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High Temperature Heat Pump Research and Development

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HIGH TEMPERATURE HEAT PUMP RESEARCH AND DEVELOPMENT

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SUMMARY

The goal of this research is to enhance utilization of the heat pump in the heating processes of diversified industrial sectors and also to increase the maximum utilization temperature of the electrically driven compression type heat pump from 110 to 130°C. Research and development activities are comprised of the following three steps:

(1) Fundamental Research and Investigation:
After a general study of various families of Freon and Hydrocharbon refrigerants which included evaluation of thermal stability and cost as well as durability testing (Sealed tube test) of combinations of promising refrigerants and lubricating oils, a normal pentane was selected as the best refrigerant and a polyglycol synthetic oil as the best lubricating oil.

(2) Pilot Plant Research and Development:
A motor driven 75KW pilot plant was designed and constructed and excellent performance results for the refrigerant, lubricating oil and compressor were obtained through 1,500 hours of continuous operation. For example, the coefficient of performance was range 4 under the condition of 135°C condensing temperature and 80°C evaporating temperature.

(3) Practical System based on Demonstration Plant:
Currently, field testing is being carried out at a certain chemical factory based on a 500KW class demonstration plant. It is expected that applications for high temperature heat pump, will be found in a wide range of industries.

1. INTRODUCTION

A heat pump can raise the temperature of various forms of waste heat, contributing to their effective utilization. Application in a variety of fields is expected. These include distillation columns in the petrochemical industry where heating processes coexist with waste heat sources. The maximum available temperature of the high temperature heat pump has, however, been 110°C because of technical restrictions such as the working fluid.

Should the utilization temperature be raised, application of the heat pump can be further widened to distillation columns requiring temperatures of 130°C and many other applications.

The purpose of this research is to develop a heat pump system capability of enhancing available temperature to 130°C based on the high temperature heat pump technology for up to 110°C developed in the Moonlight Project previously carried out by the Agency of Industrial Science and Technology, Ministry of International Trade and Industry, in its study of the expansion of heat pump applications to various industrial processes..

2. OUTLINE OF RESEARCH AND DEVELOPMENT

(1) Development target:

a. Motor-driven compression type heat pump producing maximum utilization temperature of 130°C (Condensing temperature: 135°C).

b. Coefficient of performance of approx. 4 when waste heat of 95°C is utilized.

(2) Development theme

a. Search for and selection of refrigerant having stable physical properties at higher temperature (Condensing temperature: Higher than 135°C).

b. Search for and selection of lubricating oil for compressors displaying thermal stability when coexisting with refrigerant.

c. Development of high temperature screw compressor (Condensing temperature: Higher than 135°C).

d. Technological confirmation and substantiation of high temperature heat pump system.

3. DEVELOPMENT STEPS AND RESULTS

(1) Basic survey and research (December, 1983 through March, 1984).

a. Market research investigation for high temperature heat pump. An interview survey was conducted to determine the level of usable temperature of waste heat in production processes at factories producing chemical products, foods, and pulp & paper. The applicability of the high temperature heat pump for such was then examined and the following findings were obtained.

(a) Levels of waste heat temperature and available heat temperature (Ref. Fig. 1).

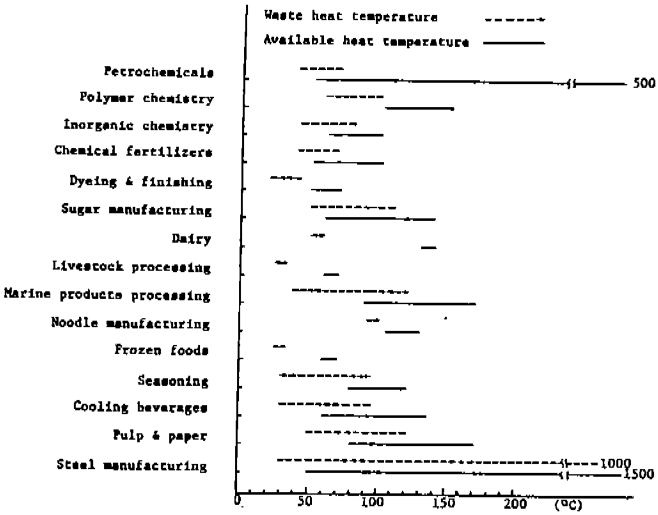


Fig. 1. Waste heat temperature and available heat temperature classified by industry.

