provide make-up water to a once-dead lake that is now thriving with gamefish and waterfowl. Cooling costs were reduced by two-thirds. Although the system has additional maintenance costs (chemical treatment, coil cleaning, etc.), first-year savings were $ 2,000, and are expected to increase as the owner makes adjustments to controls and operating procedures.

(Excerpted from: ASHRAE Journal, March, 1986)

Second Edition of HPC Bibliography on Non-Azeotropic Mixtures Now Available

Over 200 publications are abstracted in the latest edition of the Heat Pump Center bibliography, **„Non-Azeotropic Mixtures as Working Fluids in Compression Heat Pumps,“** compiled and edited by HPC staff member Jörg Herrmann. This bibliography is a world-wide review of research, applications, thermodynamic properties and patents for non-azeotropic mixtures. Compared with the conventional refrigerants developed especially for the use in refrigeration machines, non-azeotropic mixtures can have significant advantages when used in heat pumps. By mixing two conventional refrigerants, it is possible to optimize a working fluid with regard to favorable operation and capacity limits through little additional investment. Because of the increasing interest in this topic, the number of publications from research institutes in Europe, the USA and the Far East is growing. This updated bibliography provides a comprehensive compilation of all completed, on going and planned research that is now available.

The citations are listed in reverse chronological order, and the bibliography includes author, key word, and research organization indexes. The report is available now to those in Heat Pump Center member countries (Austria, Canada, F.R. Germany, Italy, Japan, the Netherlands, Sweden, and the United States of America) for DM 220 (postage included, VAT additional in FR Germany). Use the order card on the last page of the Newsletter, or call/write the Heat Pump Center directly.

M. Meal*

The International Energy Agency Encourages "Enhanced Collaboration" Among its Member Countries

The IEA Heat Pump Center is operated within the framework of the International Energy Agency (IEA). HPC goals to develop advanced heat pumps are directly parallel to the broader objectives of the IEA to maintain energy security and to reduce dependence on foreign oil. The IEA was founded in 1974 in response to the first oil price shock, and since that time has acted as a catalyst to improve collaboration between member countries on energy policy and RD&D programs. As such, the IEA Heat Pump Center is only one of many activities aimed at fulfilling the IEA's objective to maintain sufficient energy supplies at a reasonable cost. To provide HPC Newsletter readers with a broader perspective for Heat Pump Center activities, I met with Dr. Pietro Caprioglio, director of the Office of Energy Research, Development and Technology Applications at the IEA, and two of his staff, Dr. Michael Taylor and Dr. Jose Gonzalez. This article briefly reviews the range of projects now going on through the IEA's Committee on Research and Development (CRD), as well as overall IEA policy and directions for the future.

IEA goals and objectives

Dr. Pietro Caprioglio, director of Energy R&D, on the objectives of the IEA: „To do whatever can be done jointly to ensure better security of energy supply in member countries at an acceptable cost.“ In order to fulfill these objectives, the IEA brings together energy specialists from its member countries, with work divided into the following groups:

Long-term cooperation: encourages long-term reductions in oil dependence through the promotion of the use of alternative energy sources and structural changes in the energy economies of member countries;

Research and development: encourages cooperative research by member countries on new energy technologies (Heat Pump Center activities are administered through this group);

Emergency questions: has established and maintains an oil-sharing system in the case of a major oil supply disruption;

Oil markets: collects and analyzes information on the international oil market; and

Relations with producer and consumer countries: considers global energy developments, and possibilities for cooperation with non-member countries and international organizations.

A Governing Board of Energy Ministers from the IEA member countries directs these activities and makes major policy decisions. Directly relevant to the work of the Heat Pump Center, in July 1985, the Energy Ministers adopted a program for enhanced international collaboration on energy research and development projects. Specifically, the Ministers directed the IEA to act as a catalyst for enhanced international R&D collaboration and joint program planning, to increase awareness of opportunities for and benefits of collaboration, and to reduce the obstacles to collaboration.

RD&D programs

Dr. Jose Gonzalez, Secretary of CRD's Working Party on End-Use Technologies, calls the IEA a "marriage broker" between member countries that are interested in pursuing similar kinds of energy research. Collaborative research conducted under the IEA umbrella is grouped into the following areas:

- End-Use Technologies
- Fossil Fuels
- Renewable Energy
- Fusion Energy

CRD itself takes a "hands-off" approach to these collaborative projects, acting primarily to bring interested countries together, and to provide administrative support. It is up to the participating countries to decide on project scope and content, under the direction of „Working Parties" of expert representatives from member countries in each of the research areas above. Many of the projects are task-shared, meaning that participants contribute and benefit from shared knowledge without added strains on national RD&D budgets. On-going collaborative projects are organized under various Implementing Agreements. Relevant to heat pump RD&D are the Implementing Agreements under End-Use Technologies, which are as follows:

- Buildings and Community Systems
- Advanced Heat Pumps (including the Heat Pump Center)
- Combustion
- Energy Cascading (completed)
- Heat Transfer and Heat Exchangers
- Energy Storage
- Cement Manufacture (completed)
- High Temperature Materials
- Pulp and Paper
- Iron and Steel (completed)
- District Heating
- Alcohol Additives to Fuels

CRD also conducts "thematic" reviews of national energy RD&D programs, to provide an objective assessment of these programs in the light of the overall objectives of the IEA. These reviews also provide useful comparisons for non-reviewed countries and help to identify potential areas for collaboration. In 1987, these reviews will have end-use technologies as their theme.

Information dissemination and the role of industry

One of the primary goals of enhanced collaboration is to bring member countries together in the early stages of new RD&D projects. Equally important, however, is transferring results from successful projects to industry for commercialization. As far as end-use technologies are concerned, Dr. Gonzalez points out that most energy-conserving end-use technologies have already been invented, and that future RD&D will focus on three key elements: analysis, evaluation, and dissemination. Dr. Caprioglio agrees, in that diffusion of successful end-use technologies into the market place, not basic research, is critical.

