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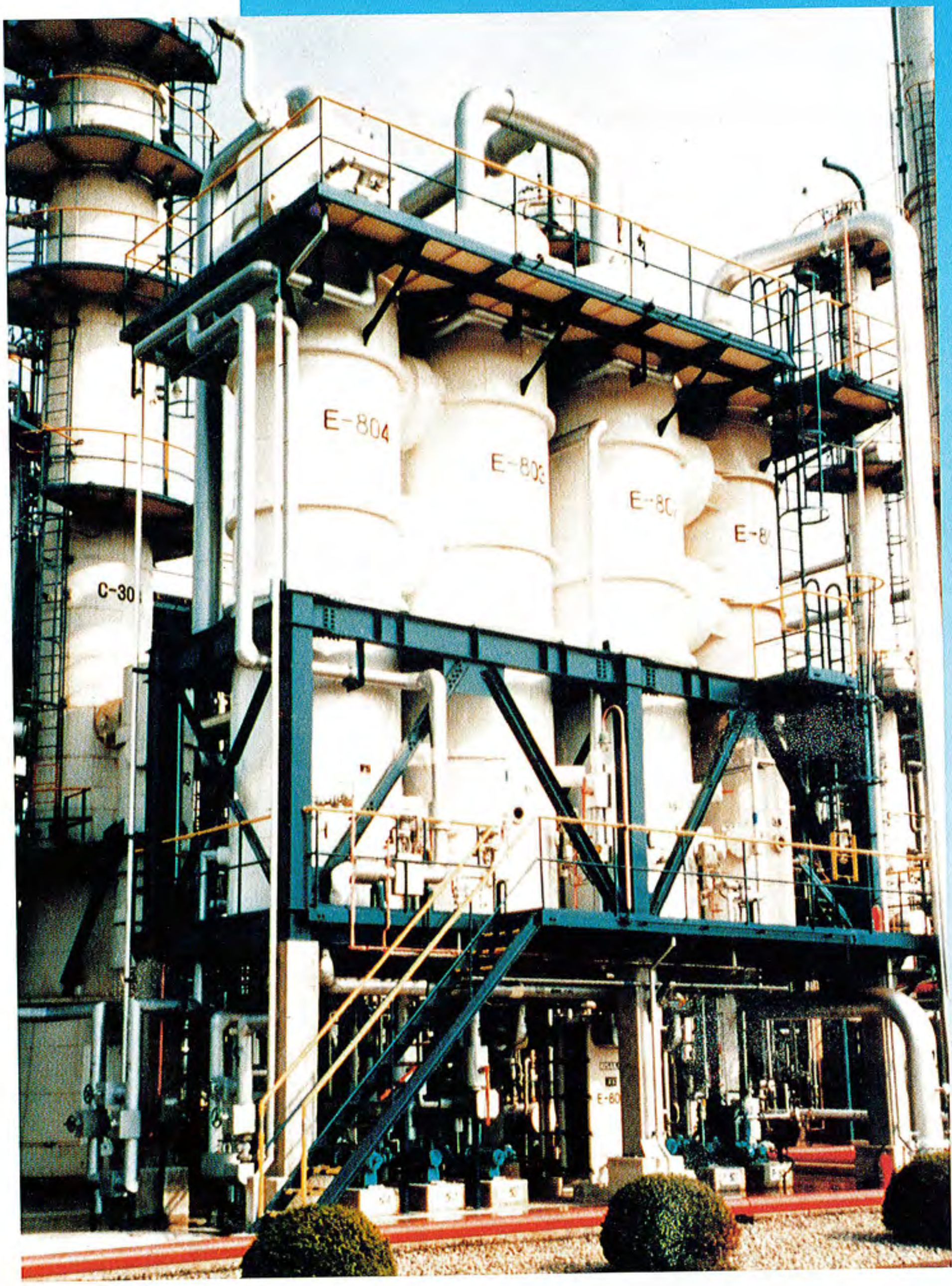
IEA Heat Pump Centre

NEWSLETTER



IEA heat pump centre

Contents

Front Cover: A Heat Transformer in an Alcohol Plant from the Yokkaichi Factory of Japan Ethanol Co., Ltd., (see page 41).

International Energy Agency
The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Cooperation and Development (OECD) to implement an International Energy Programme.

A basic aim of the IEA is to foster cooperation among the 21 IEA participating countries to increase energy security through energy conservation, development of alternative energy sources and energy research, development, and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of 42 Implementing Agreements, containing a total of over 80 separate energy RD&D projects. This publication forms one element of this programme.

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Editorial

The topic for this issue of the Newsletter is **Sorption Heat Pumps.** Until now sorption systems have been applied in limited numbers in industrial processes. Waste heat recovery from process streams is a classic example of a sorption system application. Heat transformers, amongst others, are often used for this purpose. Industrial heating and cooling is another example of the energy efficient and economic application of absorption heat pumps.

In general, technical and operational performance of the systems fulfill expectations and specifications. However, corrosion problems have occurred in a number of cases with high system temperatures.

It is encouraging that joint efforts between industrial companies can result in finding solutions to corrosion problems, as is shown in this issue. It is of great importance that despite these problems, industry is willing to share these experiences internationally. In addition, the new installation, which is under construction, has been enhanced on the basis of the results of the corrosion study. To motivate international co-operation in this area, a users' club of large-scale sorption systems will be established under the auspices of the HPC. The intention is that the users' club will provide an informal forum for the exchange of practical information.

A step forward in high temperature sorption systems may be the newly developed fluid Alkitrate. It has most promising features and field testing should throw light on its capability. A major challenge, primarily for the private industry, is to further improve absorption technology, products and costs. This will generate confidence among potential industrial and other users.

Small and medium-scale sorption systems for residential and commercial markets have not yet reached the breakthrough point, but as is shown in this issue, gas-fired absorption heat pumps are about to enter the residential market. A number of interesting developments are currently being worked on in Europe, Japan and the USA.

It is hoped that as a result of growing concern for our environment these systems will be given a fair chance.

Jos W.J. Bouma
General Manager HPC

Absorption Heat Transformer Saves Energy in an Alcohol Plant

*Hirotaka Tokano, Takashi Yano

Summary

This article illustrates the application of waste heat recovery from a distillation tower top vapour of an ethanol plant by using an absorption heat transformer (AHT). An AHT is installed at the Yokkaichi Factory of Japan Ethanol Co., Ltd. (see cover photograph). The tower bottom liquid is directly fed into the absorber where it is evaporated. Since the start of operation in September 1987, the AHT's operational performance has been as expected. The introduction of the AHT has reduced steam consumption by about 30,000 tonnes/year.

Introduction

Whatever the price of oil, energy saving technology which reduces oil consumption is one of the most important topics for mankind. Investigations into energy saving technology must be continually promoted on a global scale, not only for the reduction of oil consumption but also for environmental protection.

Situation Before Adopting the AHT

Between 1975 and 1988, the Japan Ethanol Co., Ltd. Yokkaichi factory had applied energy saving systems prior to adopting the AHT. During that period, steam consumption had been decreased by half. Only low temperature waste heat below 100°C, which had no use, had not been recovered. During the spring of 1986 a survey of low temperature heat source recovery methods was made. As a result, it was found that an AHT could generate low pressure steam, using 80°C top vapour from the distillation tower of the ethanol plant and 30°C cooling water.

Investigation for Applying the AHT

An investigation was carried out to determine whether an AHT was technically and economically feasible. Figure 1 shows the flow sheet of the distillation tower prior to installing the AHT. All tower top vapour was condensed at 78.7°C in the condenser by cooling water, with a cooling capacity of 7,090 kW. All tower bottom liquid was evaporated at about 110°C in the reboiler by low pressure steam, with a heating capacity of 7,090 kW.

At first, the option of generating 124°C low pressure steam for the reboiler by using an AHT was considered. Two cases were originally identified:

Case 1: If a single-stage one-absorber AHT was to be used, the COP would be about 0.5, but the heat transfer area would be too great.

Case 2: If a two-stage two-absorber AHT was to be used, the heat transfer area would not be so great, but the COP would only be about 0.3.

Neither cases were adopted as they were not economically attractive enough. It was then decided to feed the tower bottom liquid directly into the absorber of a single-stage AHT, where it vaporises at 112°C. In this case, although the heat transfer area would not be too great, the COP would be about 0.5. This is one of the characteristic features of this AHT. The following illustrates the reasons behind the decision for this option:

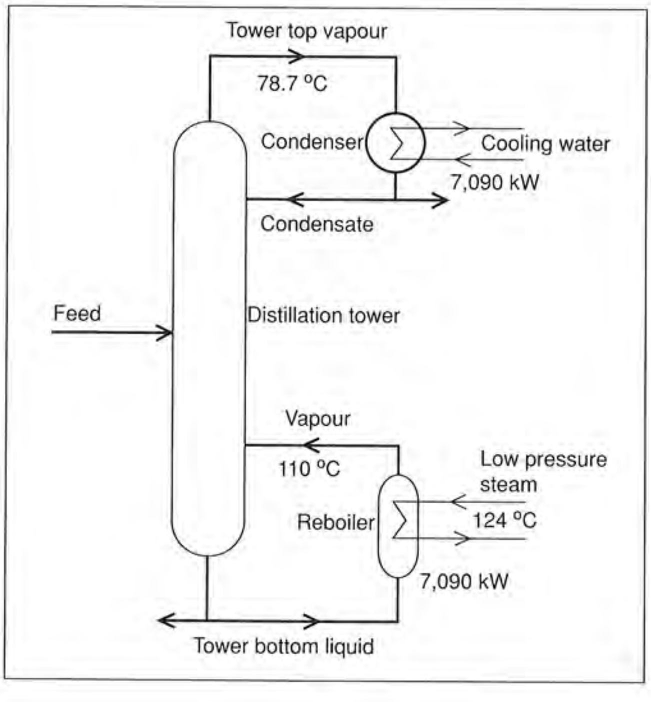

Figure 1: Flow sheet of Distillation Tower Before Applying the AHT.

Table 1: Tube Material List of the AHT

	Internal fluid	External fluid	Tube material
Regenerator	Absorbent	Tower top vapour	CuNi
Condenser	Refrigerant	Cooling water	Copper
Evaporator	Refrigerant	Tower top vapour	Stainless steel
Absorber	Absorbent	Tower bottom liquid	CuNi

Note:
Absorbent : H_2O-LiBr
Refrigerant : H_2O
Tower top vapour : Ethanol + water
Tower bottom liquid : nearly equal to water
CuNi : alloy of copper and nickel

- It is rational to generate steam because the main heat exchangers of Hitachi Zosen's AHT are of the vertical type and the upper channel of the absorber can be used for the steam separator.
- The Cupro-Nickel (CuNi) tube material of the absorber is resistant to corrosion by the tower bottom liquid.
- Part of the tower bottom liquid circulating in the absorber continually returns to the distillation tower, thus preventing concentration of the tower bottom liquid.

The cooling water design temperature then had to be reviewed because the AHT's heat transfer area is affected by it. Generally, in Japan, the cooling water temperature may rise above 30°C in the summer and below 10°C in the winter. If the design temperature of the cooling water is based on the summer maximum value, the heat transfer area of the AHT becomes too great. In this plant, the temperature of the cooling water rises above 27°C for only a short period in the summer. When it rises 1°C over the design temperature, the heat quantity recovered by the AHT is reduced by about 5%. Taking these points into consideration, the design temperature of the cooling water was chosen at 26.7°C, thus optimising the heat transfer area of the AHT.

The tube material was chosen on the basis of its corrosion potential with respect to both the internal and external fluids (see Table 1). The main heat exchanger shells are made of carbon steel.

In this plant it is intended to reduce the consumption of low pressure steam by applying the AHT and, at the same time, to reduce the consumption of middle pressure steam by improving the efficiency of the steam turbine, since the low pressure steam was previously made by middle pressure steam. As a result of subsequent investigations it was found that the payback period of the AHT investment, including remodelling work surrounding the AHT, was less than eight years, in spite of low oil prices and the comparatively short annual operational period (about 5,000 hours). After careful evaluations, it was decided to use the AHT.

Specifications and Operating Record

The main AHT design specifications are shown in Table 2.

Figure 2 shows the flow sheet of the distillation tower after installing the AHT. All tower top vapour is condensed at 78.6°C in the AHT and its heat capacity is 7,090 kW. About half (3,370 kW) of the

Table 2: Main design specifications of the AHT

Type No.	**HHP-2S-450**		
Output (Distillation tower bottom liquid)	Heat quantity	3,370	kW
	Flow rate	5.44	ton/hr
	Temp.	111.5	°C
Waste heat source (Distillation tower top vapour)	Heat quantity	7,090	kW
	Flow rate	28.0	ton/hr
	Temp.	78.7	°C
Cooling water	Flow rate	800	ton/hr
	Inlet temp.	26.7	°C
	Outlet temp.	30.6	°C
COP		0.475	-
Electric power consumption		32.0	kW
Operational weight		124	ton
Main Dimensions	Length	10.0	m
	Width	3.2	m
	Height	13.9	m
Dimension of main heat exchangers (Diameter x Height)	Regenerator	ø2.0 x 10.2	m
	Condenser	ø1.6 x 9.8	m
	Evaporator	ø2.0 x 10.2	m
	Absorber	ø2.0 x 10.7	m

driving heat is used to vaporise the tower bottom liquid. As a result, the low pressure steam consumption at the reboiler is halved, and the heat quantity removed by cooling water is also halved. The existing condenser and reboiler have been left in place as a back-up system in case the AHT should, for whatever timespan or reason, be shutdown. As to the control of the external fluids, only the tower bottom liquid is equipped with a control device. There is no so-called 'capacity control' which can adjust the AHT in accordance with the load variation of the tower top vapour.

The control system of the internal fluids which operates the AHT usually consists of a) liquid level controllers to maintain the refrigerant level in the evaporator and the absorbent level in the regenerator, and b) sequential circuits to start and stop the operation, and to protect the AHT when the operating conditions cannot be kept within the allowance value. Operational records of the AHT for 60 days, between April 1988 to May 1988, are shown in Figure 3. The AHT operation has been stable and the level of performance for heat output and COP has been as expected. The total operational time of the AHT is about 16,000 hours up to September 1990.

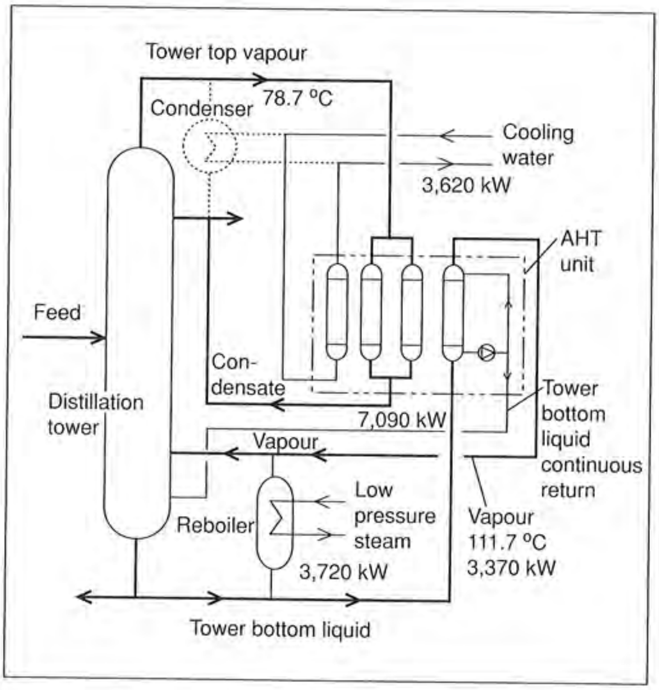

Figure 2: Flow sheet of Distillation Tower After Applying the AHT.

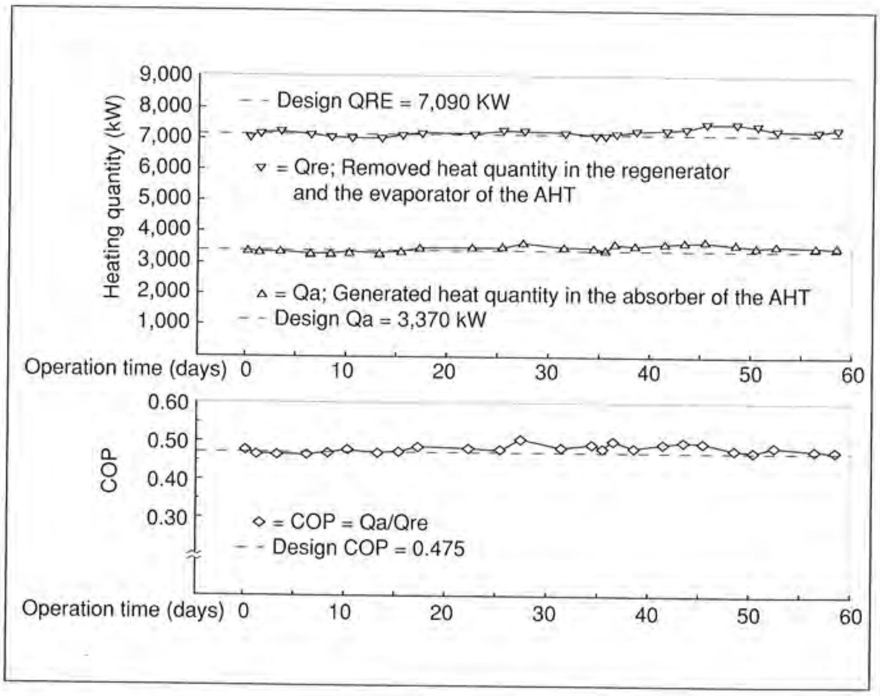

Figure 3: Operational Records of the AHT.

Conclusion

The AHT has decreased the consumption of steam by about 30,000 tons/year. The payback period of the AHT investment is expected to be one year shorter than the first estimation (less than eight years), because oil prices are higher than in1987 and the annual hours of operation of the ethanol plant have also increased.

It has been confirmed that the AHT is an effective device for low temperature energy saving in industrial processes. Today it is believed that emission of CO_2 must be decreased to protect the earth's environment. Therefore, the reduction of oil consumption has become more important, not only from an energy saving point of view. This AHT will therefore play an increasingly important role in helping to reduce energy consumption and the plant's environmental impact.

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260°C Absorption Working Pair Ready for Field Test

*Lawrence A. Howe and Donald C. Erickson

Summary

Many studies have identified the potential benefits which heat pumps, and especially absorption heat pumps, could bring to industry. However, it has long been recognised that the conventional Lithium Bromide (LiBr) absorbent cannot satisfactorily achieve the high temperatures and lifts needed for most industrial heat pumps. Thus, numerous researchers have endeavoured to identify improved high temperature absorbents (Matthys and Trepp, 1989; Narodoslavsky et al., 1989).