- Waste heat temperature: Generally between 40 and 100°C. Form varies, e.g., steam, hot waste water, gas, etc.
- Available heat temperature: Generally can be classified into two groups of 60 to 100°C and 100 to 150°C.

60 to 100°C -- Chemical fertilizers, dyeing & finishing, livestock processing, sugar manufacturing, frozen foods

100 to 150°C - Polymer chemistry, petrochemicals, dairy industry, sugar manufacturing, marine products processing, pulp & paper

(b) Situation regarding applications

- There are applications of several units already in dyeing and finishing, sugar manufacturing, livestock processing and frozen food processing. The usable temperature is from 50 to 70°C.
- Applications are aggressively being reviewed in some sectors of the chemical industry such as polymer chemistry and inorganic chemistry. In such cases, a payout period of 2 years for the initial facility investment is normally considered.

b. Selection of applicable refrigerant and lubricating oil

(a) Investigation and selection of refrigerant

In order to select the appropriate refrigerant for a high temperature heat pump having a condensing temperature of 135°C, Freon-based refrigerants (R11, R21, R114), hydrocarbon-based refrigerants (Normal pentane), new refrigerants (Carbonfruoride , Trifruoroethanol) and water, which were promising temperature-wise according to manufacturer's or other data, were examined from the viewpoint of thermal stability, coefficient of performance, safety, price, refrigerant pressure during operation, required capacity of compressor, etc. Normal pentane, R114, Carbonfruoride & Trifruoroethanol were then selected. In the screw type compressor of the heat pump developed during the present research, refrigerant and lubricating oil coexist inside the compressor under high temperature conditions. Various combinations of refrigerant and lubricating oil were placed in sealed tubes for testing purposes and kept at 175°C in a constant temperature oven for 17 days. Thereafter, changes in the various characteristics of the mixtures were analyzed and evaluated from an overall point of view. Finally, normal pentane was selected.

Table I. Comparison of various refrigerants

Item \ Refrigerant	R114	Normal Pentane	Carbon-fluoride	Trifruoroethanol
Chemical formula	$C_2Cl_2F_4$	C_5H_{12}	C_6F_{14}	$CF_3CH_2OH + H_2O$
Boiling point (°C)	3.8	36.1	56	75
Solidifying point (°C)	-94.0	-129.1	-90	-63
Critical temp. (°C)	145.7	197.2	178.5	236.5
Saturation pressure at 85°C (MPa)	1.020	0.414	0.231	0.147
Saturation pressure at 135°C (MPa)	2.697	1.201	0.624	0.768
Pressure ratio	2.61	2.90	2.69	4.92
Heating capacity (Kcal/m³) *1	937	607	370	410
Coefficient of performance	4.57	5.77	5.52	7.03
Toxicity *2	6	5b	(5b)	(5a)
Explosive inflammability	None	Yes (flash point: -40°C)	None	Yes (flash point: 41.7°C)
Price (Yen/Kg)	1,500	350	7,000	10,000

Notes: *1: TC:135/TE:85°C
(): Estimated value
*2: Classification by underwriters' Laboratory

(b) Selection of lubricating oil
Requirements of lubricating oil:
- Good thermal stability and oxidation stability,
- Proper viscosity in working temperature range,
- Small solubility to the refrigerant,

Since the oil temperature of the compressor developed in the present research is approx. 100°C, a viscosity of at less 30cSt is required. Polyglycol-based synthetic oil having high stability against thermal cracking, oxidation reaction and small solubility to refrigerant has been selected based on the sealed tube testing coexisting with refrigerant mentioned above.

(2) Research and Development using Pilot Plant (April, 1984 through March, 1985)
An engineering review was carried out for the compressor in particular as it is considered to be the source of more thermal problems in the research than other mechanical components in the high temperature heat pump system. A 75kw Pilot Plant was then designed and constructed on an experimental basis. After continuous operation for 1,500 hours using the above stated refrigerant and lubricating oil, the performance, endurance of the compressor, the stability of the refrigerant and oil and the overall operationability and reliability of the system were evaluated. Good results and promising prospect were obtained. The 75KW Pilot Plant shows satisfactory performance even at higher temperature, as shown in Table 2. For example, in recovering 130°C heat from approx. 90°C waste heat, the estimated coefficient of performance is approx. 4 even considering the characteristics of the heat-exchnager (condensing temperature: 135°C, evaporative temperature: 80°C).
Testing results:
(a) Endurance
- The degree of wear of all parts, such as the rotors, bearings, mechanical seal assembly, etc. was measured and inspected during disassembly, after 500 hours and 1,500 hours of operation. There was almost no trace of wear after use and thus it was concluded that the system can withstand long-term operation.