Dr. Caprioglio also stresses that more attention should be paid to the transfer of government RD&D to industry. Specifically, CRD has responded to the July Ministerial directive by stating, "Enhanced collaboration is clearly not an end in itself. It has to be seen as a means to speed up the development of high priority new technologies, and to make sure that they are satisfactorily introduced into the market place," and further that "Enhanced collaboration must be organized with full awareness of the interests and activities of industry, since in most cases national programs are carried out in close connection with industrial organizations, and since industry will bear ultimate responsibility for commercialization activities."

In recognition of the need for improved technology transfer of RD&D results to industry, the IEA is cosponsoring (with the Commission of the European Communities and the United Kingdom Department of Energy) an international seminar on the Promotion of Demonstrated Energy Technologies, to be held in October 1986. This seminar will bring together experts to discuss how international organizations, governments, and other agencies can best bring about wide-spread implementation of proven energy-advantageous technologies.

Falling oil prices – new RD&D opportunities

At first glance, one might see the recent plummet in world oil prices as reducing the incentive for governments to aggressively pursue RD&D programs to develop oil alternatives. On the contrary, in its report, "Energy Research, Development and Demonstration in the IEA countries, 1984 Review of National Programs," the IEA concludes that "the current market conditions for oil should be viewed as providing an opportunity through RD&D to reduce energy system vulnerabilities." The 1985 IEA Energy Technology Policy Study points out, "Relief provided to the world economy by the lowering of oil prices [is] likely to be temporary and that there remains a risk of a renewed energy constraint on growth unless the industrialized countries strengthen their policies to restructure their energy economies." This continues to be true, as oil prices have continued to fall since these reports were published.

Where the Heat Pump Center fits in

CRD sees information dissemination as a key to removing market barriers to commercialization of new energy technologies. As one of the many collaborative projects administered by the IEA, the Heat Pump Center collects information, performs analyses and evaluations, and disseminates results in order to promote heat pump development and commercialization. Working to promote increased penetration of successful heat pump technologies into the heating market is just one of the many ways that the IEA is fulfilling its objectives to reduce dependence on oil and to ensure energy supplies at a reasonable cost to its member countries.

*M. Meal, IEA Heat Pump Center, Karlsruhe, F.R. Germany

Readers' Column

To the Editor:

The environmental aspects referred to in your March 1986 issue are of such importance that some misunderstandings which may arise should be corrected. I would like to comment on the following points:

1. Page 3 (Table 1): An increase in human skin cancer is not an expected consequence of direct exposure to leaking CFC refrigerant. CFCs that are used in heat pumps, principally CFC-12 and 22, have been extensively tested and found not to produce carcinogenic effects on animals even under conditions greatly exceeding normal leakage. However, increase in skin cancer is one of the postulated effects of a reduction in the ozone layer.

2. Page 13: according to the latest figures collected for the EEC Commission: the sale of CFC-11 and 12 for refrigeration end-use, of which heat pump use is only a small part, is only between 10 and 11% of the total sales of these two CFCs within the European Community. Recent calculations indicate that cumulative increases of up to 1.5% per year will have no significant effect on the ozone layer. Therefore, current scientific understanding of the ozone hypothesis would indicate the possibility of substantial increase in heat pump use without an environmental penalty.

3. Page 14: the author refers to lack of data with regard to refrigerant leakage. In fact, the quantitative safety limits, or TLV-TWA and TLV-STEL values of CFC refrigerants have been established for decades. A very large leak, or CFC vapor accumulation in low places presents a definite danger of oxygen exclusion. A chilling effect, or even injury due to frostbite, is possible if liquid refrigerant contacts the skin.

4. Page 15: this author also exaggerates the scale of use of CFC refrigerants. A recent paper prepared for the Swedish Environment Protection Board by Kemiinformation AB estimates total imports of CFCs into Sweden (1984) at 4765 metric tons, of which 1125 metric tons are for cooling and heating applications (a trade association estimated 1265 metric tons).

5. Same page: a great deal is known about the physiological effects of exposure to CFCs (most experiments done on animals). Important omissions in the "Criteria Document" to which the author refers were revealed during a medical-scientific meeting organized by the Board in January 1984, and published by the Karolinska Hospital, "Tox Notiser 2. 1984."

6. Same page: it is not necessary to dilute CFC discharged to the air immediately to the level of 500 ppm quoted by the author. The Swedish hygienic limit value, corresponding to the TLV-TWA (which is 1000 ppm, in most countries other than Sweden, for all of the CFCs normally used in heat pumps) is intended to be a limit for regular exposure for a full working life. The immediate danger is oxygen exclusion and less frequently frostbite.

7. Same page: we point out: Suitable and reliable sensors and alarms are only just coming onto the market now. The stability of CFCs makes them difficult to detect.

A full face breathing apparatus is effective if it has any air supply independent of the volume of air containing excess quantities of CFC. Leakage inwards of CFC is not a problem as long as sufficient oxygen, or air, is supplied.

It is not recommended to enter an area containing excess quantities of CFC vapor unless it is essential, for example, to rescue a person overcome by the vapor. Dispersal of the vapor is fairly rapid.

CFC manufacturers' literature should be consulted for further information, for example on types of medication not to be used in such cases.

T.H. Christie
Market Development Manager
Du Pont de Nemours International S.A.
9, Route des Jeunes
CH-1211 Geneva 24, Switzerland

(Editor's note: this letter has been edited due to space limitations)

M. Meal, author of the article, "Newsletter Focus: Environmental Aspects of Heat Pump Applications," responds:

The risk of increased incidence of skin cancers from chlorofluorocarbon leakage in Table 1 refers to the effects of decomposition of the ozone layer resulting from CFC release into the stratosphere, not to direct CFC exposure.