Seven years ago Energy Concepts advanced a new family of compositions as a candidate for high temperature absorption heat pumps, and commenced research to prove their suitability. The initial development of this high temperature absorption working pair (AWP), called Alkitrate, has previously been reported on (Davidson and Erickson, 1986; Erickson and Howe, 1989). Since the last paper was published, extensive pilot plant testing has been completed. The testing has uncovered no apparent obstacles to the use of Alkitrate at 260°C. In addition, all testing to date indicates that carbon steel is a suitable construction material, from a corrosion standpoint, for temperatures up to 250°C.

A successful AWP must show good performance levels in the following key properties:

- Stability
- Corrosion
- Solubility range
- Thermodynamic performance (efficiency)
- Pressure
- Heat and mass transfer
- Safety
- Cost

Many AWPs have been found which satisfy at least some of these criteria. However, a failing in even one of these areas can make an AWP unusable. Alkitrate appears to satisfy all of the criteria. During the past three years, Alkitrate has undergone pilot plant and laboratory testing for each of the criteria mentioned above.

Stability

Alkitrate consists of alkali metal nitrate salts and water. Thermal decomposition in aqueous solution consists of decomposition of the NO_3 anion to NO_2 and a hydroxide anion. The NO_2 is emitted as a gas. In the condenser, and especially in the evaporator, it is partially dissolved into the condensate. Both as a gas and in solution the characteristic yellowish-brown colour is evident.

Decomposition information is available from two sources: static corrosion tests and pilot plant tests. In the static corrosion tests, sealed Pyrex capsules containing Alkitrate and various metal samples were exposed at 250°C for six months (DeVan and Wolf, 1988). In these tests there were no visible discoloration of the solutions or evidence of NO_2 formation.

Decomposition was measured more accurately in pilot plant experiments. NO_2, which is formed in the generator, combines with water in the condenser to form HNO_2 and HNO_3. The pH of the condensate is therefore a sensitive indicator of decomposition. The data showed that a bulk fluid temperature of 240°C, over 50 years of continuous exposure would be required to decompose 1% of the absorbent. At 260°C, a lifespan of 24 years is indicated. More importantly, the observations show that, during tests lasting 120 hours (see Figure 1), the pH of the condensate eventually stopped changing. This was to be expected because decomposition raises the pH of the absorbent, and a high pH discourages further decomposition due to the Le Chatelier Principle.

Corrosion

A variety of corrosion tests were run at Oak Ridge National Laboratory (ORNL) (DeVan and Wolf, 1988). C-ring and constant strain-rate tests were run on welded and unwelded specimens of carbon steel, low-alloy steel, stainless steel, and Monel [R]. Temperatures from 170 to 250°C, and exposure times from two weeks to six months were used. In no case did the corrosion rate exceed 0.06 mm/yr. For the six-month tests, the corrosion rate for carbon steel averaged 2×10^{-4} mm/yr. More importantly, the tests showed that none of the materials tested are susceptible to stress corrosion cracking. A 9,144 hour test at 250°C was recently completed, with similar results.

One question which should be asked is whether low corrosiveness can be maintained with a small amount of air present, because, in an industrial setting, occasional air contamination is likely. Based on pilot plant experience, Alkitrate is non-corrosive to stainless steel (SS) 304 even with frequent air exposure.

Whether carbon steel can withstand substantial air exposure is still an open question. As mentioned previously, carbon steel is suitable when no air is present. To test the susceptibility of carbon steel to air exposure, Energy Concepts Co. ran corrosion tests in which a controlled amount of air was continuously bled through the test vessel. In that test a tenacious film of magnetite was produced on

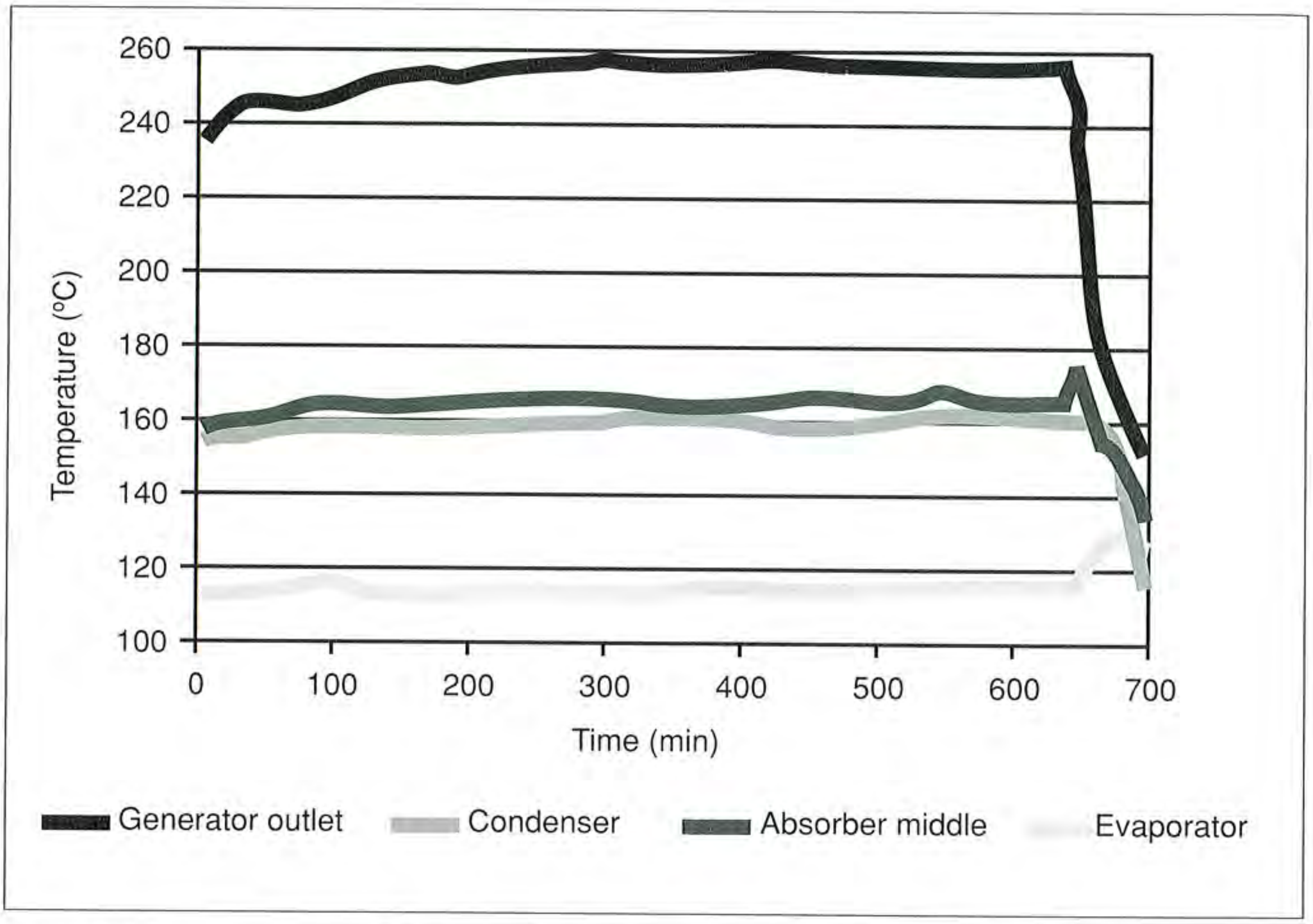

Figure 1: The temperature measured during a 12 hour time period (including shutdown) of a 120 hour test.

the samples. The growth rate and stability of this film, and its susceptibility to erosion, will be investigated in the future.

Solubility

The range of solubility of the Alkitrate absorbent has been described in earlier papers. In summary, the solubility range is unlimited, i.e., crystallisation cannot occur, as long as the water vapour partial pressure is maintained above 0.25 atmospheres absolute (25 kPa). This corresponds to condenser and evaporator temperatures of 70°C or above. Solubility extenders are available which will allow the absorbent to be used at even lower temperatures and pressure (Erickson, 1987).

The solubility range of Alkitrate does present one minor disadvantage: the typical working concentration of Alkitrate cannot be cooled to ambient temperature and remain a liquid. The absorbent must be diluted with water to about 55 weight percent salt in order to remain a liquid during extended shutdown.

Thermodynamic Performance

Alkitrate is almost equal to lithium bromide in thermodynamic performance. In the heat amplifier (HA) mode, a heating COP of 1.65 to 1.70 was measured with temperature lifts (absorber outlet temperature minus evaporator temperature) over the range of 25 to 60°C. In the temperature amplifier (TA) mode, a COP of 0.46 to 0.49 was measured with lifts of 40 to 61°C. Thus the achieved COPs almost match those of LiBr, whereas lifts achieved in this single-stage machine were much higher than those achievable with $LiBr/H_2O$.

Pressure

Since Alkitrate uses water as the working fluid, pressures are quite reasonable. For example, a working concentration has a pressure of 660 kPa at 250°C.

Heat and Mass Transfer

The pilot plant gave an overall heat transfer coefficient U of 310 to 990 W/m^2K in the absorber. The absorber is cooled by making steam, so the absorber film coefficient is close to the U value. It was observed that not all the absorber area was moistened by the solution. Also, the film Reynolds number is about 12, which suggests that higher liquid flow rates should yield better performance. Note in Figure 1, that the temperature difference between the generator and condenser is considerably greater than the difference between the absorber and evaporator. This is due to the relatively poor performance of this particular absorber.

Absorption heat transfer testing was also carried out at ORNL. Film coefficients of 910 to 1150 W/m²K were measured (Ally, 1990). These numbers are sufficient, in most cases, to produce an economical design. It should also be kept in mind that Alkitrate has more lift than is required for many applications. This extra lift can be used to increase the heat exchanger ΔT and decrease the size of the heat exchanger, with little penalty in COP.

The measured pilot plant solution-heat-exchanger U values range from 180 to 336 W/m²K. The solution heat exchanger is a shell-and-coil design. The shell side flow is about 1.8 l/min, which results in very low flow velocity (~0.75 cm/ s). It is expected that substantial improvement will be realised at higher flow velocity.

Safety

This category can be broken down further into toxicity, flammability, reactivity, and environmental safety. None of Alkitrate's four ingredients is toxic in small amounts. In fact, three of the four are used in making food. Alkitrate is not flammable, but it is an oxidizer. Potentially it could react with a fuel species. However, industrial heat transfer fluids which contain the same oxidizing agent have been used for high temperature heat exchange with flammable fluids at least since the 1930s. Since the only volatile component of Alkitrate is water, it does not contribute to ozone depletion or greenhouse warming.

Cost

Based on 1989 prices of one tonne quantities, Alkitrate is half the cost of LiBr, if equal volumes of a working concentration of the two fluids are compared.

Conclusion

The Alkitrate absorption working pair has now completed extensive characterisation and testing. The measured thermodynamic properties include vapour liquid equilibrium, crystallisation, specific heat, viscosity, and density. Pilot plant testing has confirmed the high temperature stability, low corrosiveness, and good heat and mass transfer ability. Alkitrate appears to meet all the requirements for a successful high temperature absorption working pair.

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Absorption Heat Pump System for a Chocolate Production Line

*Tadashi Iwatsuki

Summary

Tokai Works, Meiji Seika Ltd., introduced an absorption heat pump system into its chocolate production in January 1985. The system simultaneously produces chilled water for air-conditioning, high temperature water for heating of oils and fats as starting material, and also low temperature water to prevent chocolate from hardening. The heat pump COP is 1.67, and the number of years required to recover additional investment is 2.5.

The History of its Introduction

Tokai Works is situated in Fujieda City, Shizuoka Prefecture, on the Pacific coast which is in the centre of the mainland of Japan. The works produces a wide variety of confectionery, such as chocolate, snacks and candy, amounting to some Yen 30,000 million per year. Because the type of products vary and processes with different levels of heat load disperse across the works, it has so far been difficult to take effective energy conservation steps. However, as a result of an in-depth examination it was found that the heat load within the works is stable all year round and both cooling and heating exist simultaneously at the chocolate production line. Hence, the introduction of an absorption heat pump system into the chocolate line was a logical step.

As shown in Figure 1, the chocolate production line is composed of a series of sequential processes, i.e., mixing of feed materials (cacao, sugar, powdered milk and oil and fats), grinding, liquefying, moulding, cooling and packaging. High temperature (58°C) water is required to heat oil and fats and retain their temperature, while low temperature (43°C) water is required to prevent materials from hardening during mixing and moulding. Also cooled water (21°C) is used for cooling and air-conditioning the packaging room. While utilising waste heat from air-conditioning, comprising a large capacity, the absorption heat pump at this works satisfies the three types of heat demand simultaneously. The system flow is shown in Figure 2 and the technical data are shown in Tables 1 and 2.

Since the system was put into operation, it has continued to run for 24 hours a day and about 8,750 hours per year. No notable problems have occurred, thus helping the working environment to become cleaner and achieve energy conservation.

Operational Performance

COP

The COP of the heat pump, defined as the ratio of the total heat output for heating and the heat of the steam for driving, amounts to 1.67.

Maintenance and inspection

During operation the absorption heat pump generates a very small quantity of hydrogen, although it decreases as the number of operating hours increases. Additionally, since the system operates under vacuum, it is inevitably affected by invading air. So, in order for the heat pump to operate properly it is necessary to vent the system twice a week, for about 15 minutes each time. It is also necessary to inspect the system once a year, including cleaning of the heat exchanger tubes. Since January 1985, the heat pump has been in full operation, almost without problems.

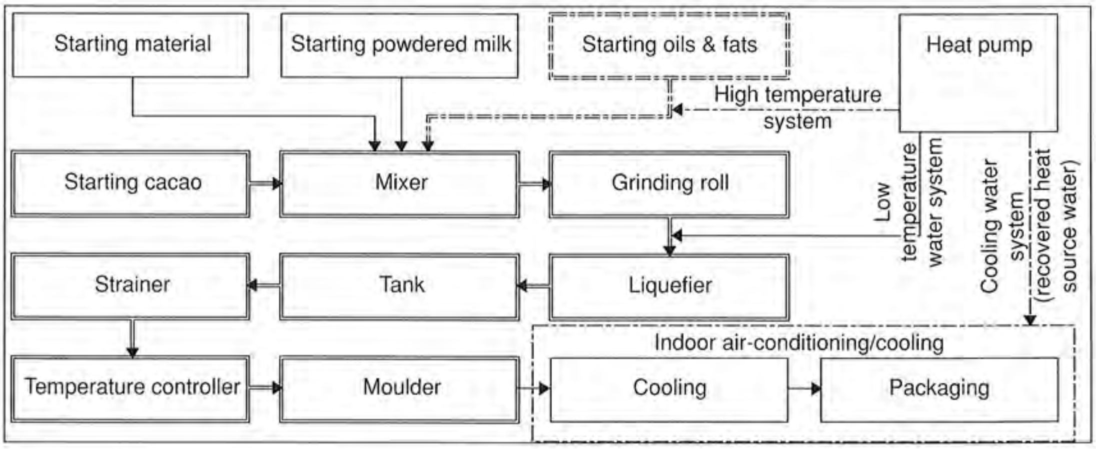

Figure 1: Chocolate Production Line.

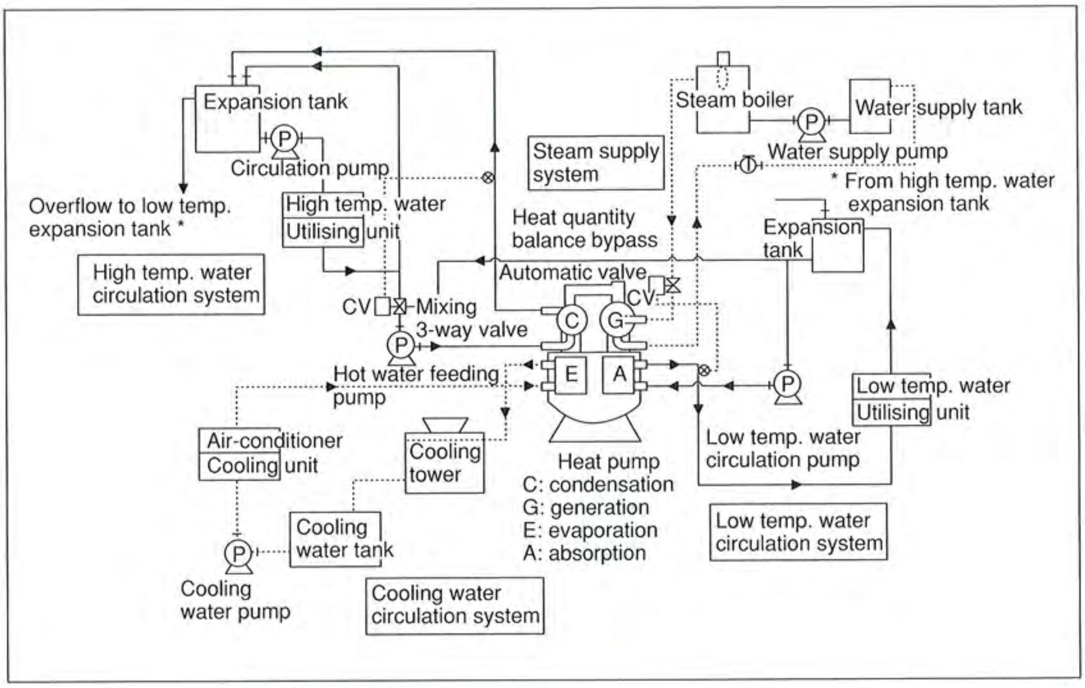

Figure 2: System Flow.

Effect and Economy

The required quantity of steam was 3,100 tons/year. With the introduction of the heat pump, two oil boilers were abolished, leading to 500 litre oil reduction a day. Since the oil storage tank and other auxiliary equipment were also removed, maintenance efforts reduced accordingly. Furthermore, gas-fired boilers now provide the driving steam for the absorption heat pump and therefore, the stack gases became cleaner. Thanks to the waste heat recovery 167 kW electrical energy can now be saved in winter and 158 kW in summer. The result is that the additional investment in the heat pump installation has been paid back in 2.5 years.

Table 1: Absorption Heat Pump

Manufacturer/type:	Sanyo Electric Co., Ltd./AH-50XVS Steam-driven type
Working fluids:	H_2O/LiBr
Heating capacity:	237 kW (absorber) 181 kW (condenser)
Heat quantity recovered:	167 kW (evaporator) side
Pumps:	solution pump (1.1 kW), refrigerant pump (0.2 kW), vacuum pump (0.2 kW)
External dimensions:	3.4 m (long) x 1.9 m (wide) x 2.6 m (high)
Weight in operation:	6.2 tons

Table 2: System Design Conditions

		Inlet temp.	Outlet temp.	Flow rate
Heat source:	cooling water for air-conditioning	24.0°C	21.0°C	48 m³/h
Heat sink:	Low temp. water	41.3°C	44.7°C	60 m³/h
	High temp. water for temp. retention	54.0°C	60.5°C	24 m³/h
Driving steam:	pressure 4 kg/cm² G (5 bar), temp. 151°C, quantity 376 kg/h			

Conclusion

The absorption heat pump applied is capable of delivering high and low temperature hot water, by using waste heat from air-conditioning equipment. The system features conspicuous energy conservation. In the light of the operational results achieved so far, it is advisable that introduction of a heat pump be preceded by an in-depth survey of heat load conditions along the production processes and an accurate calculation of the expected yearly energy conservation, so that the system is designed to reflect the actual conditions.