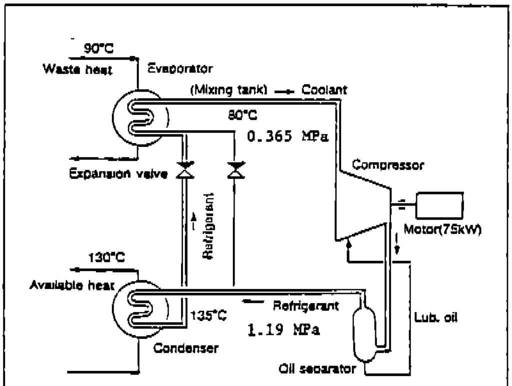
- It was also determined that clearances were normal and proper.
- Temperature rise and vibration at each part were found to be normal and stable.

(b) Performance

Characteristics of heating capacity and coefficient of performance were analyzed based on the test data obtained from the Pilot Plant and are shown in Fig. 2.

(c) Stability of refrigerant and lubricating oil

The refrigerant and lubricating oil were sampled and analyzed before operation, after 500 hours of operation, after 1,000 hours of operation and after 1,500 hours of operation. The results are as shown in Table II. It was found that both of the refrigerant and lubricating oil were changed little and were stable. They are, therefore, suited for use in the high temperature heat pump.



Conseptual diagram of system

Type:
electric-motor-driven compression

Compressor: variable-capacity screw compressor

Working Fluid: pentane

Lubricating Oil: synthetic oil (polyglycol-base oil)

Maximum output temperature: 130°C

Condensing temperature: 135°C (135°C down to 95°C)

Evaporating temperature: 90°C (90°C down to 60°C)

Capacity: 75 kW (motor input)