J.A.W Oldenhof, author of the article, "Research in the Netherlands on Heat Pumps and the Environment," responds:

The conclusions of the study which Mr. Christie comments on item 2 deal with CFC emissions, one of the sources of which is heat pumps. In the event of the widespread application of heat pumps, as forecast in the study concerned, the figures for CFC sales, and the ultimate emission of CFCs into the environment (assuming that no steps were taken to control them) would be many times greater than in the case of the much more limited application of heat pumps that exists today. If heat pumps were to be used on a large scale, then obviously the emissions from other sources would become appreciably lower in percentage terms than if heat pump sales remained low. The study is by no means discouraging in its conclusions as regards the use of heat pumps, in the way that Mr. Christie suggests, because it also puts forward a number of good opportunities for working towards solutions to minimize CFC emissions.

The piece from which Mr. Christie quotes in item 3 is incomplete, as he omits the qualification, "under typical heat pump conditions." The heat pump as an alternative heating system would in practice preferably take the place of or be installed alongside the existing heating system. In a Dutch context, the existing gas-fired boiler is placed in the attic in many houses. In this situation, the installation will be in the vicinity of bedrooms. Additionally, heat pump systems powered by gas engines may find widespread application in residential areas. The combination of naked flames or hot spots with substantial quantities of refrigerant within the home or in the vicinity of residential areas is therefore different from the situation with the present applications for refrigeration purposes. It will presumably be fairly easy to solve the potential problems as such but it is not true to say that the present refrigeration standards are suited to the possible large-scale application of heat pumps in the circumstances outlined above.

B. Isaksson, author of the article, "The Environmental Aspects of Large Heat Pump Stations: Aspects of Occupational Safety and Health," responds:

Item 4: According to the data collected by Mr. T. Aurell in "Svensk Atervinningsforskning" (Swedish Research of Recovery), February 1982, under the heading of "Atervinning av klor fluor-kol" (recovery of CFC), the consumption of freon in Sweden in 1981 was 7,750 metric tons, of which 2,800 metric tons were for the application of Cooling and Heating.

The difference between these figures and those mentioned in the letter (4,767 and 1,125 metric tons respectively) may be due to the difficulty in defining the consumption of CFCs in Sweden as well as the imports into Sweden. A large amount of apparatus is imported filled with freon and this is not included in the statistics.

The remaining fact, however, is that the limit for CFC exposure in Sweden is still 500 ppm.

The Heat Pump Center welcomes letters to the editor responding to articles in past issues or providing new information on developments in the heat pump field that are of interest to our readers. Letters concerning past Newsletter articles will be sent to the authors concerned for their response before being printed. Please send your letters to: Editor, IEA Heat Pump Center Newsletter, c/o Fachinformationszentrum, D-7514 Eggenstein-Leopoldshafen 2, F.R. Germany. Letters may be edited as space limitations dictate.

Selected Book and Report Reviews

Reviews of the most recent publications on heat pumps

Heat Pumps in Industry; F. Moser, H. Schnitzer; Chemical Engineering Monographs, Vol. 20, Elsevier Science Publishers B.V., Amsterdam, the Netherlands, 1985 (in English).

Over the last few years, it has become clear that industrial heat pumps will have to be designed and made available in tailor-made and process-integrated packages. In many cases, plans to mass produce heat pumps for industrial applications were not successful. This book is designed to bridge the gap between suppliers and users of industrial heat pumps, and describes basic principles and different yardsticks used to compare heat pump applications and operation. Application of heat pumps in unit operations is described using practical examples. The authors summarize experience obtained from several different sources; they have been active for several years in theoretical and practical research, and have carried out a study supported by the Austrian Ministry of Commerce on the range and impact of heat pump applications in Austrian industry, and the potential for primary energy savings.

The Development of the Super Heat Pump Energy Accumulation System; New Energy Development Organization, Tokyo, Japan, 1986 (in English).

In 1978, the Agency of Industrial Science and Technology (AIST) in the Minstry of International Trade and Industry (MITI) started the "Moonlight Project" for energy savings. The "Super Heat Pump Energy Accumulation System," started in 1984, is the seventh project of the Moonlight Project. This report reviews the R&D plan and research on element techniques. The project focuses on development of heat pumps of high performance or with high output temperatures (up to 300°C) and on thermal storage systems for efficient conversion and high-density storage of excess electricity generated at night, and utilization of this energy during the day for air conditioning or industrial processes. Project elements include: (1) fundamental research on refrigerants, chemical reactions and materials, (2) advanced compressor-driven heat pumps, (3) chemical heat-storage systems, and (4) composition of the total system.

The project will run for eight fiscal years, through 1991. The total budget supplied by the Japanese government is estimated at 10 billion yen (U.S. $ 45 million).

Survey and assessment of chemical heat pumps; Kaplan, S.I., Ally, M.R., Chappell, R.N., Friedel, W., Hanna, W.T., Huntley, W.R., Krause, H.H., Perez-Blanco, H., Rebello, W.J., Sanders, R.D. Sr. Oak Ridge National Laboratory, ORNL/TM 9544, November 1985 (in English).

The vapor-compression heat pump is now recognized as a means of reclaiming and recycling waste energy from industrial processes. Chemical heat pumps (CHPs) are promising for extending the achievable range of temperature lift for heat recovery at a cost below that of primary fuel. This document describes the physical principles of CHPs and their operating characteristics and presents a worldwide collation and bibliography of current CHP technology. Two major types of CHPs are identified, according to the driving force: (1) heat of chemical reaction (HRCHP) or (2) heat of phase interaction (sorption, dilution, etc.), labeled collectively heat of mixing (HMCHP). The advantages, disadvantages, and desirable characteristics of various current approaches to CHP technology, and particularly of the working media pairs that perform the HMCHP cycle, are assessed. The future for industrial CHP applications in the United States lies in: (1) identification of specific examples of major applications; (2) improved high-temperature working media; and (3) cycles that achieve economic competitiveness via improved internal efficiencies and long-term operating reliability. Recommendations for future CHP research are proposed for HMCHPs: these include container material and corrosion inhibitor research and design and feasibility assessment of promising concepts. For HRCHPs (still in the conceptual stage), the list is similar, with emphasis on identification of new chemical reaction sequences, laboratory characterization, and catalyst research.