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□

Experience with a Heat Transformer in the Chemical Industry

*J.W.J. Bouma

Summary

In October 1985 a large-scale heat transformer started operation in The Netherlands. The heat transformer uses the waste heat derived from an ethylene amine production plant. The objective of this demonstration project was to prove the integration of a heat transformer in an existing production plant, without the need for adaptation of the production process. The fluid pair being used is Lithium Bromide (LiBr)/water. Although monitoring by TNO showed that the heat transformer met the performance specifications, with the exception of a slightly lower steam temperature, corrosion problems occurred after six months of operation. The operational experience over a period of almost five years and an investigation into the corrosion phenomena are described below.

Monitoring

The heat transformer is operated by Delamine BV, a manufacturer of ethylene amine in Delfzijl, the Netherlands. (Refer to reference[1] for a description of the installation.) Figure 1 shows a diagram of the installation. The heat transformer produces 11 tonnes of saturated steam at 145°C and 4.6 bar at full load and uses saturated steam at 100°C to drive the system. The measured heating capacity is 6.7 MW at 11 tonnes of steam per hour, whilst 13.7 MW waste heat is needed to drive the unit. The measured heat ratio of the heat transformer is 49%. The total power needed for circulation pumps, etc., is 53 kW, less than 1% of the output.

During the measurements the cooling water temperature differed from the specified design value, i.e., 24°C. Extrapolation proved however, that under the conditions tested, the design specifications were in fact met. Under these conditions the annual saving on natural gas is approximately 6 million m^3. Analysis of the measured results also proved that low cooling water temperatures during the winter are not adequately dealt with in the design, resulting in relatively high thermodynamic losses in the condenser. The heat transformer also proved flexible in operation and the system allows for smooth load adaptation.

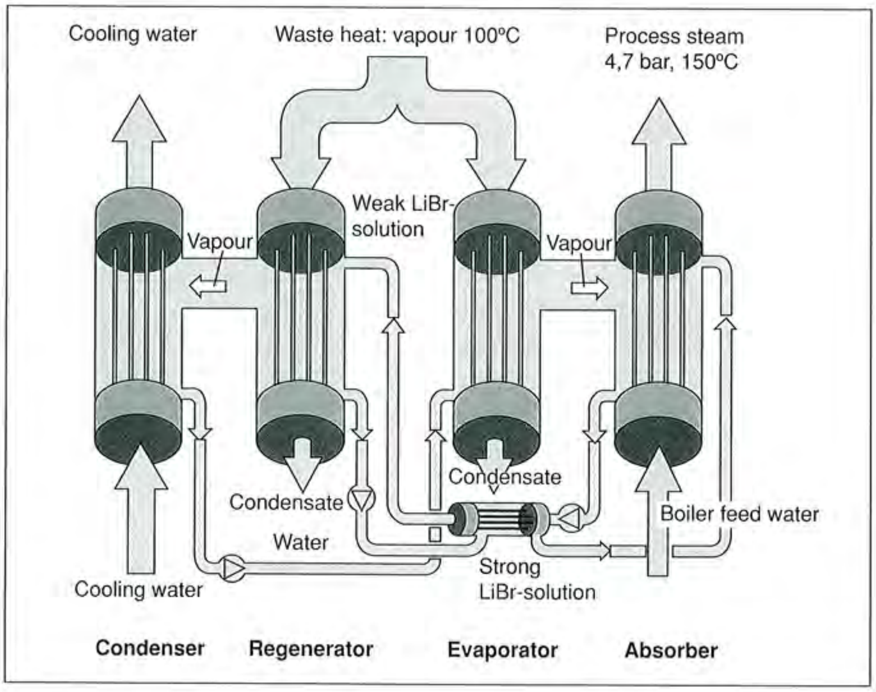
At the time the system was installed, the payback period was two years (gas price Dfl. 0.445/m^3 at 7,800 hours annual operation). The payback period at the energy prices of mid 1990, i.e., before the Gulf crisis, was approximately 7 years (gas price Dfl. 0.22/m^3). For a technical and economical analysis refer to reference[2]. Figure 2 shows the installed heat transformer at Delamine.

Prior to filling the system with LiBr solution and water, substantial attention was paid to the internal cleaning, chemical treatment and leak testing of the heat transformer components. Operation began in October 1985 and continued without any problems for a period of six months. Thereafter interruptions occurred due to corrosion. The corrosion problems fall into two categories:

- leakage resulting from corroded components of the equipment;
- clogging by corrosion products.

The parts where corrosion was first noticed were the intermediate heat exchanger (as a result of a leaking seal), circulation pumps and steel tubes. Shortly afterwards, severe

Figure 1: Heat Transformer Flow Diagram.



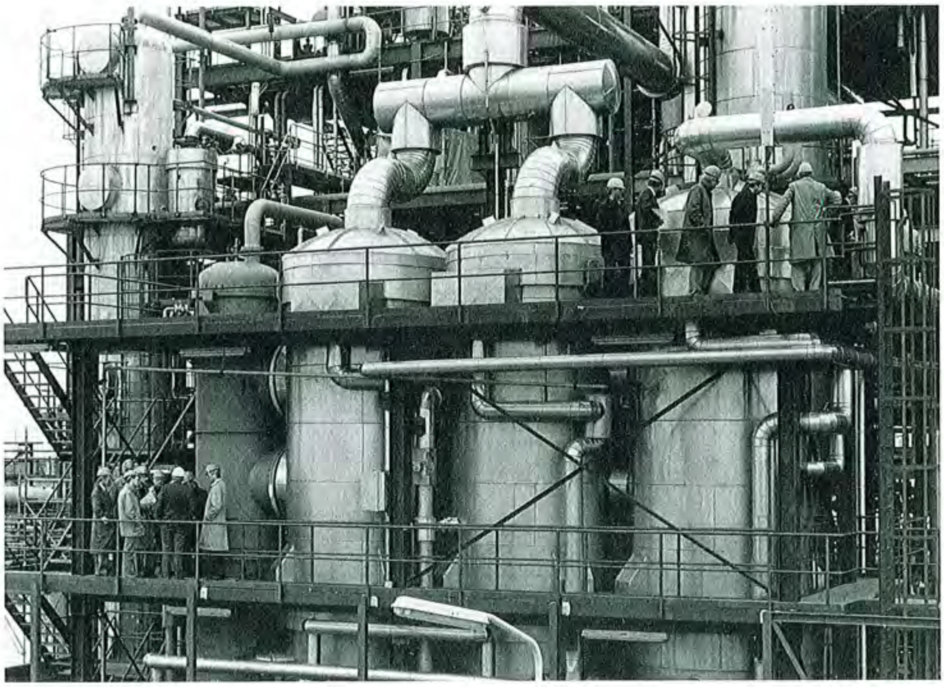


Figure 2: Delamine Heat Transformer.

corrosion problems developed in other heat exchangers and the performance, as well as the steam production, decreased dramatically. The latter was a result of clogging of passages in components by corrosion products. These particles may settle or attach to a metal surface and cause corrosion due to deposit attack. The heat transformer is now only able to operate on average at 30% load due to the clogging.

A period of shut-down and part-load operation then followed during which solutions had to be found for the regular recurring corrosion problems. Since operational experience with heat transformers is limited - only approximately 15 installations exist worldwide - it was extremely difficult to tackle the problems and find adequate solutions. However, similar problems had occurred in a smaller plant of the same type in Japan. In this heat transformer pitting occurred in the regenerator. Therefore, it was decided at the design stage of the Delamine heat transformer to use titanium (Ti) instead of stainless steel pipes in the regenerator. One of the challenges faced whilst designing a heat transformer for relative high system temperatures is the selection of materials and a proper inhibitor (concentration); another, of great importance, is the construction of the unit and the accessibility of components.

Intermediate Heat Exchanger (IHX)

The IHX is of the plate type and is equipped with Ti plates and EPDM (Ethylene Propylene Diene Polymer) gaskets. Crack corrosion was a result that occurred in the construction that houses the gaskets. Once leakage had become too great, the IHX was replaced by a new one which was fitted with Ti/Pd (Paladium) plates. This IHX gradually corroded after only a few hours of operation. Inspection afterwards proved that it failed due to flow-induced vibrations which caused stress corrosion. A new, original type, IHX, with Ti plates and safeguards to eliminate the plates vibrating was later installed. During the following operation clogging of the IHX occurred due to the settling of corrosion particles, resulting in reduced flow rate and capacity.

In order to keep the amount of corrosion particles circulating in the system to a minimum, two filter devices were added. Nevertheless, corrosion and fouling still continue and plates have to be replaced twice a year. The principle corrosion type in the IHX is deposit attack. The plate material becomes brittle locally and extremely sensitive to cracking.

Condenser

Inspection of the condenser after six months of operation proved that two pipes were leaking. It was assumed that these leakages occurred due to thermal stress corrosion. Once the tubes were plugged and the internal vapour flow path modified, the condenser has continued operation without problems.

Evaporator

Leakage in the vacuum system of the evaporator occurred after seven months. During leakage tests four tubes (stainless steel) were found to be leaking and other tubes had pit corrosion. The leaky tubes were replaced and, in addition, 55 corroded tubes also had to be plugged (1% of total area). In order to solve this problem, a new evaporator, with Ti tubes and a CuNi (a copper and nickel alloy) cladded inner shell and lower tube plate, was thus installed. The evaporator, as well as the regenerator and absorber, are of the falling film type and are equipped with liquid distribution trays. Inspection of the dismantled evaporator showed that all unalloyed steel parts which were in direct contact with LiBr and the inhibitor were covered with crusty corrosion products. Carbon steel parts, such as the shell, had suffered from galvanic effects.

Due to the corrosion products collected at the trays, the LiBr flow was forced to follow unusual paths, causing corrosion, and lower output of steam, see Figure 3. The construction that distributes the liquid into a film flow on the heat exchanger tubes is very sensitive to clogging by corrosion products of which the trays and narrow passages are particularly sensitive parts. A modification of the trays and internal parts is required to provide adequate film flow in the tubes at all times, and to improve accessibility for inspection.

Solution Pump

The weak solution pump had to be replaced after five months operation due to short-circuiting. It is a canned pump. Stainless steel parts like the inducer had broken, and an adjustment ring had cracked. The inducer had probably suffered from cavitation during operation which led to fatigue load and stress corrosion. Meanwhile, the pump manufacturer has been advised to apply better corrosion resistant materials like Hastelloy C22. It has now been proved that the same type of corrosion occurs in the pumps as in the IHX, i.e., deposit attack. A definitive solution for the pump problems has not yet been found. Therefore, the problem is being controlled by regular preventive maintenance and inspection.

Corrosion Study

In order to understand the corrosion phenomena and find solutions, a joint study was initiated in December 1986. Partners involved in the investigation were Delamine, a joint venture of Akzo and Japanese Tosoh, the Centre for Materials and Corrosion Engineering AMC of Akzo, Hoogovens IJmuiden, a major steel and aluminium works, and Novem, the Netherlands Agency for Energy and the Environment. Stork, a boiler manufacturer participated at the beginning. Hoogovens is very interested in the corrosion aspect and is participating in order to develop, and to have access to high quality information, which is required for the design of a planned heat transformer that connects two of its mills. AMC was the operating agent of the project. The research was carried out by AMC, at the corrosion laboratories of Hoogovens and TNO. Novem provided co-ordination and financial support.

The investigation was carried out along two lines. On the one hand it focused on the Delamine heat transformer, with an objective of studying the causes of corrosion and to finding solutions. This was accomplished by inspection, failure research and both laboratory and in-situ research. On the other hand, resulting from the information requirements of Hoogovens, topics such as alternative materials and inhibitor systems were handled, as well as construction and engineering aspects for new heat transformer designs.

The research focused on the materials and components in the high temperature system (100 to 155°C), with a rich solution and in the lower temperature system (30 to 100°C), i.e., the refrigerant (water) system. The first system contains two pumps, the absorber, the regenerator and the IHX. In this system the largest corrosion problems occur at 155°C. The latter system contains the evaporator and the condenser.

Figure 3: Corrosion products on upper tube plate, bundle, tie-rod and trays.

Although not part of the study, the waste heat stream contained traces of chloride from the process. This caused pitting on the inside of the stainless steel evaporator tubes. The evaporator was damaged by corrosion on both the inner and outer side of the tubes.

LiBr Circuit

In order to control corrosion in LiBr systems up to 100°C, corrosion inhibitors are used frequently. Well-known inhibitors are combinations of chromate-hydroxide and molybdate-hydroxide. Various written materials indicate that the first combination can be used for carbon steel, copper and stainless steel at 180°C. The Delamine heat transformer also contains the chromate-hydroxide inhibitor. Moreover, the unit is composed of a great number of alloys.

The study focused on the alloys which were present in the system containing the 155°C solution of 60 to 64% LiBr with inhibitor. Investigation was made to find out what the optimum inhibitor concentration would be, as well as the impact of deviations in concentration. Further studies were made to determine the conditions under which local and galvanic corrosion effects occur and the consequences of fouling and erosion. The capability of molybdate as an inhibitor has also been investigated.

Refrigerant Circuit

As a result of entrainment, the water vapour from the regenerator is contaminated with traces of LiBr/inhibitor. This also causes an increase of concentration in the water to the evaporator which has been proved to result in corrosion in the evaporator.

Recommendations

Experience and investigations have resulted in the following general recommendations:

- for an adequate design of a heat transformer a balanced choice of materials is required;
- operation and inspection of a heat transformer requires maximum care;
- heat transformer components should enable easy access for inspection and maintenance;
- solution pumps need preventive maintenance at regular intervals;
- great attention should be paid to adequate and continuous removal of non-condensable gases;
- prevention of any leakage of oxygen into the system and prevention of loss of vacuum should be taken;
- adequate LiBr handling procedures should be developed;
- maintenance and monitoring of the prescribed inhibitor concentration should also be undertaken.

An important need expressed by the user of the Delamine heat transformer, supported by Hoogovens, is to exchange information and 'know-how' between users and potential users.

As a result of the study, the Delamine heat transformer will be revamped in July 1991. The measures to be taken are replacement of the absorber and replacement of the carbon steel piping, which is in direct contact with the LiBr solution[3], by CuNi.

The planned heat transformer at Hoogovens will benefit from the information obtained. This unit will provide cooling for the hot strip mill. The waste heat stream, at a rate of 1,700 m^3 water per hour of 90°C, drives the heat transformer and will produce low pressure (2.7 bar) steam for a cold reducing mill. The capacity is 4.5 MW and steam production is 6.5 tonnes per hour at 130°C. The estimated annual natural gas saving is 5 million m^3 and estimated investment costs are Dfl. 7 million. The heat transformer will be erected at a distance of 700 m from the hot strip mill and will consist of vertical heat exchangers and be designed and delivered by Rinheat OY, Finland.

Operation of the system will be fully automatic. It is also intended to add other waste heat sources to the system in the future and to attract external consumers of the heat produced. The installation is scheduled for start-up mid 1991 and will be part of a joint venture between Hoogovens and the provincial electricity utility, PEN.

Conclusion

The industrial heat transformer at Delamine proved to perform according to the specifications. A heat ratio of 49% was achieved at full-load. The system also proved very flexible in following load changes. However, operation is hampered by corrosion problems. Corrosion causes clogging of flow paths in components, which results in a heat transformer part-load operation and regular stops for inspection and cleaning of the system. A study into the corrosion phenomena has provided useful insight and knowledge on how to operate the Delamine heat transformer, given the corrosion problem, and how to select suitable materials and inhibitor conditions for new designs. Under the present conditions, i.e., at 30% load, the system operates reasonably well, although the corrosion problems require regular attention.

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Market Opportunities of Industrial Chemical Heat Pumps in the United States

*P.E. Scheihing, L.A. Cuervo.

Summary

A study of Industrial Chemical Heat Pump (ICHP) market opportunities in the United States process industries was performed[1]. A large market for ICHPs over the next twenty years is projected, as well as for conventional industrial heat pumps (IHPs), (mechanical vapour recompressors (MVRs) and thermal vapour recompressors (TVRs)). The US Department of Energy (DOE) will use this study to focus research, development, and demonstration (RD&D) of all types of IHPs in a variety of process industries.

Introduction

To assist US industry in improving productivity through energy efficiency, the US DOE Office of Industrial Technologies (OIT) co-sponsors with industry RD&D of advanced energy efficient equipment and processes. IHP RD&D is one area under OIT sponsorship. Specifically to conserve energy required for industrial process heating through the use of IHPs, the OIT has two projects :

1 **Prototype IHP Applications** - This project identifies novel IHP applications, and will demonstrate to industry the attractive economics of IHPs with installed and operating IHP equipment[2]. IHP equipment is currently being designed for eight participating US companies and include: two petroleum refinery, three chemical processing, one pulp and paper, and two food processing host sites.

2 **Industrial Chemical Heat Pumps** - A project to design full scale ICHPs, and eventually demonstrate these ICHPs in an industrial application, is proceding due to successful laboratory ICHP bench scale tests[3,4]. There are two specific projects. One ICHP project will be a solid/vapour adsorption ICHP by Rocky Research to be installed in a food plant. The second ICHP project will be a liquid/vapour absorption ICHP by Litwin Engineers & Constructors and Energy Concepts Company using the working fluid Alkitrate™ that will be installed in a petroleum refinery. These ICHP installations are intended to demonstrate to industry an advance in ICHP technology by using ICHP working media that are compatible with relatively inexpensive materials of construction (e.g., mild steel). Low ICHP capital cost and good equipment reliability (i.e., minimal corrosion), yet with no adverse degradation of the ICHP energy efficiency, is hoped to be demonstrated by 1992.

Costs for Boiler and Industrial Heat Pump

When considering installing any type of IHP, cost must be compared with a boiler. After all, the IHP is simply a means to reduce boiler fuel burn for a retrofit situation, or to supplement additional boiler capacity requirements. For process heating, there are four choices of IHPs; the MVR, TVR, ICHP/Heat Amplifier (HA), and ICHP/Temperature Amplifier (TA) (see Figures 1a to 1d).