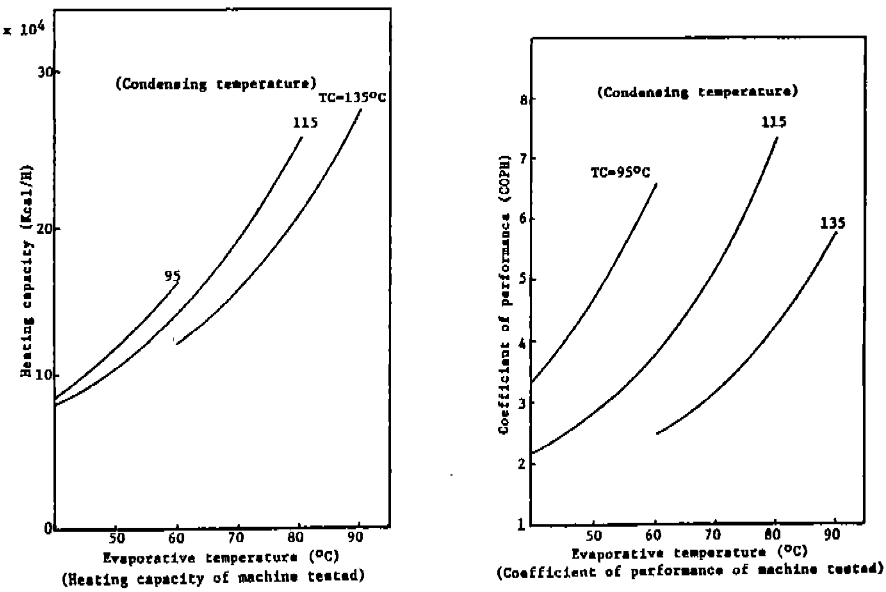


Fig. 2. Structure and characteristics of 75KW Pilot Plant

Table II. Results of analysis of refrigerant and lubricating oil samples

(a) Results of analysis of refrigerant

Sampling date		July, 1984	27, July	24, Aug.	17, Sept.
Operating hours		0	527	1,011	1,525
Status of equipment		Stopped	Stopped	Operating	Operating
Purity	n- pentane	96.67	85.05	97.21	96.27
	i- pentane	3.23	8.12	2.54	3.63
	Pentane	99.90	93.17	99.75	99.90
Cracked gas	CH_4	0.0011	4.97	0.0011	0.00
	C_2H_6	0.0015	0.547	0.0028	0.0001
	C_3H_8	0.001	0.008	0.0015	0.0002
	n-C_4H_{10}		0.011	0.0031	0.0034
	i-C_4H_{10}		0.006	0.0005	0.0004
	CO		0.315	0.001	0.001
	CO_2		0.862	0.040	0.007
	H_2		0.031	0.134	0.001
	Others	0.006	0.008	0.066	0.087
	Total cracked gas	0.010	6.830	0.250	0.010
Total		100	100	100	100

(b) Results of analysis of lubricating oil

Operating hours (H)	0	527	1,011	1,525
Color (ASTM)	L5.0	D8.0	D8.0	D8.0
Viscosity at 40°C (10^{-6} m^2/sec.)	244	237	234	236
Viscosity at 100°C (10^{-6} m^2/sec.)	32.8	32.5	32.0	32.3
Viscosity index	181	182	181	181
Total acid number (mgKOH/g)	0.63	0.38	0.42	0.40
Falex load (kg)	725	610	635	610
IR analysis	-	Same as new oil	Same as new oil	Same as new oil

(3) Energy saving and economical effects of the heat pump

If the temperature is to be raised by 40°C using the high temperature heat pump, 450KW of electricity serves a plant that requires 1.5 MKcal/H of pressurized steam.

Consequently, the energy saving effect derived from utilization of the heat pump is equal to 500 Kl of crude oil (40% energy saving) on the assumption that in case of steam heating, boiler efficiency is 80%, in case of heat pump, electrical energy is 2,450 Kcal.KWH and annual operation rate is 80%. The results show great merit on both enterprise and national scales.

Regarding economical efficiencies, all sectors of industry that generate steam for heating purposes except those where low cost steam is generated by private power generation equipment can expect considerable effects. For example, in the case of a unit price for steam of 5,500 Yen/ton under the same conditions as stated above, the heat pump assures low running costs.

According to trial calculations a payout of two years for the initial facility investment can be considered.

4. FUTURE WORKS

Pentane was used as the refrigerant in the system developed this time. Pentane is, however, flammable and application is considered best suited to fields such as the chemical industry where the handling flammable materials is established procedure.

Field tests using a demonstration plant (500KW class) are scheduled and will be carried out in order to determine the characteristics of the system as a whole.

For applications in other fields, performance and endurance tests using incombustible refrigerant in a pilot plant are scheduled to be carried out in the future.

RECHERCHE ET DEVELOPPEMENT SUR LA POMPE DE CHALEUR A HAUTE TEMPERATURE

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RESUME

L'objet de cette recherche est de promouvoir l'utilisation de la pompe à chaleur dans les procédés de chauffage de secteurs industriels diversifiés et également de porter la température maximale d'utilisation de la pompe à chaleur à compression entrainée électriquement de 110 à 130°C. Les activités de recherche et de développement comprennent les trois opérations suivantes:

(1) Recherche et études fondamentales:

Après une étude générale des diverses familles de réfrigérants au fréon et aux hydrocarbures qui comprenait une évaluation de la stabilité thermique et des coûts ainsi que des essais d'endurance (essai en tube scellé) des combinaisons de réfrigérants et huiles lubrifiantes prometteurs, on a retenu un pentane normal comme meilleur réfrigérant et une huile synthétique polyglycol comme meilleure huile lubrifiante.

(2) Installation pilote de recherche et développement:

Une installation pilote de 75 KW entrainée par moteur électrique a été construite; elle a présenté d'excellents résultats de performance pour le réfrigérant, l'huile lubrifiante et le compresseur sprès 1500 heures de fonctionnement en continu. Ainsi, le coefficient des performances s'est trouvé dans la plage 4 dans des conditions de température d'évaporation de 80°C.

(3) Système pratique basé sur l'installation de démonstration:

A l'heure actuelle, des essais locaux sont en cours d'exécution dans une certaine usine chimique; ils sont basés sur une installation de démonstration de la classe 500 KW. On s'attend à ce que les applications pour is pompe de chaleur à haute température s'étendent à des industries très diverses.