Swedish Heat Pump Projects 1984-1985; Supplement to Swedish Heat Pump Projects 1979-1983. Research - Development - Full-scale experiments supported by governmental organizations. B. Malmqvist, Editor. Swedish Council for Building Research, D6:1986 (in English).

This report is a catalog of heat pump projects in Sweden dating from 1983 to the first half of 1985 (not including projects in the previous catalog). Information given for each project is: project title, grant number and amount, address and telephone for responsible party, technical specifications, project description, and available reports. Over 150 projects are included.

Review of Energy-Efficient Technologies in the Residential Sector; Volume 1: Executive Summary, and Volume 2: Data Review and Synthesis; Synergic Resources Corporation, prepared for the Electric Power Research Institute, Palo Alto, California, USA, EPRI EM-4436, February 1986 (In English).

This report presents and integrates information on the cost, performance, and load impacts of nine residential energy-efficient technologies, including heat pump water heaters (integral and add-on), air-source heat pumps, add-on heat pumps, and ground-source heat pumps. Data were gathered from 34 utility programs conducted by 26 utilities. Utilities cited diverse objectives for their testing and promotional programs. Many testing programs focused on how wide-scale use of technologies affects load shape and energy use. Utility experience shows that heat pump water heaters result in lower peak demands and higher load factors than electric-resistance water heaters, with average winter- and summer-day peak load reductions of about 30 and 40%, respectively. Utility average annual performance factors ranged from 1.49 to 1.80 with an overall average of 1.64. Seasonal performance factors of air-source heat pumps ranged from 1.6 to 2.0, with winter demand reductions of 2 to 4 kW per installation. Performance factors for add-on heat pumps, not including the degrading effects of auxiliary heating, ranged from 1.68 to 2.00, and reported findings show that add-on heat pumps can displace 46 to 82% of a customer's normal fossil fuel consumption. Ground-source heat pump SPFs were higher (2.7-3.0). One utility reported a peak demand of 4.6 kW for a ground-coupled heat pump, versus 29 kW for an all-electric system.

The report also emphasizes the need to strengthen preliminary indications that current-model heat pump water heaters exhibit improved performance and reliability over older units, and the lack of information on ground-source heat pumps.

Treble Rankine Cycle Project, Final Report; Brockel, D., Lang, A., Schwarz, N., Stehle, H., Wolter, I., Woudstra, N., et al. Kernforschungsanlage Jülich GmbH, Bundesministerium für Forschung und Technologie BMFT-FB-T 86-046, July 1986 (in German).

Recent development in alkali metal technologies implies the possibility of significantly improving the efficiency of electricity generation in fossil-fired plants. The

Selected Book and Report Reviews

Reviews of the most recent publications on heat pumps

temperature at the hot end must be increased by application of a topping process. Rojakovics suggested a Treble Rankine Cycle (TRC) as a technical solution. This technology combines outstanding ecological advantages with high energy efficiency. The project aimed at ascertaining technical feasibility and giving a realistic assessment of cost upon which an investigation of econmic feasibility could be based. To obtain a realistic cost picture, the design of non-conventional components has been developed to an advanced state by experienced manufacturing firms. The study, therefore, was a "pre-design study." Results showed that the TRC is technically feasible. The expected efficiency of approx. 51% and consequently the ecological advantages are realistic. The cost of electricity generation ranges from 0 to 5% above that of a conventional power plant (anticipating its future development). As a consequence, hardware development for the process should start. The various steps and the time and cost requirements are described in the study.

Entwicklung einer monovalenten Resorptionswärmepumpe für die Hausheizung, Schlussbericht; (Development of a monovalent resorption heat pump for residential heating. Final report.) Engelhard, J., Maschinenfabrik Augsburg-Nürnberg (MAN) A.G., Munich, F.R. Germany. Bundesministerium für Forschung und Technologie BMFT-FB-T 85-157, December 1985 (in German).

A prototype heat pump was built for a maximum heating capacity of 18 kW, and can be operated with two-stage gas or oil burners. The heat pump uses a modified absorption process with an ammonia-water solution. Under favorable conditions, a heating efficiency of 1.3 is possible. A microprocessor control system optimizes the process according to heat demand. The heat pump can be used in monovalent operation or in combination with a heating boiler.

Wärmepumpe mit äusserer Verbrennung, Schlussbericht; (Heat pump with external combustion. Final Report.) Bauer, B., Mantel, A., Stuttgart Univ., Inst. für Thermodynamik der Luft- und Raumfahrt. Bundesministerium für Forschung und Technologie BMFT-FB-T 85- 142, December 1985 (in German).

The objective of this project was to develop a heat pump unit that connects the heat pump cycle and a Claudius-Rankine vapor power unit with a common condenser and a combined expansion-compression machine. Heat is used as drive energy. Two expansion-compression machines were developed according to the free-piston principle, one with air and one with R12 as a working fluid. A heat pump test facility was built to test the thermal stability of refrigerant.

Fernwärmeerzeugungsanlage mit gas- und elektromotorisch betriebenen Wärmepumpenaggregaten, Schlussbericht; (District heating system with heat pump aggregates driven by gas engines or electric motors. Final report.) Dohrn, E., Gemeinde Leck, Bürgermeisteramt. Bundesministerium für Forschung und Technologie BMFT-FB-T 85-169, December 1985 (in German).

For the supply of a small district heating grid, gas-engine and electric heat pumps operating in tandem were developed. The gas engine drives an electric asynchronous motor via a shiftable clutch connected with the heat pump. Water from surface wells of an adjoining flood land is used as a heat source for the heat pumps. In normal operation, gas-engine heat pumps are used during High-Tariff-Time and heat pumps with electric motors during Low-Tariff-Time. In case of insufficient power, or for reheating downstream water during Low-Tariff-Time, boilers will be utilized. For peak power supply to the public power distribution grid, or in case of insufficient temperature of heat source water, only electric power will be generated. The operational data gained during one year show the expected savings of primary energy. By selecting the appropriate method of operation, the plants can be adapted to all operating conditions and thus achieve maximum energy efficiency.