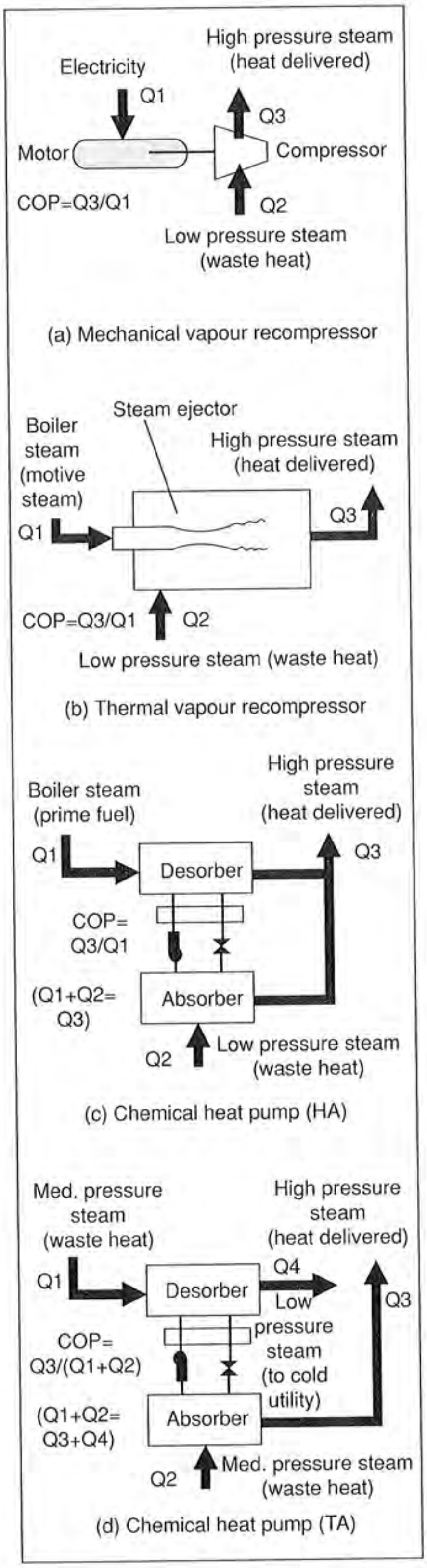

Figure 1a-d: Industrial Heat Pumps for Process Heating.

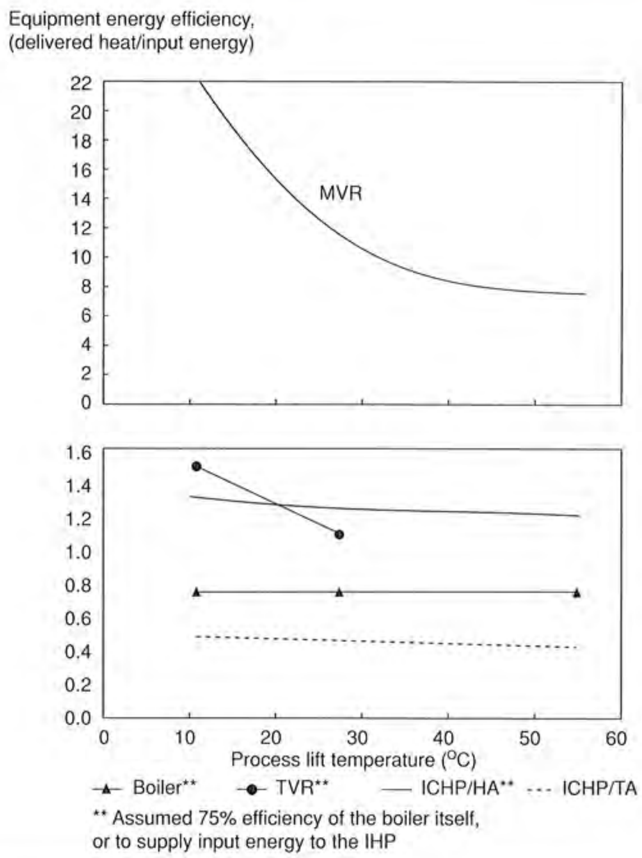

Figure 2: IHP and Boiler Energy Efficiency.

Figure 3: IHP and Boiler Installed Cost.

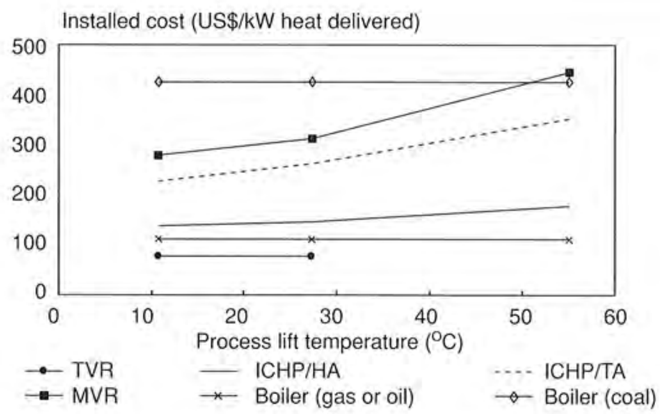

Table 1: Electricity to Fuel Price (E/F) Scenarios		
	E/F = 2	E/F = 6
Electricity Price (US$ / [MW-hr])	30.7	51.0
Fuel Price (US$ / [MW-hr])	15.4	8.5

Each IHP lifts low temperature heat (usually in the form of low pressure steam) to higher temperature. The energy efficiency (Figure 2) and equipment cost (Figure 3) of the four types of IHPs and a boiler are based on hypothetical cases with each type of IHP and the boiler delivering 2.93 MW (10 MMBtu/hr) of heat. The ICHP energy efficiency and cost projections are based on recent laboratory results,[3, 4] and projections made by DOE. The levelised annual cost (LAC) of all the IHPs will be less than a boiler's LAC for all IHP lift temperatures considered, and for a wide range of fuel prices (see Table 1, Figure 4). The LAC is the annual cost of using a particular piece of equipment over the equipment lifespan (assumed to be 15 years in this case), which includes capital depreciation, operating (mostly energy) and maintenance costs - note the low LAC of the ICHP/TA. This is due to the fact that the ICHP/TA is primarily waste heat driven.

ICHP Market Analysis

The market analysis that was performed, concentrated on industrial process heating opportunities in the US. To properly evaluate the market potential of the ICHP, over 140 previously performed "pinch" analyses were screened for IHP potential[5]. Of the 140 total processes screened, 70 were selected for additional evaluation. The selection was based on the ICHP's technical suitability (operating time, heat pumping capacity, and temperature lift), and preliminary economic competitiveness. A rough economic evaluation of an MVR, TVR, ICHP/HA, and ICHP/TA was performed for each of the 70 processes, for which the following was considered:

- The process waste heat and delivered heat temperature.
- The amount of heat pumped and delivered.
- The energy savings from heat pumping.

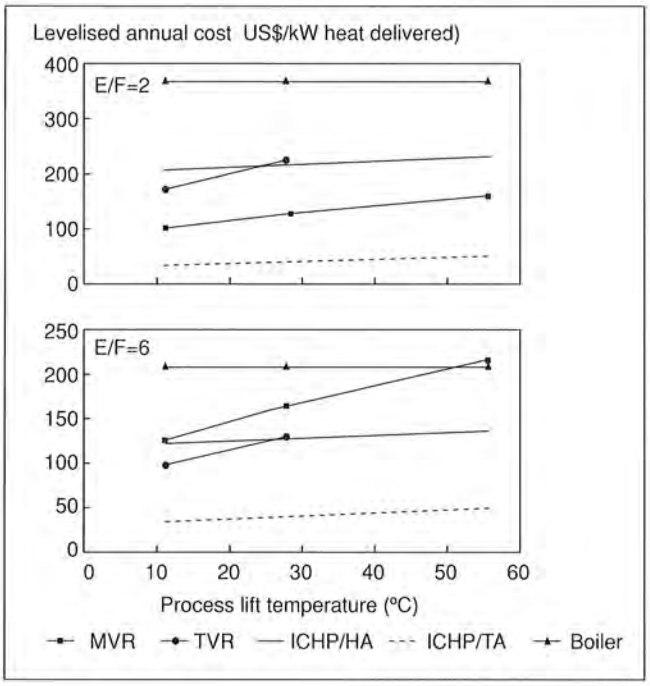

Figure 4: IHP and Boiler Life Cycle Costs.

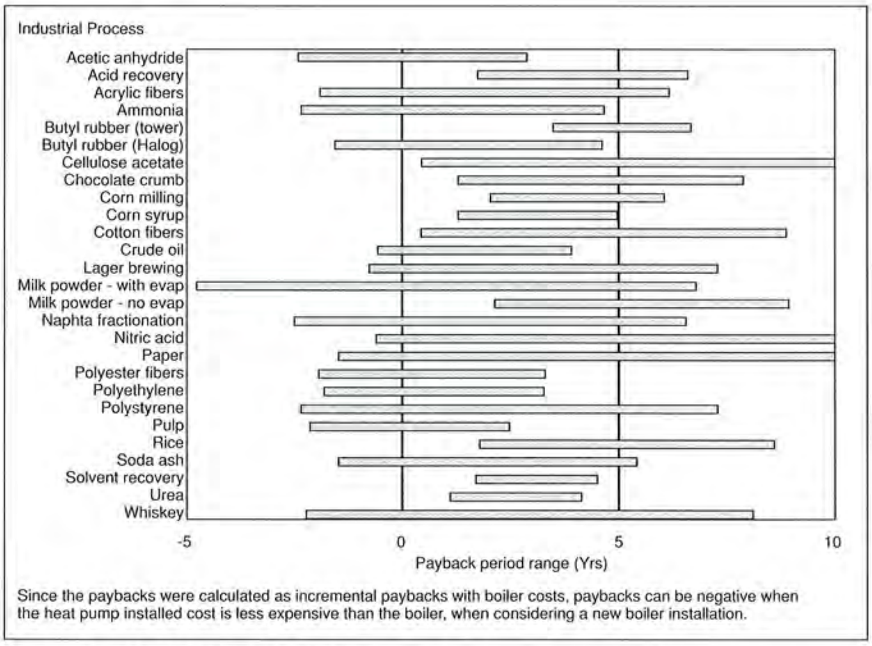

Figure 5: IHP Payback Period Ranges .

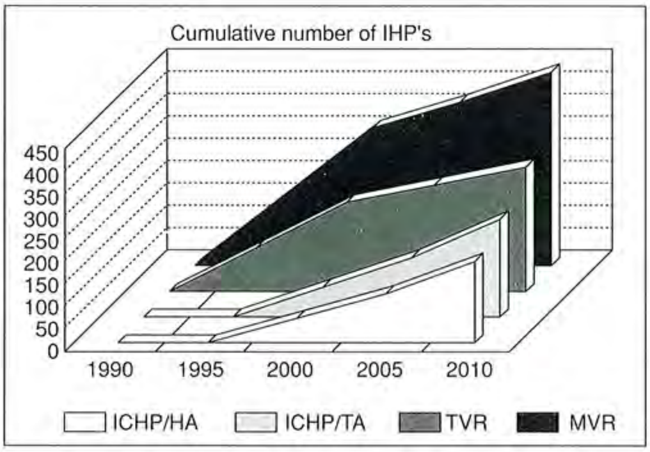

Figure 6: US Market Development of IHPs.

Using the respective equipment energy efficiency (Figure 2) and equipment costs (Figure 3) for the four types of IHPs and a boiler, a payback period for each type of IHP was calculated compared to a boiler. Those processes where IHPs were most economic compared to boilers, and where the IHP usually exhibited a payback period of three years or less, were selected (27 total) for market penetration analysis (see Figure 5).

Market penetration of IHPs in the 27 selected processes was projected to the year 2010. An average annual growth of 4 % for fuel prices and 0.5 % for electricity prices was assumed, together with an annual US industrial growth rate of 1.5 %. For the ICHP, its commercial readiness was assumed to be in 1994. Market penetration analysis was limited to IHPs capable of heat pump lifts to 55°C (100°F).

Using these conditions, the commercial development of IHPs, in the 27 selected processes in the US, is projected to be 1,110 IHP units by the year 2010 (see Figure 6). These 1,110 units will include 400 ICHPs, 430 MVRs, and 280 TVRs. Based on the types of processes evaluated, most of the IHP installations will be in the chemical industry (684 units). The food processing, pulp and paper, and petroleum refining industry are projected to have 184, 168, and 71 units, respectively.

US Energy Conservation with ICHPs

The implementation of over 1,100 IHPs will yield substantial energy conservation. Annual energy savings of 211 million GJ (200 trillion BTU) from all IHPs, and 72 million GJ (68 trillion BTU) from ICHPs, are projected (see Figure 7). This translates to almost a billion US 1990 dollars in annual energy cost savings. Further screening of other processes will identify more IHP or ICHP opportunities.

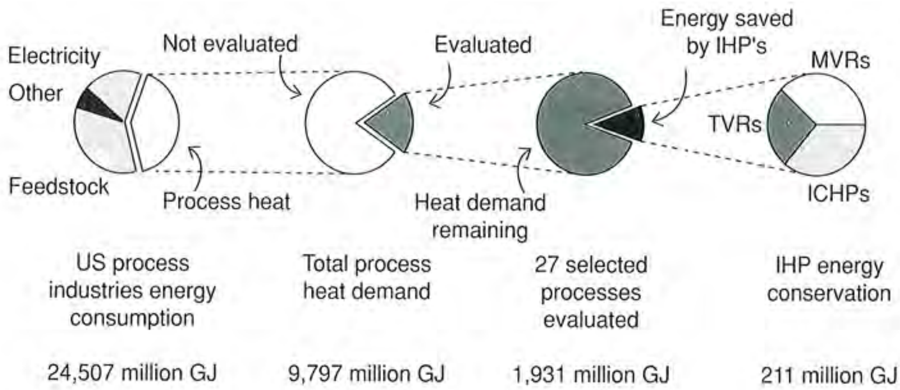

Figure 7: Annual US Energy Conservation with IHPs (Year 2010).

Conclusions

The market penetration of ICHPs holds the promise of substantial energy conservation within the US. The acceptance of the ICHP by US industry will depend on a number of factors:

- Industry must firstly, more fully realise the benefits of heat pumps in processes.
- ICHPs must prove economic and reliable.
- Full potential of ICHP technology will not be realised until higher temperature capability (e.g., to 250°C) is demonstrated to work reliably.
- Industrial demonstrations are needed in a petroleum refinery, a pulp & paper plant, a chemical processing plant, and a food processing plant.
- More companies which market ICHPs are needed.

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The Columbia Gas Double-Effect Absorption Heat Pump (DEAHP)

*H.C. Meacham, F.B. Cook and S.E. Petty

Summary

The Columbia Gas System Service Corporation is funding the development of a high-efficiency, reversible absorption heat pump for the residential market. This heat pump would benefit residential natural gas customers by providing year-round space conditioning for about the same annual energy consumption and cost as space heating alone with conventional natural gas warm air furnaces and boilers. The natural gas utility serving those customers would also benefit by preserving its annual gas load, reducing winter peak consumption, and shifting on-peak winter load to the off-peak summer cooling period. The DEAHP is also environmentally more acceptable since it uses no CFCs.

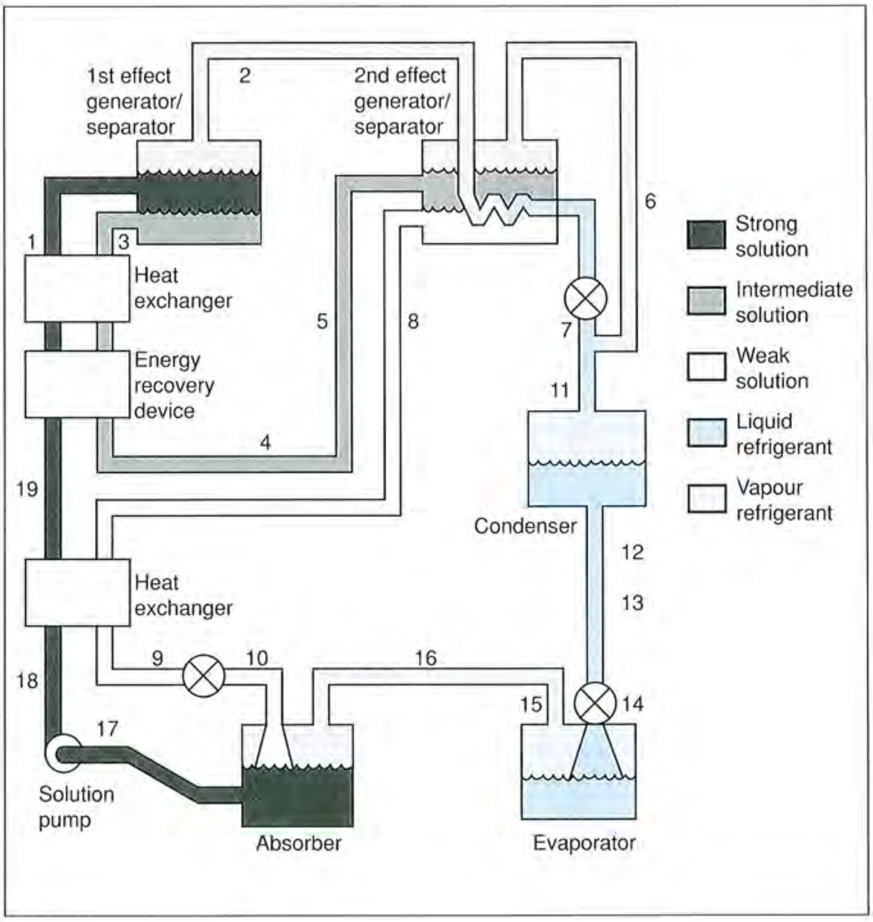
Columbia's gas heat pump concept is a double-effect absorption cycle using a unique solution pair consisting of ammonia (NH_3) and sodium thiocyanate (NaSCN). The nominal three-ton heat pump provides 10.5 kW (36,000 Btu/h) of cooling at an outdoor temperature of 35°C (95°F) and 21 kW (72,000 Btu/h) of heating at 8°C (47°F) outdoors. The heat pump performance targets are a cooling coefficient of performance (COP) of 0.80 and a heating COP of 1.50, including parasitic electric power consumption. The Seasonal Performance Factor targets are 0.72 for cooling and 1.35 for heating, including electric power consumption. In many US locations, a gas heat pump providing such performance would reduce the cost of heating an average residence by 33% compared to a high-efficiency condensing gas furnace, and by 50% compared to standard gas furnaces. It would also provide space cooling at approx. twice the efficiency of commercially available gas air-conditioners.

Double-Effect Absorption Cycle

The double-effect absorption cycle was chosen for its high efficiency compared to single-effect cycles, and for its inherent reliability compared to engine-driven cycles. The efficiency gain over single-effect ammonia-water cycles is more than 50%, and the solution pair provides considerable design simplification by eliminating rectifiers and analysers. Absorption cycles traditionally have offered significantly higher reliability and less periodic maintenance than gas engine-driven systems because they have fewer moving parts, less critical ignition systems, and simpler lubrication requirements at comparable initial equipment cost.