Gaswärmepumpenanlage Luft/Wasser, Ganzjahrbetrieb, Wohnlage Felix-Klein-Strasse, 8520 Erlangen, Schlussbericht; (Monovalent gas heat pump for year-round use, complex on Felix-Klein-Strasse, 8520 Erlangen. Final Report.) Wurzschmitt, R., Bub, G., Wenzl, B., Stadtwerke Erlangen A.G., Ingenieurbüro Meissner, Ebert und Bub, Nürnberg, Forschungsstelle für Energiewirtschaft, München. Bundesministerium für Forschung und Technologie BMFT-FB-T 85-145, December 1985 (in German).

A monovalent gas heat pump was constructed and operated for space and water heating in a complex of 77 council houses, with a total heated area of about 6,200 m^2 and a heating capacity of 670 kW (DIN 4701). The monovalent air-to-water gas heat pump for year-round use ($tA = -18°C$) has a performance factor of 1.5, supplies radiator heating 70/40°C, uses screw compressors, and has generators for independent electricity supply (evaporation blower). The heating seasonal performance factor of the plant was about 1. The monovalent design caused technical problems and was uneconomical. Problems were encountered in sizing (heat requirements), control of space heating (water volumes and temperatures), the screw compressor (shaft sealing, refrigerant, oil), and the evaporator (thawing processes). Given the present state of the art, monovalent air-to-water gas heat pumps cannot compete with modern heating boilers in terms of economic efficiency (investment, energy and operating costs). Bivalent concepts seem to offer advantages, e.g. optimum component design, lower investment costs, and a high seasonal performance factor.

Modellvorhaben zur Energieeinsparung mittels gasbefeuerter Absorptionswärmepumpe und anlagenintegriertem Speicher sowie Erdwärmenutzung, Schlussbericht; (Model investigation project to ensure saving by a gas-fired absorption heat pump and system-integrated heat storage, as well as utilization of geothermal energy. Final Report.) Reinmuth, F., Kraftanlagen A.G., Heidelberg. Bundesministerium für Forschung und Technologie BMFT-FB-T 85-143, December 1985 (in German).

The objectives of this project were to design, engineer, install, start up, and evaluate the profitability and economic efficiency of a gas-fired absorption heat pump (monovalent) and utilization of geothermal energy. Model calculations were developed for the capacity and energy requirements of the entire system, including capacity optimization of the monovalent heat pump system, with heat storage for peak load coverage. The absorption heat pump has now been operated for three winters. The annual heat pump plant COP specified in the contractual warranty was met. The profitability of the entire system (including all peripheral electricity consumers) is, however, not quite sufficient at present (see report for details).

Assessing customer acceptance of heat pump marketing strategies; Davis, T.D., Hoch, L., Synergic Resources Corp., Bala Cynwyd, PA. From: Electric Utility Market Research Symposium: Proceedings, Electric Power Research Institute, EPRI-EA 4338, CONF-841171, November 1985 (in English).

Two utilities, one in New England and one in the Southwest, conducted separate

Reviews of the most recent publications on heat pumps

Selected Book and Report Reviews

studies to identify the factors that influence customer acceptance of heat pumps. They both found that electricity has significant market appeal, but the cost of electricity represents a significant barrier to customer adoption. Efficiency and reliability were two powerful selling points. Heat pumps seem to present greater benefits to those valuing higher cooling comfort. A number of respondents were concerned about high installation, operation, and repair costs.

Analytical study of liquid-piston heat pump technology; Gerstmann, J., Hules, K., Advanced Mechanical Technology, Inc., Argonne National Laboratory report ANL-CT 85-2, December 1985 (in English).

While the evaluation of the feasibility of the liquid-piston heat pump concept is not yet complete, several preliminary conclusions may be stated based on initial results: (1) Simulation of an isothermal LPHP using the second order computer model indicates that the LPHP can self-start and achieve stable oscillations. (2) Examination of principle loss mechanisms has identified no losses that are peculiar to the LPHP, and indicates that the magnitudes of the losses are similar to those of conventional Stirling engines and heat pumps. (3) The cooling COP of an LPHP operated from a 40°C heat source is estimated to lie between 0.3 for an adiabatic high pressure-ratio heat pump, up to about 1.2 for an isothermal heat pump or an adiabatic, low pressure-ratio heat pump. (4) Examination of liquid piston frictional effects and other practical considerations suggest that it will not be feasible to achieve isothermal expansion/compression in practice. Therefore, prediction of LPHP performance should be based on an adiabatic model. (5) Although a true optimization has not yet been performed, preliminary indications are that the favorable operating frequency of an LPHP will be in the range of 1 to 10 Hz. In order to achieve high specific power (e.g. of the order of 10 kW/liter displacement) a mean pressure of the order of 7 MPa (1000 psia) is required. (6) Taylor instability of the liquid piston interface will occur at all frequencies of interest unless some means of stabilizing the interface is employed. Loose fitting floats should provide an acceptable solution.

Heat Pumps: Absorption; ASHRAE Technical Data Bulletin Vol.1, No.4; order no. TDB-24, 1985 (in English).

This report presents eleven papers on the development of a gas-fired absorption heat pump and information on steady-state modeling, modular computer simulation and the development and performance of a directly-fired, periodically-operating absorption heat pump. Advanced cycling for domestic, commercial and industrial applications is provided. Additional reports include design and performance of a high-temperature-boost absorption heat pump and a parallel flow chiller-heater.

'86 Statistical Panorama, Air Conditioning, Heating and Refrigeration News; April 7, 1986. Published annually, this edition of the ACHR News contains a review of 1985 industry, market and housing trends. The overview article notes 1985 as a year where prior margins of strong market growth are eroding into a „flat" market. Under these conditions, growth can only come from an increased market share of this relatively steady market. While new construction is expected to slow, the replacement market is strong and should remain strong. In the comfort industry, heat pumps are shown to be the "stars" of the air conditioning market, capturing about 30% of new single-family homes and close to 40% of new multi-family units.

The '86 Statistical Panorama also includes a review of new housing characteristics in 50 states, for 1975-84. Other topics given special attention are fuel choice, fuel prices, labor trends and the replacement market. In addition to shipment statistics and detailed information on 1985 for individual products, key shipment statistics for the last decade are also summarized.

Schedule of Conferences

June 8-12, 1986

Asheville, North Carolina (USA); **77th Annual Conference and Exposition of the International District Heating and Cooling Association (IDHCA-77);** Sponsored by the International District Heating and Cooling Association (IDCHA), Washington, D.C.; Contact: International District Heating and Cooling Association, 1101 Connecticut Ave., Suite 700, Washington, D.C. 20036 (USA)

June 10-15, 1986

Guangzhou (People's Republic of China); **China's 2nd International Total Energy Exposition and Conference;** Contact: Ms. D.C. Rowe, International Trade and Expositions Ltd., 553/579, Harrow Rd., London W10 4RH, UK

June 22-25, 1986

Portland, Oregon (USA); **1986 ASHRAE Annual Meeting;** Sponsored by the American Society of Heating, Refrigerating and Air-Conditioning Engineers; Contact: Judith Breese, ASHRAE, 1791 Tullie Circle NE, Atlanta GA 30329, USA

June 23-26, 1986

Rome (Italy); **3rd International Stirling Engine Conference;** Contact: Organizing Secretariat, Gibi studio congressi, Via Marco Besso, 40, 00191 Rome (Italy), Telephone: 3273291 or 3286897

June 25-26, 1986;

Stillwater, Oklahoma (USA); **Closed-Loop/Ground-Coupled Heat Pump Installation Workshop, Annual Workshop and Equipment Exposition;** Sponsored by Oklahoma State University; Contact: Oklahoma State University, Engineering Technology Extension, 313 Crutchfield, Stillwater, OK 74078 (USA)

August 4-7, 1986

West Lafayette, Indiana (USA); **International Compressor Engineering Conference;** Sponsored by the International Institute of Refrigeration; Contact: James F. Hamilton, Conference Chairman, Ray W. Herrick Laboratories, Purdue University, West Lafayette IN 47907 (USA), 317/494-2132

August 5-8, 1986

West Lafayette, Indiana (USA); **Progress in the Design and Construction of Refrigeration Systems;** 1986 International Institute of Refrigeration (IIR) Commissions B1, B2, E1 and E2 Meeting; Sponsored by the International Institute of Refrigeration; Contact: Raymond Cohen, Conference Co-Chairman, Ray W. Herrick Laboratories, Purdue University, West Lafayette IN 47907 (USA), 317/494-2132

August 17-22, 1986

San Francisco, California (USA); **8th International Heat Transfer Conference;** Sponsored by the American Society of Mechanical Engineers (New York); Contact: ASME Meetings Department, 212/705-7788 (USA) or Prof. E. Hahne, Universität Stuttgart, Inst. für Thermodynamik und Wärmetechnik, Postfach 80, D-7000 Stuttgart 80 (FRG)

August 17-23, 1986

Santa Cruz, California (USA); **American Council for an Energy-Efficient Economy's "Summer Study,"** University of California, Santa Cruz; Contact: Alan Meier, Program Chairman, ACEEE Santa Cruz Summer Study, Building 90-H, Lawrence Berkeley Laboratory, Berkeley, California 94720 (USA); Tel 415/486-6048

September 1-5, 1986

Dubrovnik (Yugoslavia); **18th International Symposium on Heat and Mass Transfer in Cryoengineering and Refrigeration;** Sponsored by the International Center for Heat and Mass Transfer (Belgrade), the United Nations Educational, Scientific, and Cultural Organization (Paris), and the Institut za Nuklearne Nauke Boris Kidric (Belgrade), the International Inst. of Refrigeration (Paris); Contact: Prof. J. Bougard, Faculte Polytechnique de Mons, Rue de Houdain, B-7000 Mons (Belgium)

September 9-12, 1986

Verona (Italy); **24th International COMPLES Conference on Solar Energy;** Sponsored by the Cooperation Mediterraneenne pour l'Energie Solaire, (13-Marseille); Contact: Prof. R. Visentin, C.P. 6042, I-00100 Roma Prati (Italy)

September 14-17, 1986

Dublin (Ireland); **CIBSE/ASHRAE '86;** Contact: Steve Comstock, Director of Communications/Publications, ASHRAE, 1791 Tullie Circle NE, Atlanta GA 30329 (USA), 404/636-8400

September 21-23, 1986

Edmonton (Canada); **Conference of the Heating, Refrigerating and Air Conditioning Institute of Canada;** Sponsored by the Heating, Refrigerating and Air Conditioning Institute of Canada (Islington, Ontario); Contact: W.J. Heeley, Heating, Refrigerating and Air Conditioning Institute of Canada, 5468 Dundas St. W, Suite 226, Islington, Ontario M9B 6E3 (Canada)

September 22-26, 1986

Karlsruhe (F.R. Germany); **3. Internationales Symposium: Klima - Bauen - Wohnen** (3rd International Symposium: Climate - Construction - Living); Contact: Prof. Dr. K. Höschele, Universität Karlsruhe, Institut für Meteorologie und Klimaforschung, Kaiserstr. 12, D-7500 Karlsruhe 1 (FRG)

September 28–October 2, 1986

Dubai (United Arab Emirates); **MERVAC 86** (Middle East Refrigeration, Ventilation, Air Conditioning and Heating Exhibition); Contact: J. Krupka, Fairs and Exhibitions Limited, 51 Doughty Street, London WC1N2LB, United Kingdom, Tel. 01-831-8981, Tlx. 299708 Efanee G