Figure 1 illustrates the Columbia's double-effect generator cycle. Beginning with line 1, preheated rich solution (that is, it has a high concentration of refrigerant) enters the first generator, where it is heated by an external gas flame. As the solution is heated, refrigerant is boiled off and exits through line 2 as a hot, high-pressure vapour. The weakened, or intermediate solution leaves the primary generator, line 3, and pre-heats the rich solution in the first of two solution heat exchangers. That intermediate solution then enters the second generator through line 5 after

Figure 1: Double-Effect Absorption Cycle.



passing through an energy recovery (pressure-reducing) device. Heat is applied to the secondary generator from two sources. First, the high-pressure vapour releases heat by condensing in an internal heat exchanger, passing from line 2 to line 7. Second, additional heat is obtained by passing the products of combustion leaving the primary generator over the secondary generator. These heat inputs boil off additional refrigerant vapour which leaves through line 6, after passing through a separator. The weak (in refrigerant) solution leaves the secondary generator through line 8 and then heats the strong solution in the second of the solution heat exchangers. It then passes into the absorber, line 10, after passing through another pressure reducer. In the absorber, the low pressure weak solution is recombined with the low pressure refrigerant entering through line 16 and passes into the pump, line 17, where the pressure is raised.

The refrigerant side of the heat pump is similar to all Rankine cycle refrigeration cycles with the exception of having two incoming refrigerant streams and having a refrigerant heat exchanger. The condensed high-pressure refrigerant stream passes through a pressure reducer and is mixed with the intermediate-pressure vapour. Although the high pressure refrigerant does form some vapour upon pressure reduction and the intermediate pressure vapour is superheated, line 11 entering the condenser is a saturated mixture of liquid and vapour, generally less than 30% liquid by weight. The refrigerant is all condensed in the condenser, gives up heat, and is further subcooled in a refrigerant heat exchanger. The liquid refrigerant enters the evaporator through line 14 after passing through the last pressure reducer. In the evaporator, the refrigerant returns to the vapour phase by taking in heat and is then further superheated in the refrigerant heat exchanger. The low pressure, superheated refrigerant vapour then enters the absorber through line 16 and is absorbed in the

Table 1: Nominal External Heat Balance

Primary generator	-	+10.11 kW (+34,500 Btu/h)
Secondary generator	-	+ 0.44 kW (+1,500 Btu/h)
Condenser	-	- 7.33 kW (-25,000 Btu/h)
Evaporator	-	+10.55 kW (+36,000 Btu/h)
Absorber	-	-13.77 kW (-47,000 Btu/h)

Figure 2: Cooling COP (excluding parasitics).

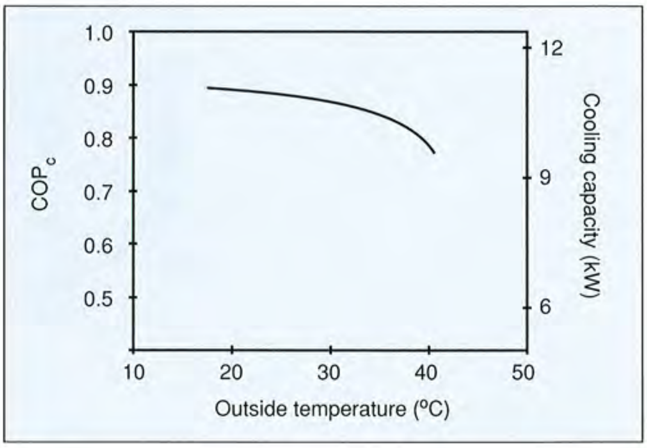
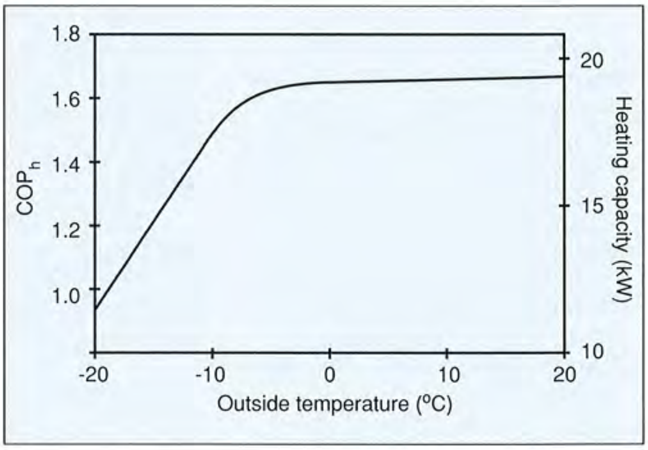


Figure 3: Heating COP (excluding parasitics).



solution. A nominal external heat balance is shown in Table 1.

Assuming a gas combustion efficiency of 85% and a parasitic electrical demand of 0.75 kW, the gross gas and electrical input is then 13.16 kW, resulting in a cooling COP of 0.80 and a heating COP of 1.50 at ARI rating points of 35°C and 8°C, respectively. Predicted performance curves for the other ambient temperatures are shown in Figures 2 and 3, based on computer simulations of the cycle. As is discussed later, actual performance is still slightly below the predicted performance.

Programme History

Development from 1978 onwards by Columbia Gas, together with several subcontractors, and co-funded by the Gas Research Institute, showed that the performance objectives of the double-effect refrigeration cycle, working with the unique solution pair NaSCN/NH_3, were attainable.

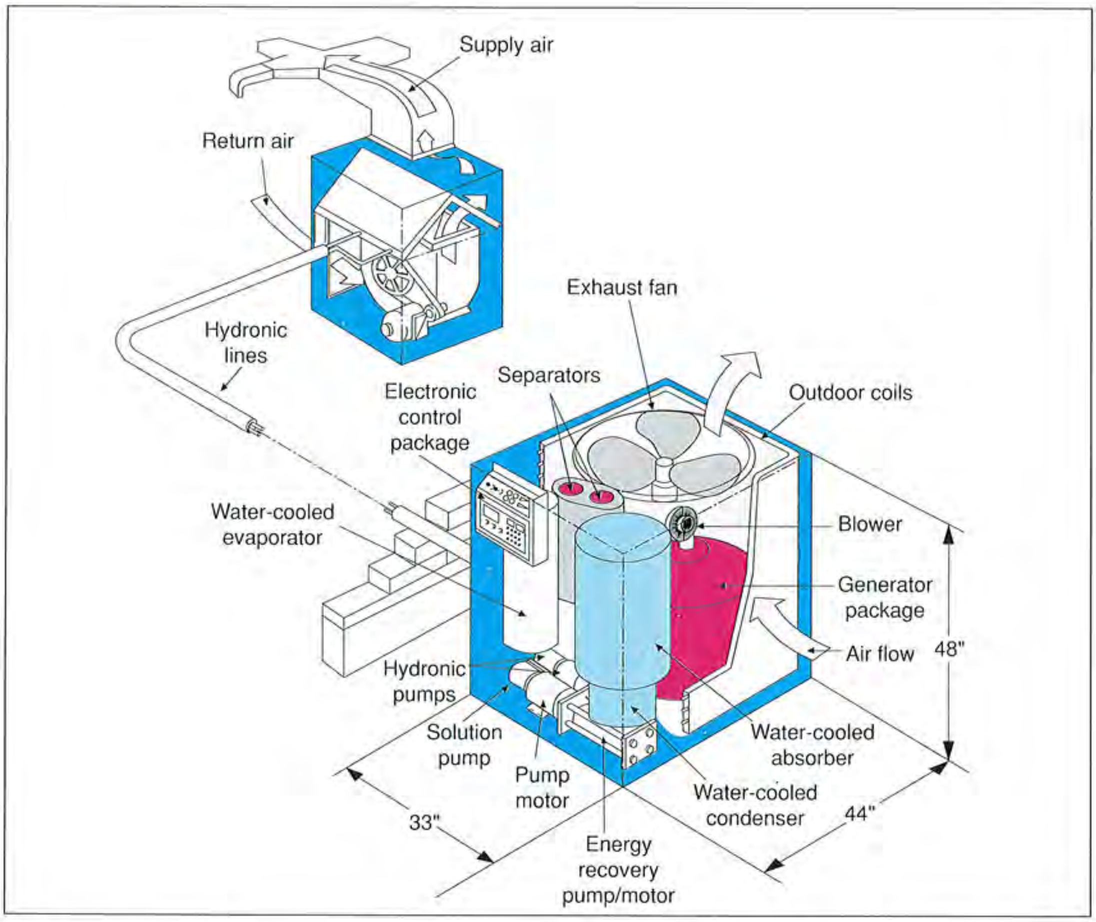


Figure 4: Overall Layout of the Columbia Gas DEAHP.

To date, Columbia has moved through a series of hardware development programs. The layout of the latest DEAHP is shown in Figure 4. Major components of the heat pump include the generator package, the absorber/ condenser package, the evaporator, the solution pump/motor, the energy recovery pump/motor, and the outdoor coil. More detail on the patented generator package is shown in Figure 5. This compact unit incorporates the gas burner and four heat exchangers which are arranged concentrically around the central axis. The heat exchangers include the primary generator, the high temperature heat exchanger, the secondary generator and the low temperature heat exchanger.

All four heat exchangers are formed from coiled tubing, and are separated by baffles which force the flue gasses from the central burner to successively pass over each of the four coils and emerge through outlets at the outer lower edge of the package.

This design is compact and efficient in terms of heat transfer, and also lends itself readily to changes in configuration. For example, in areas where a small "footprint" is required (as in Japan), the generator package can be made higher and smaller in diameter by winding the coils on smaller diameters. Conversely, if low height is a criterion (as in the US), the unit can be made lower and wider.

The condenser, absorber and evaporator are the "coil-in-can" type, incorporating coils of tubing encased in shells through which water or brine flows to transfer heat. Again, dimensions can easily be varied to give flexibility in the package design.

In absorption systems, the solution pump typically has been the "Achille's heel" of these devices. Therefore, early in the programme Columbia directed major effort toward the evaluation of numerous solution pump concepts from a variety of potential suppliers. Ultimately, a diaphragm pump built by a major pump manufacturer was selected for use in the system. In addition, to meet the target electrical goal (775 watts), a device was required to recover some of the solution pressure letdown energy. Such an energy recovery device has been designed, built, and tested.

Early prototypes of this recovery device were tested in the lab to demonstrate the concept, and second generation units are now undergoing endurance tests. The solution and energy recovery pumps are based on commercial pumps already in production, but adapted to the specific needs of the heat pump. Endurance tests of pumps are conducted in a separate laboratory. Solution pump life of over 20% of the design goal of 40,000 hours has been achieved and life testing of these pumps continues.

Facilities were also designed and built to make corrosion tests on materials under consideration for use in the various components of the heat pump. These and other tests are continuing at the facility of a subcontractor specialising in corrosion testing and analysis.

The majority of the work completed to date has been done in the cooling mode. The unit has demonstrated a system capacity of more than 11.02 kW (37,600 Btu/h) at a COP of slightly less than design (0.81). These performance values were obtained at slightly lower temperatures than the required rating point. Also, at the present stage of development, the parasitic electrical power is in the order of 1,200 watts. This increase from the goal of 775 watts only decreases the COP from 0.80 to 0.78.

In the first laboratory prototypes, the inability to meet design goals in cooling was traced to an undersized absorber, and to some flue gas bypassing in the "generator package." Additional laboratory testing was then conducted to establish heat transfer coefficients and pressure drop for the specific DEAHP configuration and cycle state points. Based on these results, a new generation of components was designed and built. These components are incorporated in the present laboratory heat pump, and tests are under way to establish performance over a range of ambient temperatures.

Another very important part of the DEAHP is the control system. The control system design is still evolving, but will consist basically of a microprocessor programmed to react to inputs from several sensors which measure system levels, temperatures, pressures, etc. Different modes of control (for example, subcooling versus level control) are now being evaluated in the laboratory runs. After the basic control technique is selected the control system design will be expanded to include operation from a thermostat.

An advantage of Columbia's gas-fired heat pump is its potential to vary heating or cooling energy by over-firing or under-firing the burner. This is particularly advantageous in the heating mode, where over-firing the full heating demand by 50% temperatures approximating -25°C can be met.

Furthermore, this heat can be delivered at air temperatures well above 40°C, alleviating one of the common complaints of conventional electric heat pumps in which delivered air temperatures are below body temperatures and feel cool to the occupants.

Heating work to date has been limited, primarily due to limitations in available room temperature at the current test location. At the present time a new packaged heat pump of the design shown in Figure 4 is being built. This unit will be installed in a controlled environmental chamber where both heating and cooling tests can be performed. These tests are scheduled to begin later this year.

Future Programme Plans

Current design activities are dedicated to decreasing the package size and developing a field unit ready for testing in 1991. This field test hardware will be developed by moving through a series of two increasingly smaller packaged units. Intensive effort during 1990 and 1991 will concentrate on construction and testing of self-contained units in environmental chambers, as well as continued development of the pumps, control system and corrosion-resistant materials. Columbia is currently seeking manufacturers/licensees of this technology to commercialise the DEAHP.

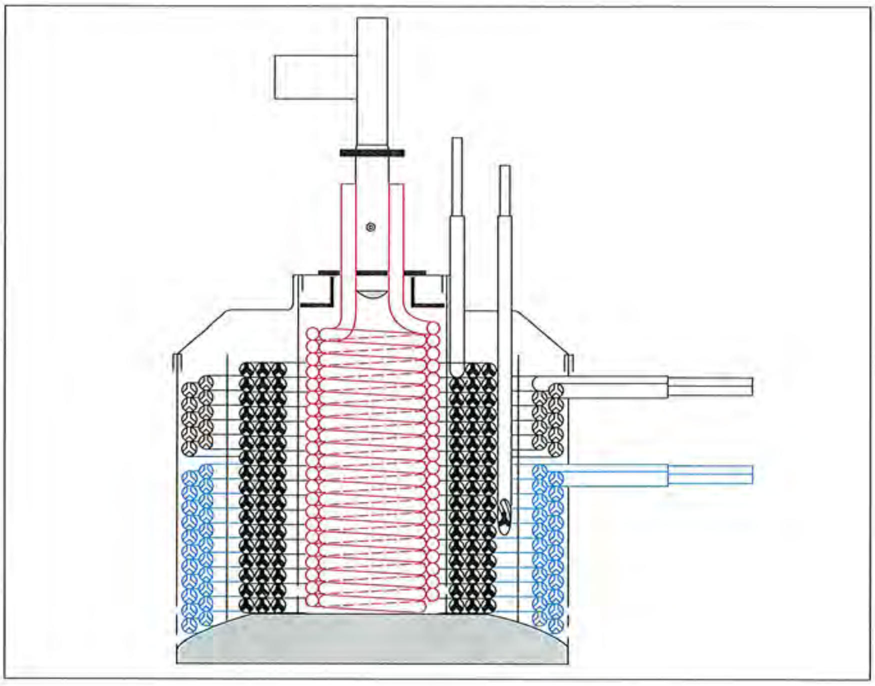


Figure 5:
Cross-Section of Generator Package.

*Authors:
H.C. Meacham, F.B. Cook, S.E. Petty, Columbia Gas, USA.

□

Waste Heat Powered Absorption Refrigerating Plant

*E. Podesser, P. Enzinger

Summary

Absorption refrigerating plants utilising waste heat are gaining importance as a result of environmental concern and of the continuously rising cost of electricity. The possibilities for absorption refrigerating plants have been investigated in the Austrian food industry. As a result, an NH_3/H_2O absorption refrigerating plant (rated 60 kW at -29°C) using the waste heat recovered from a 400 kW biogas engine was installed in a potato processing company in 1987. A computer aided data acquisition system was installed to monitor the plant performance. Operating experience has been gained over a period of two years.

Introduction

Waste heat is usually produced by energy conversion processes; examples are cooking, baking and frying in the food industry. Figure 1 shows possibilities of waste heat utilisation in general.

Direct recovery of heat is often an economical way of utilising waste heat. ORC processes (Organic Rankine Cycles) are sometimes used for power generation with vapour temperatures below 300°C. Thermo-electric generators provide direct current without moving parts; however, due to the high cost of the present technology, thermo-electric generators are only used for special applications.

The interest should be focused on the utilisation of waste heat by means of heat pump systems. However, with the aid of heat pumps no significant increase of the value of the heat can be reached. The price of such heat is lower than the price of low pressure steam (about 0.35 AS/kWh). (Note: 1 Austrian Shilling (AS) = approx. US$ 0.09).

If, however, refrigeration can be provided, e.g., for freezers, the price is equal to the price of electricity (1.00 to 1.5 AS/kWh). Therefore, this method of utilising waste heat is most attractive.

Process Principles

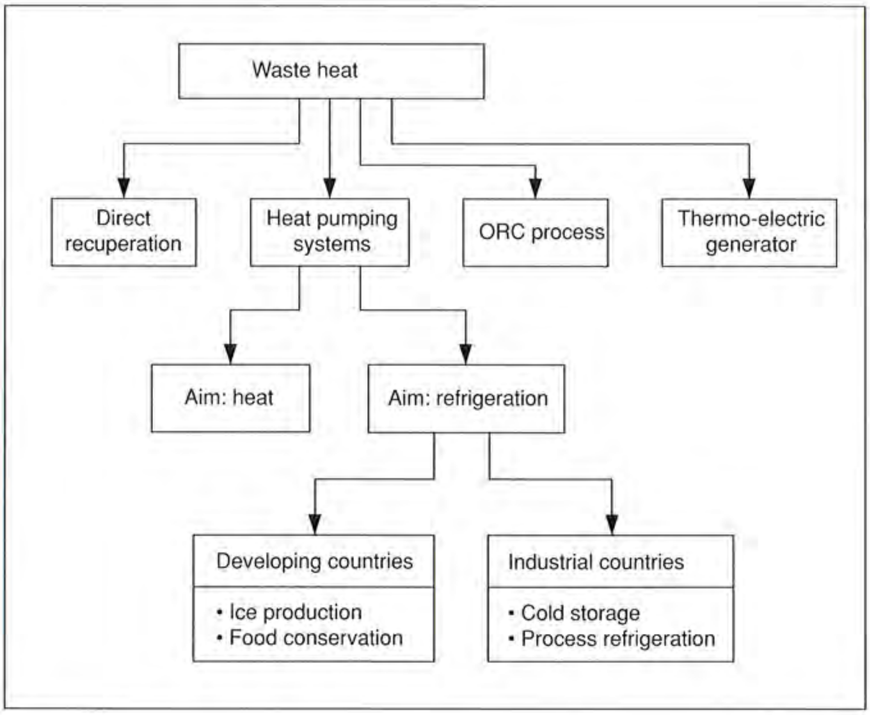
The most qualified system for the utilisation of waste heat in industry at temperatures from 90°C up to 130°C is the single-stage, continuously working absorption refrigerating machine. About 30 to 60% of the waste heat input is converted into refrigeration. The low percentage applies to low evaporation temperatures, e.g., -30°C, and the high percentage to climatisation.

Waste Heat Sources and Refrigeration Demand in the Food Industry

In the Austrian food industry investigations at selected enterprises regarding existing waste heat sources and refrigerating demand have been carried out. A report presenting the results is available[1]. The following sections of the food industry appear to offer good possibilities for the application of the proposed technology.

- **Large dairies**
  Generally waste heat exists at temperatures from 60°C up to 90°C. Refrigeration is required for milk cooling and for deep-frozen milk products.

Figure 1: Possibilities of Waste Heat Utilisations.