October 3-6, 1986

Canberra (Australia); **Technical Conference of the Australian Institute of Refrigeration, Air Conditioning, and Heating;** Sponsored by the Australian Institute of Refrigeration, Air Conditioning, and Heating (AIRAH); Contact: R.M. Richards, Australian Institute of Refrigeration, Air Conditioning, and Heating Inc., Clunies Ross House, 191, Royal Parade, Parkville, Victoria 3052 (Australia)

October 15-17, 1986

Orlando, Florida (USA); **6th International Conference on Cogeneration: Energy for Economic Recovery and Exhibition (COGEN-6);** Sponsored by the International Cogeneration Society (ICS) (Washington, D.C.); Contact: International

and Trade Fairs

Cogeneration Society, 1700 K St. NW, Suite 1300, Washington, D.C. 20006 (USA)

October 21-24, 1986

Atlanta, Georgia (USA); **9th Annual World Energy Congress;** Sponsored by the Association of Energy Engineers; Contact: Ms. A. McFarland, Association of Energy Engineers, 4025 Pleasantdale Rd., Suite 420, Atlanta, GA 30340 (USA)

October 26-29,1986

Graz (Austria); **Research Activities on Advanced Heat Pumps;** Sponsored by the Technical University of Graz; Contact: Dr. Hans Schnitzer or Dr. Michael Narodoslawsky, Institut für Verfahrenstechnik, TU Graz, Inffeldgasse 25, A-8010 Graz, Austria, Tel. 0316/7061-7467 or - 7465, telex 31221

October 30-31, 1986 and December 4-5, 1986

Atlanta, Georgia; Chicago, Illinois; Washington, D.C (USA); **Course on Energy Cost Reduction for Industry and Buildings;** Sponsored by the Association of Energy Engineers (Atlanta, GA); Contact: Ms. A. McFarland, Association of Energy Engineers, 4025 Pleasantdale Rd., Suite 420, Atlanta, GA 30340 (USA)

November 3-7, 1986

Brussels (Belgium); **5th Expoclima Congress;** European Fair for Refrigeration, Heating, Ventilating, Air Conditioning, Vacuum Cleaning and Drying; Organized by the European Committee of Manufacturers of Refrigeration Equipment and the European Committee of Air Handling and Air Conditioning Equipment Manufacturers; includes special congress, First European Symposium on Air-Conditioning and Refrigeration; November 5-6, 1986; sponsored by REHVA, IIR and ATIC; Contact: Brussels International Trade Fair, Place de Belgique, B-1020 Brussels, Tel 2/478-48-60, Telex 23-643

November 11, 1986

Köln (F.R. Germany); **Tagung über Emissionsminderung bei Heizanlagen** (Conference on reduction of emissions from heating systems); Sponsored by Verein Deutscher Ingenieure (VDI) - Kommission Reinhaltung der Luft (Düsseldorf), and VDI - Gesellschaft Technische Gebäudeausrüstung (TGA) (Düsseldorf); Contact: Verein Deutscher Ingenieure, Kommission Reinhaltung der Luft, Geschäftsstelle, Postfach 1139, D-4000 Düsseldorf 1 (FRG)

November 13-14, 1986

San Francisco, California (USA); **Intensive Seminar on Waste Heat Recovery;** Sponsored by the Association of Energy Engineers (Atlanta, GA); Contact: Association of Energy Engineers, 4025 Pleasantdale Rd., Suite 340, Atlanta, GA 30340 (USA); Note: attendance limited to 50

December 9-12, 1986

Essen (F.R. Germany); **Kurs über Heiztechnik - Neue Technologien zur Wirtschaftlichen Nutzung der Energie „Gas";** Sponsored by Gaswärme-Institut e.V. (Essen), Deutscher Verein des Gas- und Wasserfaches e.V. (Eschborn), Bundesverband der Deutschen Gas- und Wasser-Wirtschaft e.V. (Bonn); Contact: Gaswärme-Institut e.V., Hafenstr. 101, D-4300 Essen 11 (FRG)

January 18-21, 1987

New York, New York (USA); **1987 ASHRAE Winter Meeting;** Sponsored by the American Society for Heating, Refrigerating, and Air-Conditioning Engineers; Contact: Judith Breese, ASHRAE, 1791 Tullie Circle NE, Atlanta GA 30329 (USA), 404/636-8400

January 19-22, 1987

New York, New York (USA); **1987 International Air-Conditioning, Heating, Refrigerating Exhibition;** Sponsored by ARI and ASHRAE; Contact: Hank Stevens, International Exposition Company, 200 Park Avenue, Suite 1204, New York NY 10166 (USA), 212/986-4232

March 25-27, 1987

Oxford (United Kingdom); **3rd International Symposium on the Large Scale Applications of Heat Pumps and Exhibiton;** Sponsored by the British Hydromechanics Research Association (Cranfield); Contact: Ms. J. Stanbury, British Hydromechanics Research Association (BHRA), Fluid Engineering Center, Cranfield, Bedford MK43 0AJ (United Kingdom)

April 13-18, 1987

Budapest (Hungary); **Symposium on the Long-Term Impact of Energy Efficiency Improvements;** Sponsored by the United Nations (Geneva), the Economic Commission for Europe; Contact: United Nations, Economic Commission for Europe, Energy Division, Palais des Nations, CH-1211 Geneva 10 (Switzerland); Note: Registration deadline Oct. 31, 1986

April 26-29, 1987

Berlin (F.R. Germany); **22. Internationaler Kongress für Technische Gebäudeaurüstung** (22nd International Congress for Technical Building Equipment); Sponsored by Verein Deutscher Ingenieure (VDI) - Gesellschaft Technische Gebäudeausrüstung (TGA) (Düsseldorf), Vereinigung von Verbänden der Deutschen Zentralheizungswirtschaft e.V. (VdZ) (Hagen), Bundesverband für Heizungs-Klima- und Sanitärtechnik e.V. (BHKS) (Düsseldorf); Contact: Prof. Dr. H. Esdorn, Technische Universität Berlin, Strasse des 17. Juni 135, D-1000 Berlin 12 (FRG)

April 28-30, 1987

Orlando, Florida (USA); **IEA Heat Pump Conference;** Sponsored by the International Energy Agency, Paris; Contact: F.A. Creswick, Oak Ridge National Laboratory, P.O. Box Y, Oak Ridge, TN 37831 (USA)

September 28–October 2, 1987

Lausanne (Switzerland); **3rd International Congress on Building Energy Management (ICBEM-3 87);** Sponsored by Ecole Polytechnique Federale (Lausanne); Contact: ICBEM '87 Secretariat, Prof. Andre P. Faist, EPFL-LESO Building, CH-1015 Lausanne (Switzerland)

October 13-17, 1987

Berlin (F.R. Germany); **13th World Conference on Housing (IHAS-13);** Sponsored by the International Association for Housing Science, Florida International University, and the Miami College of Engineering and Applied Science; Contact: Prof. O. Ural, Florida International University, College of Engineering and Applied Sciences, Miami, FL 33199 (USA)

PRODUCTS, SERVICES

Available to all HPC member countries

INQUIRIES

Have a specific question about heat pumps?

Call, write, or telex the Heat Pump Center directly with your questions about heat pump technology, marketing, economics, etc. HPC staff members will do their best to answer directly or point you to the right expert.

CALL:	(Ctry code for FRG) 07247-82-4541
WRITE:	IEA Heat Pump Center, c/o FIZ 4, D-7514 Eggenstein-Leopoldshafen 2, FR Germany
TELEX:	17724710
TELETEX:	724710 = FIZKA

DATABASE SERVICES

The Heat Pump Center maintains and continuously updates computerized databases of heat pump information. You can make inquiries to these databases according to your own needs and interests, and the HPC will send you a print-out containing the most up-to-date information available. Call or write the HPC and ask for:

RD&D Projects:
by project, country, heat pump type, research organization, principal investigator, etc.

Products and Manufacturers:
by type, heat source/sink, size, COP, manufacturer, country, and detailed information about individual manufacturers

Sample installations:
performance results and design details for actual heat pump installations, by application type/size, heat pump type/size, country, etc.

NEWSLETTER

The HPC publishes a quarterly **Newsletter,** each issue focusing on a particular aspect of heat pump technology or development, including:

- Reports on innovative heat pump installations, technological developments, heat pump sales and prices
- Trends in fuel prices and electricity tariffs
- Developments in energy policy affecting heat pumps
- Heat Pump Center projects and reports
- Book and report reviews, schedule of conferences and trade shows

Subscription free to those in member countries

AND ORDERING INFORMATION

Just use the attached card

IEA heat pump center

REPORTS

The following printed reports are available direct from the Heat Pump Center (use the attached card):

- **Heat Pump Research, Development and Demonstration Projects: Summary Report, Update 1985,** Report No. HPC-R2-1, May 1986, DM 75. This report contains half-page project status summaries for over 700 heat pump RD&D projects completed and on-going world-wide.
- **Non-Azeotropic Refrigerant Mixtures as Working Fluids in Compression Heat Pumps, A Bibliography,** Report No. HPC-B1, second edition, December 1985, DM 220. This report is a comprehensive bibliography of over 200 reports with complete citations and abstracts.
- **Literature Reviews:** literature surveys (with complete citations and abstracts in the following areas:
  - **Environmental Aspects of Heat Pump Applications,** Report HPC-L1, May 1986, DM 25.
  - **Industrial Heat Pump Applications,** Report HPC-L2, July 1986, DM 40.

A new literature review is compiled in conjunction with the focus topic of each issue of the HPC Newsletter.

*All prices include postage. VAT additional in F.R. Germany.

The IEA Heat Pump Center Newsletter is published quarterly.

Subscribers from countries participating in the IEA Heat Pump Center (Austria, Canada, Fed. Rep. of Germany, Italy, Japan, the Netherlands, Sweden, the USA) will receive the newsletter free of charge.

Subscribers from other countries will be billed DM 80.– per year.

Subscription cancellation is possible with one month's notice to the end of the calendar year.

ORDER FORM AND SUBSCRIPTION CARD

IEA heat pump center

NEWSLETTER SUBSCRIPTION:

Member countries:

○ start my subscription to the HPC Newsletter (no charge)

Non-member countries:

○ start my subscription in 1987 (DM 80/yr)

○ also send me all back issues through the end of 1986 (DM 80 additional)

PLEASE SEND ME THE FOLLOWING (member countries only):

Report No.	Title

Date ____________ Signature ____________

Please fill in address on reverse side

6/86

Our next issue: Sorption Heat Pump Systems

The September issue of the Heat Pump Center Newsletter will focus on sorption heat pump systems. Planned contributions from our member countries include:

1. Update on United States RD&D on residential absorption heat pumps
2. Canadian activities involving absorption heat pumps for industrial applications
3. A new absorption fluid for temperatures above 260°C in the United States
4. New developments in Germany
5. Research and development in the Netherlands
6. Excerpts from the HPC literature review on sorption heat pump systems

Also included will be our regular features: Book reviews, conferences and trade fairs, and news updates. If you have further contributions relevant to sorption heat pump systems, please send them to the Heat Pump Center.

IEA Heat Pump Center Newsletter
(ISSN 0724-7028)

Edited by: IEA Heat Pump Center
c/o Fachinformationszentrum
Energie, Physik, Mathematik GmbH
D-7514 Eggenstein-Leopoldshafen 2
Telephone: (0 72 47) 82-45 41
Teletex (17)72 47 10=FIZKA

Published quarterly
Annual Subscription DM 80.–
including postage
(V.A.T. not included).
Free of charge for subscribers from HPC Member Countries

Printed in Germany by
kraft druck gmbh,
Industriestraße 5b,
D-7505 Ettlingen-Oberweier