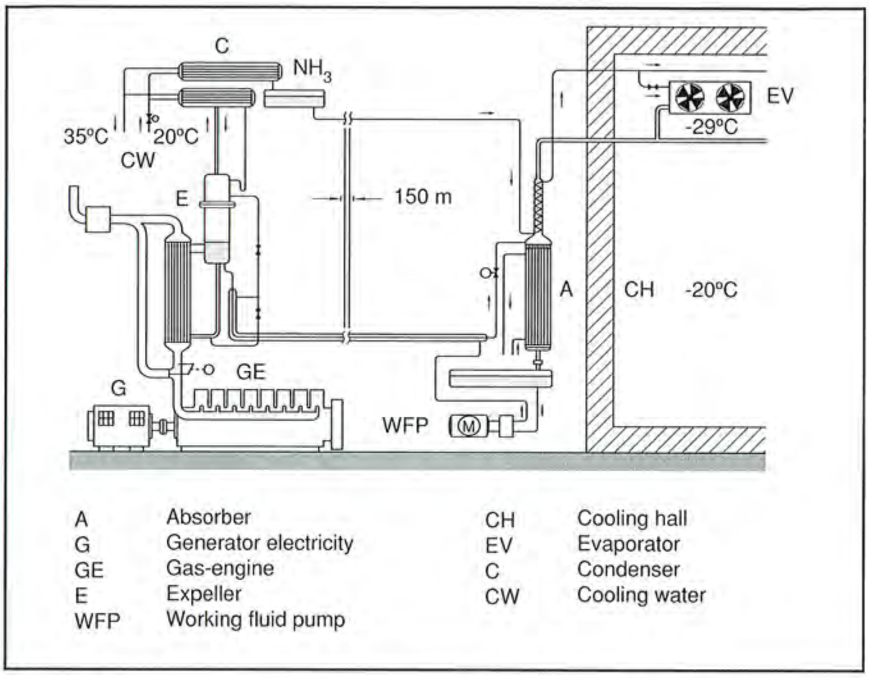


Figure 2: Waste heat driven absorption refrigerating plant.

- **Large Bakeries**
  Waste heat sources exist as exhaust vapours. However, most of them contain highly corrosive substances, which may lead to damage of the heat exchangers. The waste heat capacity of an industrial baking oven is about 300 kW. Confectionery products and white bakery products are stored deep-frozen. Therefore, large refrigerating capacity is required, too.

- **Breweries**
  Breweries are very large consumers of refrigeration. Large quantities of beer must be cooled and stored in a cool place. Vapours with high energy content occur at the top of the brew bottle during wort boiling.

- **Deep-frozen Food Manufacturers**
  Most factories produce a large amount of unused waste heat. In particular the heat capacity of exhaust vapours have been found to be in the range of some megawatt. Refrigeration demand for storage temperatures from -20°C to -30°C exist the year around.

Installation Example

The encouraging results of the investigation led to a pilot plant of industrial size. At a potato processing plant in Hollabrunn, Austria, about 3 tons of chips are manufactured per hour. The waste water from the production is polluted with small potato pieces and is cleaned by means of a biogas producing purification plant. The biogas gained is used by a gas engine (400 kW shaft power) for electric power generation. The hot exhaust gases are used to drive an NH_3/H_2O absorption refrigerating plant. Figure 2 shows the process and Figure 3 the energy flow chart. A 10,000 m³ hall for the storage of produced chips is cooled down to -20°C. The pilot plant was put in operation in March 1987[2].

A computer-aided data acquisition system was installed one year later[3]. At intervals of five minutes 36 characteristic values of the pilot plant operation were received and stored. The results of the monitoring enable an analysis of this kind of waste heat utilisation.

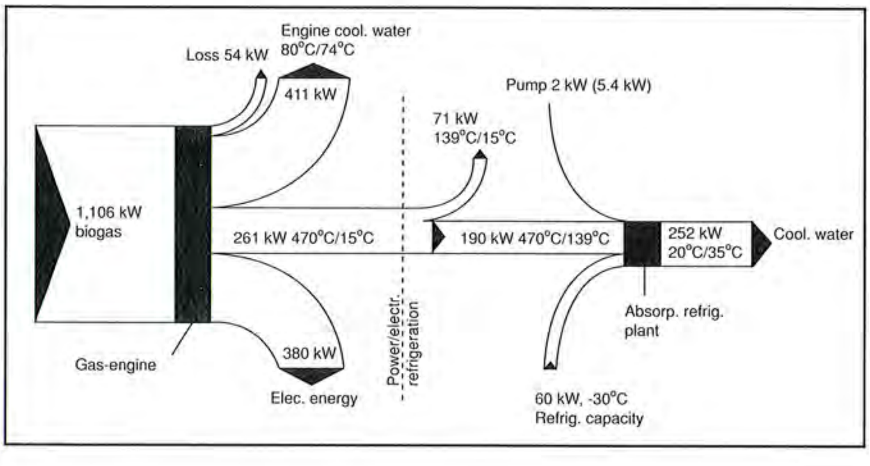


Figure 3: Energy flow chart of the waste heat driven absorption refrigerating plant (indicated temperatures are in and outlet temperatures of streams).

Cost/Benefit Analysis

Cost of the Plant:

For apparatus and control about AS 1,000,000 (approximately US$ 90,000) were invested and for mounting and piping about AS 200,000 (approximately US$ 18,000).

Benefit:

The maximum achievable benefit is calculated by means of the maximum possible annual cooling capacity produced (Q_o max. = 415,000 kWh at -29°C). On the basis of the present electricity tariff for industry a maximum profit of about AS 600,000(approx. US$ 54,000) could be achieved. However, computer monitoring shows that because of part load operation of the gas engine only about 40% of the maximum achievable annual benefit is reached. Operational problems led to a further decrease of operation time so that only 29% of the maximum possible benefit was achieved.

Conclusions and Recommendations

Process Aspects

In the food industry waste heat is frequently available as exhaust vapours, hot fluids or gases from cooking, baking and frying processes. The products often demand cooling capacity for storing in cooling halls. Therefore, in such cases utilisation of waste heat seems technically feasible and economically profitable. Nevertheless, the following conditions should be fulfilled:

- The waste heat offered and the cooling capacity demanded should exist simultaneously.
- The distance between the heat source and the refrigerating demand should not be more than 200 m. (In the pilot plant discussed above the absorption refrigerating plant is divided into a high and a low pressure section; the solution heat exchanger is designed as a coaxial connecting tube.)

Economic Aspects

From the economic point of view the following conditions should be fulfilled:

- The plant should be in operation more than 5,000 hours per year.
- The evaporation temperature needed should be lower than -20°C, since the price of refrigerating capacity depends on the temperature.
- Low maintenance and service must be secured by a reliable absorption refrigerating technique and automatic control.

Technical Aspects

The following experience with the pilot plant were made:

- Operational disturbances are reduced by constant working conditions, e.g., the inlet temperature and pressure of the cooling water of the absorption refrigerating plant must be relatively constant.
- Rapid and large fluctuations in waste heat supply conditions should be reduced by specially designed expellers or buffers.
- The refrigeration process with ammonia and water as a working pair allows the utilisation of cheap steels for the apparatus. The cooling water or the waste heat streams generally contain corrosive substances, which require higher steel qualities.
- Working fluid pumps with stuffing boxes are not maintenance-free. Cavitation and pollution of the working medium entail repair work.
- Pollution of the hot waste stream may lead to sedimentation and obstructions at the heat exchanger in the expeller.
- Spare parts, e.g., for armatures, sensors and control, must be easily available for the plant owner. Interruption of operation is thereby minimised.
- Knowledge of technology and engineering of the process must be transferred to the plant owner, because the technicians servicing compression refrigerating installations are generally not able to service absorption refrigerating plants.

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[2] *Enzinger, P.; Podesser, E.; Monschein, W.; Taferner, I.: "Planung, Ausschreibung, Bauüberwachung und Inbetriebnahme der Tiefkühlabsorptionskälteanlage"; Bericht ifu-B-12-87, im Auftrag des Bundesministeriums für Wissenschaft und Forschung, 1987.*

[3] *Podesser, E.; Enzinger, P.: "Computerunterstützte Datenerfassung bei einer abwärmebetriebenen Absorptionskälteanlage"; Forschungsgesellschaft Joanneum Ges.m.b.H., Bericht-Nr.: IEF-B-02/ 90, 1990.*

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Industrial Engine-Driven Heat Pumps in Japan

*S. Sakashita

Summary

A decrease in oil prices beginning in the autumn of 1986 has had a negative effect on the interest for industrial heat pumps. In the case of the engine-driven heat pump, which uses heavy fuel oil or gasoline, no running cost inversion (operation of the heat pump at a loss) is evident but the decrease in energy costs has to a considerable extent, reduced, the low running cost advantage of the device.

As a result, drawbacks such as high initial cost and high maintenance costs, essentially inseparable from the engine-driven heat pump, have limited the profitability of the system and as a result sales of this type of heat pump have suffered, as is the case for electric motor-driven heat pumps. Improved running costs, based on effective use of waste heat, as well as reduced initial costs are, therefore, key elements in future popularisation of the engine-driven heat pump.

Application of a compound system of high efficiency, as well as the use of larger systems, which have the advantage of lower initial costs began in 1988. This article introduces details of such engine-driven heat pump systems and the prospects for future development.

Development of Sales

According to data in "Report on Industrial Heat Pump Operation Research" published by the Heat Pump Technology Development Center in March 1988, 47 sets of industrial engine-driven heat pumps have been installed as of March 1987. The following data on installed systems are based on Mayekawa shipment records as no other information on installed units and the year of introduction is available.

As Figure 1 shows, shipments of engine-driven heat pumps of up to shaft power 200 kW increased slowly but steadily until 1986. However, due to the decline in oil prices which began in late 1986 shipments dropped to zero in 1987. As a result, shipment of co-generation compound systems over 500 kW has increased. This points to a qualitative change in engine-driven heat pumps in response to changing energy prices.

Compound Systems

Problems with Engine-driven Heat Pumps

The heat pump system is capable of providing effective utilisation of primary energy, but suffers from the following drawbacks:

- High initial cost;
- Large floor space required;
- Lower reliability in comparison with the electric-driven type;
- Greater operating complexity in comparison with electric-driven type;
- Troublesome maintenance (cost and labour);
- Insufficient response to heat pump load changes. (To deal with load changes, a 10-20% greater engine power must be installed. However, such an engine normally runs at partial load which leads to higher fuel costs.)

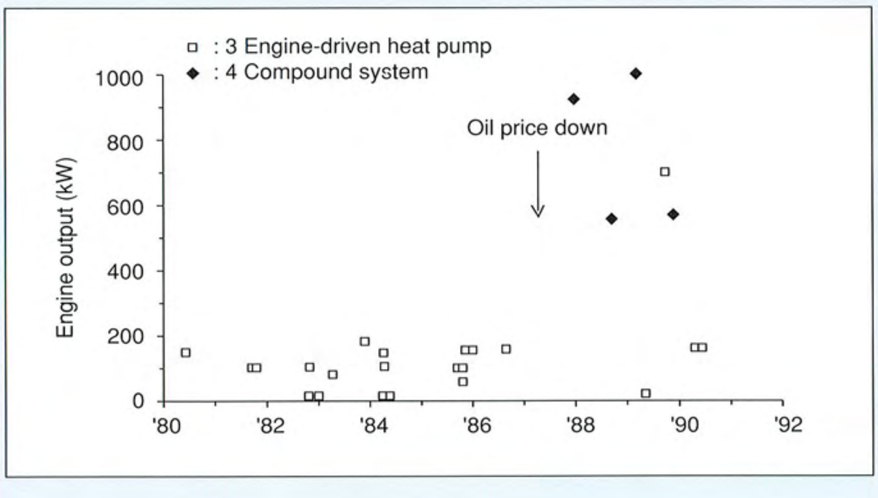


Figure 1: Shipments of MYCOM Engine-driven Heat Pumps.

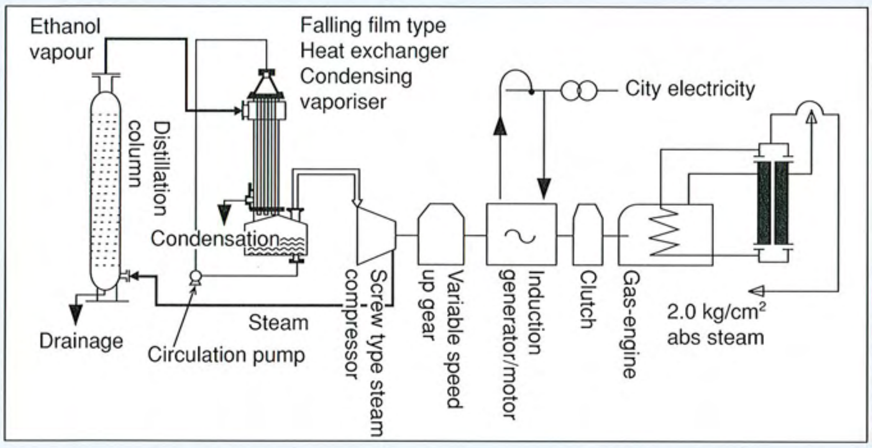


Figure 2: Flow sheet of the heat pump and co-generation systems at Matsudo Factory, Takara Shuzo Co., Ltd.

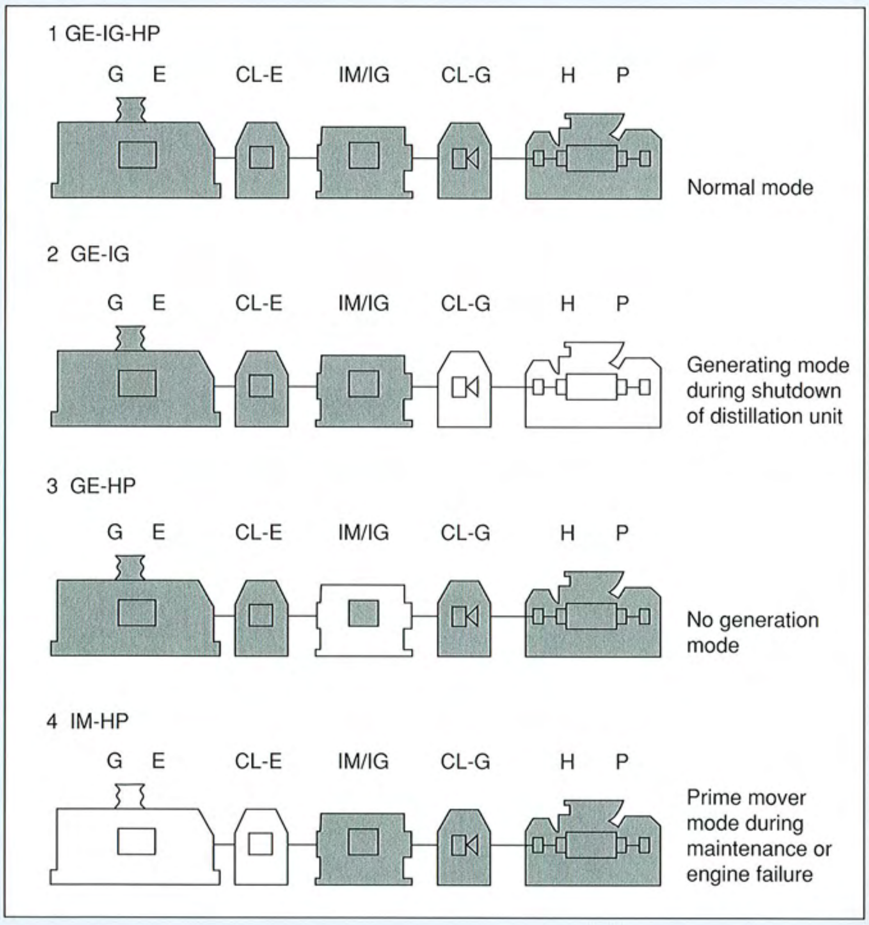


Figure 3: Operating Mode Diagram.

GE = Gas-engine
CL-E = Clutch
IM/IG = Induction Motor/ Induction Generator
CL-G = Variable Speed-up Gear
HP = Heat Pump

Operating modes:

1. **GE-IG-HP** = Gas-engine-Induction Generator-Heat Pump.
2. **GE-IG** = Gas-engine-Induction Generator.
3. **GE-HP** = Gas-engine-Heat Pump.
4. **IM-HP** = Induction Motor-Heat Pump.

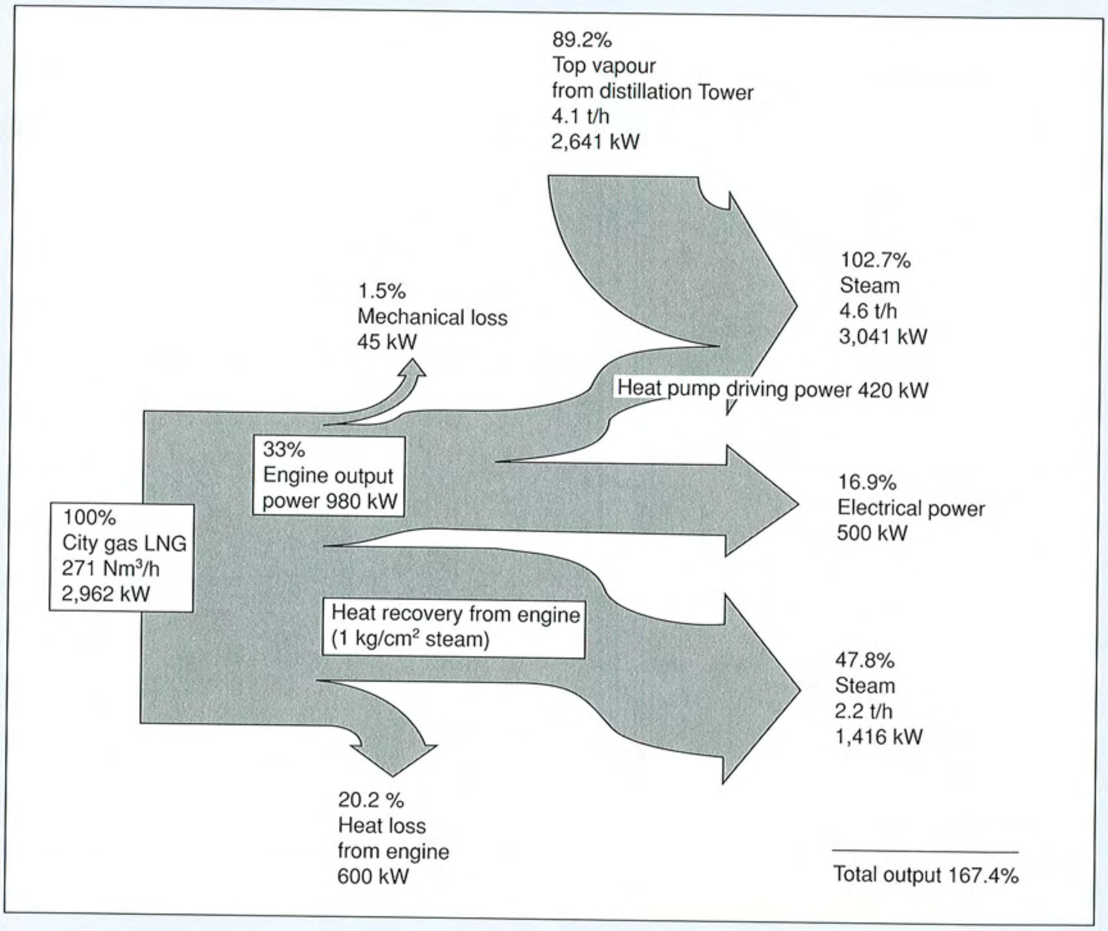
Most of these drawbacks can be overcome using a compound heat pump co-generation system. Such a system, with an induction motor and a generator located between the engine and the heat pump, was first installed at the Matsudo Factory of Takara Shuzo Co., Ltd. in 1988 and similar systems have since been introduced by other firms.

System Installed at the Matsudo Factory of Takara Shuzo Co., Ltd.

As shown in Figure 2, this heat pump system combines a large industrial heat pump for recovering heat from an alcohol distiller, with a 920 kW gas engine co-generation system. The heat pump and co-generation systems are joined by connecting the drive shaft of the steam compression system heat pump with the shaft end of the 920 kW induction generator. The induction generator, located between the engine and the heat pump, functions as a load balancing device. Almost half of the gas engine output power, that is 420 kW, is directly transmitted to the heat pump. The remaining 500 kW is used for electricity generation.

The following advantages are derived from installation of the induction generator between the engine and the heat pump:

Figure 4: Energy Flow Chart of the System



- As the induction generator provides load balance, any mechanical load change can be absorbed and, as a result, stable operation of both the engine and the heat pump is secured. In other words, the engine can always be operated at 100% load at maximum thermal efficiency.
- Power generation improves the cost merits of the system and, as a result, an improvement in initial cost performance can be achieved.
- When the engine is shut down for maintenance or in the case of a failure, the induction generator serves as the prime mover. This back-up feature assures high reliability.
- . The induction generator serves both as a driving apparatus and a generator, this providing cost and installation space savings.

Moreover, four operating modes, shown in Figure 3, can be utilised by engaging/disengaging the clutch providing optimum performance under the various operating conditions of the plant. The energy flow chart is given in Figure 4 which shows the heat efficiency of the system being 167%.

Conclusions

As the example reveals, engine-driven heat pump systems have been greatly improved to provide better efficiency. Progress in this area is continuing. Whilst most of the drawbacks of earlier engine-driven systems have been overcome, the problem of high maintenance costs remains. One aspect of this problem is that the sudden interest in co-generation systems in recent years has resulted in a shortage of skilled maintenance personnel and a substantial increase in labour costs. As maintenance costs continue to rise, this may develop into a serious problem in the future. Nevertheless, development of systems of even higher efficiency and lower cost will continue, as will efforts to reduce maintenance costs.

Author:

**S. Sakashita, Mayekawa MFG Co., Tokyo, Thermo Engineering Division.*

□

Table 1 : Cases Studied in Annex IX

Case	I	II	III	IV	V	VI	VII
Country	Belgium	Finland	Japan	Japan	Netherlands	Sweden	Italy
Yr. of Installation	1985	1982	-	1986	1985	1981	1986
Type	MVR, steam Electrical, single stage, centrifugal compressor	MVR, steam Electrical, single stage, centrifugal, compressor	Heat pump steam Elecrical 2-stage centrifugal compressor	Heat pump steam screw compressor	Heat transformer H_2O/LiBr	MRV, ethanol/ water (55/45) Electrical, 3-stage centrifugal compressor	Heat pump 2-stage centrifugal compressor
Source	Lime slaking, soda ash densification	Internal heat in black liquor evaporation plant	Top vapour	Internal heat recovery in ethanol distillation plant	Steam 103°C	Internal heat recovery in ethanol concentration plant	chemical process
Sink	Ammonia stripper		Low pressure steam		Steam 4.76 bar, 145°C		Low pressure Steam
Thermal capacity	10.8 MW th	31 MW th	0.334 MW th	2.3 MW th	6.42 MW th	2.3 MW th	2.45 MWth
Power demand	560 kW el	1100 kW el	56 kW el	420 kW el	13.78 MW th	450 kW el	974 kW el
COP; Excergetic efficiency	14.4 ; 0.53	Design : 28 ; 0.52 Full load : 27 ; 0.50 70% load : 23 ; 0.43	5.96 ; 0.53	5.5 ; 0.47	0.49 ; 0.64	6.4 ; 0.42[3]	2.37 ; 0.43
Running hrs/yr	8760 h/yr	-	-	~8000 h/yr	~7800 h/yr	3500 h/yr	6000 h/yr
Payback period	1985 : 1 yr 1987 : 4-5 yr[1]	-	-	-	1985 : 2.5 yr 1987 : 6.5 yr[2]	1985 : 2.4 yr 1987 : 4.0 yr	-
Po, To	0.675 bar, 89°C	1.01 bar, 103 °C	0.32 bar, 70°C	0.36 bar, 73°C	Steam prod.: 145°C Waste steam supplied: 103°C cooling water: 10°C	0.87 bar, 80°C	4.93 bar, 53.5°C
Pc Tc	1.1 bar, -	1.43 bar, -	1.23 bar, 105°C	1.28 bar, 105°C		3.1 bar, 105°C	24.47, 129°C
Output	13 ton steam/h	50 ton steam/h		3.6 ton steam/h	11.1 ton steam/h	5.6 ton/h	
Operational Experience	1. Very reliable 2. No unexpected problem	1. Apart from some initial problems now operating well 2. High availability	1. No corrosion 2. Stable operation 3. No deterioration of compressor oil. 4. No excessive wear.	1. Reliable continuous operation 2. Mean time between failures > 5,000h. 3. 63.3% energy saving.	1.1st 7 months trouble free operation according to design. 2. Later on corrosion problems[2]	1. 7 years of operation with-out problems during start-up 2. Minor problems. 3. Compressor revision frequency from 1 per yr to 1 per 2 years.	1. Initial problem of freon dissolution in oil during long shut downs. 2. Heat pump should be accepted by all levels of personnel to make successful operation possible.

Po, To = evaporation pressure / temperature.
Pc, Tc = condensation pressure / temperature.
MVR = mechanical vapour recompression.

1) = Increase of payback period also caused by reduced output of plant.
2) = Values of payback period based on 7,800 h/yr of operation. Not realised because of corrosion problem.
3) = Figure based on single measurement; transmitters not calibrated.

Annex IX Case Studies Summary

*P.A. Oostendorp

As announced in Vol. 8, No. 3 of the IEA HPC Newsletter, the final report of Annex IX of the Implementing Agreement on Advanced Heat Pumps, compiled by Prof. J. Berghmans, has been published. The report describes the 'state-of-the-art' of high temperature industrial heat pumps. The report includes eight case studies that analyse the technical and economic performance of existing systems. Of these, seven are actually in operation in the field and the results are briefly summarised here. The eighth case study merely describes a research project aimed at the development of a high temperature absorption fluid (Alkitrate) in the USA. Case V (heat transformer, the Netherlands), is described in detail in the article by J.W.J. Bouma on page 12 of this Newsletter.

Table 1 gives the main characteristics and performance of the systems. For the reasons mentioned above, Case VIII has not been included. However, please refer to the article by L.A. Howe, on page 7 of this Newsletter, which describes the features of Alkitrate.

From the year of installation it can be seen that the investment decisions for all the systems were made before 1985, the year in which the steady increase of fuel prices ended. The table presents a number of examples of how the payback period increases with decreasing fuel prices (I, V and VI). If it is generally true that industry only accepts payback periods not exceeding 2-3 years (as stated in the report), even systems with very high COP values become economically unattractive at 1987 fuel prices. As the additional energy saving gained by any further technical improvement can only be marginal, the conclusion is that it is very difficult to influence the rate of implementation of these systems by technical improvements. The effect of the exogenic factor of energy prices is predominant and can only be balanced by lower investments costs and/or by subsidies.

Although start-up problems in a number of cases have been reported, apart from the heat transformer the systems generally perform reliably and according to design specifications. The heat transformer showed severe corrosion problems mainly due to the high temperatures that are relatively innovative for the fluid pair H_2O/LiBr.

The report concludes that there is still a gap between the temperatures that are actually applied in closed loop industrial heat pump systems (most of them operate below 120°C), and the temperatures occurring in many industrial processes. Although it is technically possible to reach temperatures up to 200°C (case studies III and VIII), there is still a lot of uncertainty about the economics of these systems.

*Summary written by: *P.A. Oostendorp HPC, TNO.*

Meeting Reports

*J.W.J. Bouma

Heat Pump Research Activities

The 3rd International Workshop at the Graz University of Technology

At the workshop, held from 24 to 26 September, 1990 in Graz, Austria, 51 papers were presented in the following categories:

- **fundamental research** (10 papers):
  - thermodynamic properties of refrigerant mixtures;
  - heat/mass transfer and pressure drop phenomena in evaporators, absorbers;
  - measurement of fluid state properties.
- **compression heat pumps** (11 papers):
  - hybrid system (wet compression);
  - direct expansion ground coils (testing/modelling);
  - transient behaviour;
  - natural gas engine-driven systems;
  - compressor modelling (inverter scroll/screw).
- **CFC replacement** (4 papers):
  - assessment of CFC replacements R134a and R123, and industrial refrigerants R160 and R280a (for high temperature);
  - effect of new fluids on heat pump development.
- **sorption systems** (12 papers):
  - continuous/periodically operating absorption; adsorption (carbon-ammonia; methanol-water; ammonia-water);
  - high temperature (180°C) and R21-DMF heat transformer;
  - exergy/economic aspects;
  - thermally-driven solution pump/integrated absorption modules (tube type);
  - two-stage heat pump/transformer;
  - glycerol-water system.
- **integration into technical/commercial environment** (14 papers):
  - high temperature applications and markets;
  - high performance new sorption cycles for space conditioning;
  - industrial heat recovery;
  - sanitary hot water production;
  - process integration;
  - monitoring of field experiments;
  - solar-assisted systems;
  - ice-storage systems;
  - variable speed systems.

The papers were briefly introduced orally and supported by posters. Reporters summarised the discussions on each category.

The workshop provided a forum for exchange of mainly research-oriented information in the heat pump field. Insight was also given into ongoing work in some south and east european countries like Yugoslavia and Hungary. It was concluded that considerable improvement in performance of heat pumps, without increase in capital costs, can be achieved, especially in absorption-type systems. The proceedings of the workshop will be published in 1991.

Conference on Heat Pumps in Cold Climates

** J.W.J. Bouma*

On 13 and 14 August, 1990, the above conference was held in Moncton, Canada. Cold climates have always presented a challenge to heat pump equipment and the heat pump community. However, as was proved at the conference, heat pumps in cold climates have prospects. A selection of papers have been summarised below.

- In a paper by Nova Scotia Power Corp. the results of a project with a bivalent heat pump, i.e. an air-to-air heat pump, and a high efficiency condensing gas propane furnace, were presented. It was shown that the bivalent heat pump demonstrated the ability to provide benefits to both the utility and its customers when installed as an alternative to conventional resistance back-up pumps. The unique combination of energy sources makes this heat pump ideally suited to cold climate applications.

- Experiences with design and operation of space conditioning heat pumps in Canada was the topic discussed in two papers. In a paper by Caneta Research findings from a number of field studies and owner surveys on in-situ performance, reliability and customer satisfaction were presented. A definition for successful applications in cold climates was developed.

- Alderson Engineering has specialised in the commercial application of ground-source heat pump systems in cold climates. The design process was discussed and it was stated that existing design manuals do not provide all the information needed for central and decentralised loop systems.

- Improvements in components and control was dealt with by a number of speakers:

  - The Trane Co. introduced variable speed systems and their benefits to users. These systems offer greater comfort at higher seasonal efficiency through continuous capacity modulation.

  - Ontario Hydro is active in developing specialised hardware and technology for heat pumps operating in cold climates. An electronic control board for the CEA cold climate heat pump was designed jointly with the Canadian Electrical Association. It is claimed that 2 to 4 kW of demand per customer can be saved by the high performance heat pump and comfort will increase.

  - Allen Associates has been developing a small scale HVAC system that captures waste heat from within a low energy house. The heart of the Solmate Integrated Mechanical System is a liquid-to-liquid heat pump coupled, on the evaporator side, to a small (450 l) ice phase-change thermal storage. The system recovers energy from indoor air during air-conditioning, from continuously exhausting ventilation air, and from grey water for delivery to storage via chilled liquid circulation. The stored heat (0°C) is extracted by the heat pump for delivery to a 250 l hot water tank. The hot water satisfies both domestic and space heating requirements. The heat output is 6 kW with a COP of 3 at typical operating conditions. Production in limited quantities is expected to commence in early 1991.

  - Performance improvement of ground-coupled heat pumps was proved by Water Furnace International, USA. The advanced units developed utilise scroll and rotary compressors, variable speed DC fan motors, microprocessor controls, and enhanced heat exchange surfaces. The products were developed while responding to the requirements and wishes of dealers, customers and installers. Water Furnace claims that the COP and EER values are 40 to 60% higher than those for present industrial equipment (COP: 2.9-3.9 at -1.1°C, 3.3 to 4.8 at 10°C, 3.9 to 5.5 at 21.1°C).

- The prospects for international development of heat pump component technology for improved performance in cold climates was the title of a paper by Energy International, USA. Japanese developments in commercial and residential component technologies specifically suited for use in low temperature regions were shown in particular. This Japanese technology specifically uses inverters.

- The Canadian Earth Energy Association discussed the development of the industrial infrastructure that deals with standards, accreditation, certification and codes of practice in relation to earth energy. A unique relationship between the industry and the electricity utilities has been achieved, one that respects the joint need for continued quality assurance and consumer satisfaction in the market place. CEEA started in 1980 and has developed a databank on installations and their performance. 130 MW earth-coupled systems were installed in 1990 and 240 MW capacity is expected for 1996.

- The North American market for air-source heat pumps was discussed by Lennox Industries, USA. It was stated that the use of heat pumps in northern markets is increasing. It was shown that heat pumps have become a cost effective and efficient means for comfort control outside traditional southern markets. The average SEER of 9.1 in 1989 as compared to 8.5 in 1985 substantiates this. Further progress with variable output and thermal energy storage comfort conditioning is expected in the next two to five years.

The proceedings of the conference will be published before the end of 1990 and can be obtained by sending a cheque or money order for US$ 50 or CAN $ 60, made payable to Caneta Research Inc., 6981 Millcreek Drive, Unit 28, Mississauga, Ontario, Canada L5N 6B8.
Fax: +1-416-542-3160.

Workshop 'Concepts for Energy Savings in Heat Pumps and Refrigeration Systems'

**J.W.J. Bouma*

The workshop was held under the auspices of the International Institute of Refrigeration, Commission E2. Below is a summary of selected papers:

- Prof. Lorentzen addressed the CFC issue in relation to ozone depletion and the greenhouse effect in a presentation on thermodynamic heating. It was stated that CFCs should be abandoned right away and concentration should be on media, which are completely free of the increase in global warming effect. The impact of CFCs on ozone depletion is of considerably less importance. Acceptance of flammable and even poisonous substances was advocated. In addition, it was stated that the heat pump industry will have to pay more attention to energy efficiency because present heat pumps are capable of great improvement in performance and they are the future universal method of residential heating.

- Prof. Granryd gave an explanation on the dominating parameters that influence the energy use of a heat pump system and what should be done to improve efficiency. The most important factor however, is the careful monitoring of a system by motivated people.

- Heat recovery from refrigeration plants and the price/ performance consequences of implementation were presented by the Royal Institute of Technology, Stockholm. It was estimated that the payback period in these cases is approximately 2 years.

- Recreation centres offer good conditions for applying heat pumps, according to the presentation by Graz University/Elin. These centres are provided with sophisticated, carefully designed integrated energy systems, of which the heat pump is a part. Heat recovery is the main application here. In the paper, cases are handled and the merits of these successful installations presented.

- Prof. Bäckström discussed experiences with large-scale Swedish heat pumps. The main conclusions, based on 3 to 8 years of operation, are:
  - high reliability is more important than maximum SPF;
  - service availability is essential;
  - configurations should be as simple as possible;
  - the lack of a suitable R12 substitute is a main obstacle;
  - high temperature levels in existing heat distribution systems are very disadvantageous for heat pumps.

- A presentation regarding heat recovery from ammonia plants was given by Sabroe, Denmark. Examples of existing installations in a slaughterhouse, a bacon factory and a plastic manufacturing plant were discussed. However, energy prices put the economy of these systems under pressure.

- In a paper by the Gas Research Institute, USA an overview was presented of recent advances in gas-fired heat pumps.

- The performance of a 50 kW chemical heat pump test plant was reported on by the University of Perpignan, France. Tests have confirmed predicted performance values. A new reacting medium is under development which significantly improves the thermo-physical properties of system components and the system performance. The sizing of a 1 MW industrial unit will now become feasible.

- The Japanese Super Heat Pump Energy Accumulation System was reported by the Mechanical Engineering Laboratory, MITI. In the paper emphasis was on the interim evaluation of the project for super high performance compression heat pumps. It was reported that the 100 kW bench plant performed successfully. Pressed by energy saving requirements and environmental concern, the project will now focus on operation and testing with a 1 MW pilot plant to be completed by 1993.

- In a paper by the IEA Heat Pump Centre the work of the Centre in relation to information service on heat pumps and related technology was introduced. As the IIR addresses refrigeration, air-conditioning and heat pumps, co-operation and coordination can be beneficial to both organisations. Ways will be developed in order to achieve this.

The general conclusion is that a good overview of the state-of-the-art has been obtained through this workshop. Preprints of the papers are available from the HPC. The proceedings will be produced and published by the IIR.

**J.W.J. Bouma, IEA HPC.*

ASHRAE-Purdue CFC Conference: July 17-20, 1990.

**R.J.M. Van Gerwen*

The 1990 ASHRAE-Purdue CFC conference was held from July 17-20, 1990 at the Purdue University, West Lafayette, Indiana, USA, together with the USNC/IIR-Purdue Refrigeration Conference. The 41 papers on the CFC issue cover all topics of current interest: thermo-physical properties of new refrigerants; performance of systems with new refrigerants; refrigerant mixtures; alternative cycles; leak detection; leak prevention, etc. Seven of the papers were devoted to appropriate lubricants.

The attention of the refrigeration industry and research workers is primarily focused on the development of new refrigerants, especially HFC 134a as a replacement for CFC 12. Less attention was paid at this conference to other contributions to the solution of the CFC problem, such as emission prevention and alternative refrigerating cycles, when compared to the relative number of papers devoted to these topics. At the moment, most of the thermo-physical properties of HFC 134a are known. However, an appropriate lubricant is not available yet. Poly Alkylene Glycols (PAGs) are not completely satisfactory. Esters are mentioned as the most promising alternative.

The US authorities are more and more concerned with the relation between the refrigeration technology and the global warming effect. The global warming potential of several refrigerants is significant. On the other hand, the reduction of energy consumption of refrigeration plants substantially contributes to the reduction of CO_2 emissions. Therefore, reduction of energy consumption will be an important topic in the refrigerating technology for the coming years.

Please refer to the proceedings for more details.

** R.J.M. Van Gerwen, IEA HPC, TNO.*

HPC hosts meeting between National Teams of Japan and the Netherlands

**J.W.J. Bouma*

The Planning and Steering Committee of the Heat Pump Technology Center Japan (HPTCJ), representing the Japanese National Team, visited the Dutch National Team on 17 September, 1990 in Sittard. The aim of the meeting was to exchange information between both teams on operational and organisational matters, and to develop a structure for exchange of information. The Japanese delegation consisted of eight representatives from Toshiba, Mitsubishi Electric, Hitachi, Tokyo Electric Power, Shimizu, Taisei (both constructors) and the HPTCJ. From the Netherlands six people were present, including the Dutch Executive Committee delegate from the government. The Heat Pump Centre hosted this meeting. On 18 September 1990 the Japanese National Team went on to meet the Swedish National Team in Gothenburg.

** J.W.J. Bouma, IEA HPC.*

News and Views

Telephone Number for IEA HPC Changes in December!!!!!

As of December 7, 1990, the HPC telephone area code changes from (0)4490 to (0)46. A '5' precedes the old telephone number. The new telephone number is therefore +31-46-595-236 and the new telefax number +31-46-528-260.

IEA Heat Pump introduces Roswitha Muyres

Roswitha Muyres was born in 1966 in Sittard, the Netherlands. She completed her secretarial education in 1986. During the four following years she studied French and English at the Dutch State School of Translation and Interpreting. She is now a qualified Translator/Interpreter.

As of May 3, 1990, she became responsible for the office management of the Heat Pump Centre.

Codes and Guidelines

Development of International Standards

ASHRAE, at its annual meeting in St. Louis, announced its intention of expanding its participation in the development of international standards. The indoor quality standard and building efficiency standards will be amongst the first to be proposed for international adoption.
(Source: ASHRAE Journal, August 1990.)

Market News

ECR Technologies, Inc. seeks licensees and joint venturers -

for commercialisation of new refrigerant flow controls and direct expansion earth coupled heat pump.

Three years of utility testing in the northern and southern states in the US have demonstrated heating Seasonal (S) COPs of 11-18 and cooling SCOPs of 13.6-17 with ECR's direct expansion earth-coupled heat pump, resulting in 79% reduction in electricity system winter peak demand by eliminating electrical resistance heat strips customarily used in air source heat pumps. This product has been licensed in the US for space heating and cooling with an air handler, and for broader application in Austria.

The simple refrigerant flow controls which were developed to operate that system, have also been applied to air-conditioners and air source heat pumps to achieve efficiency gains of 11% and more by eliminating the need for (and inefficiencies of) superheat and subcooling, and by enabling the refrigeration system to operate efficiently in a much wider range than is possible with standard expansion devices and accumulators (see also Newsletter Vol. 8, No. 2, p. 11). When manufactured in comparable quantities, they can compete at the cost of standard controls which they replace.

For more information contact:

Hal Roberts, C.E.O., ECR Technologies, Inc.
P.O. Box 3271, Lakeland, Florida, USA
Tel.: +1-813-688-7300
Fax : +1-813-687-6283

High growth in Japan for City Gas A/C Installations in Refrigerating (ref.) Year 1989.

In ref. year 1989 (October 1988 to September 1989) Tokyo Gas installed 139,900 RT gas A/C installations, excluding small gas engine-driven heat pumps (small GHP). This is an increase of 19.4% compared to ref. year 1988. As for small GHPs which are mainly used in the field of small/medium-sized buildings, Tokyo Gas sold 4,300 units (estimated to be equivalent to 15,000 RT) which is an increase of about 200% compared to ref. year 1988.

Osaka Gas installed 114,600 RT gas A/C installations (small GHPs are included here) which is an increase of 18.6%. Small GHP installations went up by 150% in the number of installations sold compared to ref. year 1988. For ref. year 1990 the gas A/C growth goals are: Tokyo Gas: 2.3% overall, excluding small GHP; and 150% in the number of GHP installations. Osaka Gas: 22.3% overall, including GHP; and 150% in GHP installations (or 100% in capacity).
(Source taken from Japan Air-conditioning, Heating & Refrigeration News; August 25, 1990.)

Re-birth of Heat Pumps in Switzerland

In 1989 approx. 3,400 heat pumps were installed in new buildings and houses in Switzerland; 3,000 of these were sold by manufacturers and suppliers of the Working Association Heat Pumps (Arbeitsgemeinschaft Wärmepumpen AWP). The total number of heat pump installations in Switzerland is estimated at 31,000.
The AWP aims at the increased use of ecologically and energy advantageous heat pumps. The organisation has worked out extensive standards and guidelines.
(Source: Ki Klima-Kälte-Heizung, No. 9/1990.)

IEA

HPC Associate Member of IIR

The Heat Pump Centre has become an associate member of the International Institute of Refrigeration (IIR) in Paris.

Through its membership, the HPC can provide its members with special services such as access to the computerised data base Friginter, which contains 12,000 bibliographical references starting from 1981, both in English and French. Bibliographical research can also be undertaken by the IIR. The HPC may act as an intermediary if information requests are made. Consulting Friginter can be made either by presenting a bibliographical query, or by keywords. Other methods can also be used. The questioner will be invoiced directly after consulting Friginter. It is expected that co-operation and co-ordination between the IIR and the IEA HPC will be beneficial to both organisations and their members. One such example of co-operative work between the two organisations was the presentation of a paper by the HPC on its activities at the IIR workshop in Stockholm, August, 1990. A report on the workshop is included in this issue of the newsletter.

European Energy Week

The new International Energy Agency exhibit stand made its debut at the European Energy Week in Amsterdam's RAI conference centre held between May 21 to May 23, 1990. IEA Executive Director, Helga Steeg, opened the three-day energy symposium with her address, "**Energy Security - What it Means Today**".

Approximately 600 visitors stopped at the IEA stand where representatives of the IEA, CADDET, the Heat Pump Centre and IEA Coal Research offered presentations and literature on the IEA and its work.

Implementing Agreement on Advanced Heat Pumps

CONCLUDED ANNEXES

- **Advanced in-ground heat exchange technology for heat pump systems, Annex VIII** (Operating Agent: National Research Council of Canada; O. Svec).
  The Annex proved to be a successful task sharing project

between the US, Germany, Switzerland and Canada. The vehicle for success was based on exchange of results and experiences, exchange of computer programmes and staff, yielding new information in the ground source heat pump technology. An executive summary of the final report is available from the HPC.

- **New development of the evaporator part of heat pump systems, Annex VII** (Operating Agent: Chalmers University of Technology; T. Berntsson).
  Participants in this Annex were Canada, Denmark, Finland, Norway and Sweden. The different aspects of evaporator systems such as types, heat transfer and pressure drop on refrigerant and heat source side, optimisation possibilities and R&D trends were studied during this project.

NEW ANNEXES

- A new **Annex (XIX) on 'Advanced Second Law Analysis for Heat Pump Systems'** has been approved and is about to start. Operating Agent will be the 'Institut für Technische Physik E19' of the Technical University in Munich, Germany.
- The government of Belgium will be the Operating Agent for another new **Annex (XX), 'Working Fluid Safety'**. This task will collect and evaluate data on the safety of refrigeration machines and heat pumps as related to their working fluids.

Additional information can be obtained from the HPC.

Environment

ASHRAE Position Paper on Environmental Aspects

ASHRAE members approved a revised position paper on the environmental effects of CFCs. The paper endorses a worldwide consensus that unrestricted use of fully halogenated CFCs poses an unacceptable risk of environmental damage and suggests the phasing out of CFC refrigerants at the earliest possible date. The paper also supports acceptance of HCFCs as alternative refrigerants and the adoption of exacting practices to minimise refrigerant emissions along with stringent reclamation and recovery procedures.

Research projects for CFCs will account for approximately 20% of ASHRAE's 1990-91 research budget of US$ 1.4 million. One of the approved research projects includes a project on thermodynamic properties of R125 and R141b. *(Source: ASHRAE Journal, August 1990.)*

Pilot Production Plant R123

ICI PLC has commissioned a pilot plant to produce HCFC-123. The new plant is located in the northwest of England and will produce enough refrigerant for the worldwide market. *(Σουρχε: ΑΣΗΡΑΕ ϑουρναλ, Αυγυστ 1990.)*

Targets for Reduction of CO_2 Emissions

The HPC carried out a survey on the reduction of CO_2 emissions, the results of which follow:

- **Norway**: Target to stabilise CO_2 emissions at the 1989 level by the year 2000. Measures to achieve this target will be decided upon in 1991. *(Source: National Team.)*
- **Canada**: Aims to introduce legislation in late 1990 to stabilise greenhouse gas emissions at the 1990 level by the year 2000. Whether application will be specific to each greenhouse gas individually or in total is a topic of discussion. Energy conservation will be a key element; carbon taxes are being considered.
  (Source: National Team.)
- **Japan**: A draft action plan to hold discharges of CO_2 in year 2000 at the 1990 level - both per capita and in absolute quantities - was approved by the Cabinet on October 23, 1990. One of the 21 steps foreseen in the draft plan is the wider use of heat pumps, utilising effluent heat such as warm exhaust air from subways, warm waste water from sewage treatment plants, etc.
  (Source: National Team).
- **USA:** Status August, 1990: the Senate approved legislation that, among other things, requires the development of strategies to reduce CO_2 emissions by up to 20% by the year 2005. A similar bill was introduced in the House of Representatives and was scheduled for hearing in September 1990.
  (Source: Alliance to Save Energy, August 1990.)
- **Sweden**: It has been decided to stabilise CO_2 emissions at the present level. From January 1, 1991 CO_2 and Sulphur (S), and from January 1992 NO_x taxes will have to be paid. The CO_2 taxes in Swedish Krones (SEK) are: Coal 620/ton; oil for heating 720/m^3; natural gas 0.535/m^3; LPG 750/ton (1 SEK is approx. US$ 0.175). Consequently, the price of heat from heavy oil will increase by approx. 80 SEK/MWh (approx. US$ 3.9/GJ; US$ 4.1/ million btu). The S tax is 30 SEK/kg S in coal and peat and 270 SEK/m^3, % S for oil. The NO_x tax is 40 SEK/kg $N0_2$ for boilers larger than 10 MW and an energy output larger than 50 GWh/year. *(Source: National Team.)*
- **Germany**: The Government aims to reduce CO_2 emissions by 25% by the year 2005.
  (Source: Informationszentrum für Wärmepumpen und Kältetechnik.)
- **Netherlands**: New plan issued by the government aims at stabilising CO_2 emissions in 1994/95 at the 1989/90 level and a reduction of emission of 3-5% in the year 2000. Measures to reduce NO_x emissions are also foreseen. An annual energy saving of 2% is aimed at. Investment grants for industrial heat pumps are foreseen. In the Netherlands a technical breakthrough would be required for small heat pumps in the residential sector to become cost effective.
  (Source: Dutch National Environmental Policy Plan-Plus; Government Paper Energy Saving.)

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Bibliography

Codes and Guidelines

ASHRAE Guideline on Emission of CFC Reduction

ASHRAE Guideline 3, 1990, **"Reducing Emission of Fully Halogenated CFC Refrigerants in Refrigeration and Air-Conditioning Equipment and Applications"** has been published. *The guideline is available for US$ 22.00 (ASHRAE members US$ 15.00) at ASHRAE, 1791 Tullie Circle, NE, Altanta, GA 30329, USA. (English).*

New European Standards for Refrigerating Systems

Alfred Brandenberger, Ki Klima - Kälte - Heizung 7-8/1990, pp. 329-331 (German).

In anticipation of the emergence of a Common European Market in 1993, prevailing safety norms for refrigerating systems in individual European countries will have to be harmonised. For this purpose Germany initiated, in June 1989, the formation of the Technical Committee TC 182 for "Refrigerating Systems; Safety and Environmental Requirements" within the European Organisation for Standardisation, CEN. The Standard will cover the following items: design, construction, installation, commissioning, testing, maintenance, repair, operation and disposal. The time schedule of the project anticipates that by July 1991 a draft Standard can be circulated for comments. The article describes the procedure.

Design Tools

Creating a Prolog Knowledge-Based System Using an Existing Air-to-Air Refrigerant Computer Model

Paper, number CH-89-23-2, ASHRAE Publications, 1791 Tullie Circle, NE, Atlanta, GA 30329, USA. Price US$ 6.00 (English).

The Trane company has added an "expert system" to a portion of an existing heat pump computer model to optimise preliminary designs for heat exchangers. Designers can use the program to learn proper design methods while simultaneously creating useful designs. Experienced designers can use it to increase the speed and accuracy of their work. The resulting integrated program has cut engineering design time by 50 to 75% and enhanced the quality of the designs produced. See also EPRI Heat Pump News Exchange, Summer 1990, Vol. 2, No. 2 which states further information can be obtained from Carl Bergt, Manager Unitary Systems Technology, Trane Unitary Products Group, Troup Highway, Tyler, TX 75711, USA. Tel.: +1-214-581-3200.

Systems / Installations

Heat Pumps for Distillation Columns

A. Meili, Sulzer Brothers, Ltd, Winterthur, Switzerland. Chemical Engineering Progress, June 1990, pp 60-65 (English).

The fundamentals of the use of heat pumps in distillation processes are described. Cost comparisons are given for 3 distillation columns with heat pumps, built by Sulzer: Ethylenebenzene-Styrene; Isopropanol-water; and Propane-Propylene.

Performance characteristics of the water-lithium bromide-zinc chloride-calcium bromide absorption refrigerating machine, absorption heat pump and absorption heat transformer

S. Iyoki and T. Uemura, Faculty of Engineering, Kansai University, Japan. Int. Journal of Refrigeration, 1990 Vol. 13, May, pp 191-196 (English).

A theoretical analysis of the coefficient of performance was undertaken to examine the performance characteristics. The performance characteristics of this system were compared with the water-lithium bromide system and the other systems using water, methanol and ammonia as working media. This system was found to be suitable for an air-cooled single-stage absorption refrigerating machine, a single-stage, high temperature double-effect absorption heat pump and a two-stage absorption heat transformer.

Case Study: Analysis of an Existing Heat Exchanger Network and Effect of Heat Pump Installations

Bijan Farhanieh and Bengt Sunden, Chalmers University of Technology, Göteborg, Sweden. Heat Recovery Systems & CHP, Vol. 10, No. 3, pp. 285-296, 1990 (English).

The existing heat exchanger network at a refinery is analysed and redesigned by grassroots as well as retrofit designs. The results indicate that the existing network consumes approximately 6% more energy than the optimum design. Retrofitting the existing network leads to a design similar to the optimal grassroots design. The estimated payback period is 1.5 years if a large fraction of the existing heat exchanger area is re-used. The effect of heat pump installations is considered and some alternative cases are presented. Significant energy savings could be achieved but the economics are open to discussion.

Heat Pumps and Pinch Technology

R. Benstead and F.W. Sharman Electricity Council Research Centre, Capenhurst, UK.

Heat Recovery Systems & CHP, Vol. 10, No. 4, pp. 387-398, 1990 (English).

This paper describes the use made of process integration at the Electricity Council Research Centre at Capenhurst and how it has been extended to cover electric heat pumps for energy recovery.

Refrigerants / CFCs

Thermophysical Properties of Environmentally Acceptable Fluorocarbons - HFC134a and HCFC123

Published by Japanese Association of Refrigeration (JAR) (Bilingual English and Japanese).

The data book contains: a complete coverage of thermophysical properties in the entire fluid phase; original modelling of thermodynamic and transport properties; new thermodynamic equation of state covering the entire fluid phase; detailed numerical tables of essential thermophysical properties; updated information about lubricant/refrigerant fluid properties and material compatibility; pressure-enthalpy and temperature-entropy charts. Units used are SI (metric) units (pp. 250). Order from Mr. S. Inomata, Deputy Secretary, Japanese Association of Refrigeration, 4th Floor, San-ei Building, 8 San-ei-cho, Shinjuku-ku, Tokyo 160, Japan. Price: 20,000 Yen (approx. US$ 130).
Tel.: +81-33-359-5231. Fax: +81-33-359-5233.

Thermophysical Properties of Pure Substances and Mixtures for Refrigeration

Proceedings of the meeting, held in Herztia, Israel, of commission B1, March 5-7, 1990 (English and French), ISBN 2903-633-495).

The proceedings contain three sections: pure substances; refrigerant mixtures and refrigerant mixtures/sorbent mixtures; cycle and system analysis. A report can be obtained from: IIR, 177 Boulevard Malesherbes, F 75017 Paris, France.

Reduction of CFC Emissions in the Refrigeration and Air-conditioning Technique - 1st Status Seminar.

'DKV- Statusbericht' of the German Refrigeration and Air Conditioning Society, No. 4, April 26, 1990, Pfaffenwaldring 10, D-7000 Stuttgart 80, Federal Republic of Germany. (German.)

The report presents a summary of the results of R&D (involving 5.5 million German Marks) which is co-ordinated by the German Refrig. and A/C Society (DKV) and co-financed by the German Ministry of Research and Technology (BMFT). A sample of the topics includes: an NH_3 cooler; the cold air process; technical aspects of R23/R152a installations; an absorption compression installation; properties of R134a/R152a, lubrication oil aspects of R23/R152a and R134a/R152a, heat transfer measurements, fluid flow and pressure reduction behaviour of R134a with and without lubricant.

IEA Publications

Learning from experiences with Thermal Storage: Managing Electrical Loads in Buildings, CADDET Analyses Series No. 4

M. A. Piette, CASU/CADDET, Sweden, August 1990 (English).

The report is intended to help managers and users of residential and commercial buildings to understand the capabilities of thermal storage technologies to shift or reduce electricity peak demands. Utilities can benefit from the report in promoting the use of storage technologies as part of demand side management. Order from CADDET, P.O. Box 17, 6130 AA Sittard, the Netherlands.
Price: US$ 25 for CADDET member countries. For other countries contact CADDET for ordering details.

IEA District Heating:

'Guidelines for Converting Building Heating Systems for Hot Water District Heating'. *(English.)*

Keywords: District Heating, Heat Exchangers, Hot Water Heating, Building Heating, Energy Conservation, Heating Systems, Air Handling Systems, Piping Systems.

Published by Novem, 1990, Report IEA District Heating, R8.

IEA District Heating:

'A Technology Assessment of Potential Telemetry Technologies for District Heating'. *(English.)*

Keywords: District Heating, Telemetry, Load Management, Automatic Meter Reading, Telemetering, Telecontrol.

Published by Novem, 1990, Report IEA District Heating, R7.

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