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NEDO R&D Project for Innovative Thermal Management

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Abstract

A national R&D project "Research and Development Project for Innovative Thermal Management Materials and Technologies" in NEDO is introduced in this paper. In this project, technology developments are conducted to Reduce (which technologies for reducing heat usage; thermal insulation, heat shield and thermal energy storage), Reuse (which technologies for reusing heat; heat pump technologies) and Recycle (which technologies for reusing heat by converting it; thermoelectric energy conversion, waste heat power generation) unutilized thermal energy effectively, including total thermal management based on the combination of these technologies, and realize a future energy-efficient society. This paper focuses on high temperature heat pumps and its new refrigerants.

Keywords: R&D Project; Thermal Management; Unutilized Thermal Energy; Industrial Heatpumps; New Refrigerant;

1. Introduction

In July 2018, the Cabinet of Japan approved the new Strategic Energy Plan, and the new plan emphasizes the strengthening of efforts to ensure continued, concrete results towards 2030. Towards 2050, the new plan seeks to achieve energy transitions and decarbonization, in light of the global momentum in this direction and in enforcement of the Paris Agreement, and to pursue all tenable options toward this end.

In Japan, about 30% of primary energy, mainly fossil resources such as oil, coal and natural gas, are lost when they are converted into electricity and fuel [1], and at the final consumption, it is used only a small portion, so most of primary energy is considered not to be used effectively but discarded as heat. NEDO refers to such artificially discharged heat as "unutilized thermal energy", and it is the key for realizing thorough energy efficiency to effectively reduce, reuse and recycle this huge amount of unutilized thermal energy discharged into this environment, and it can be said to be a frontier.

In this paper, it is introduced that an overview of a national R&D project "Research and Development Project for Innovative Thermal Management Materials and Technologies", which aims to realize thorough energy efficiency promoted by New Energy and Industrial Technology Development Organization (NEDO). Above all they focus on R&Ds of new high-temperature heat pumps and their refrigerants that make use of heat efficient in industrial fields by reusing unused thermal energy for process heating instead of boilers.

2. Surveys of actual exhaust heat and R&D target

Although it is expected that unutilized thermal energy will be used for thorough energy efficiency, the temperature zone, amount, and location vary. Therefore, in order to grasp the actual state of unutilized thermal energy, NEDO conducted a large-scale questionnaire survey and estimated exhaust heat in industrial field, in "Research and Development Project for Innovative Thermal Management Materials and Technologies" [2]. It is believed that such data on temperature and quantity of exhaust heat are valuable for introduction

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consideration not only on high temperature heat pumps introduced below, but also on applications of relatively low temperature industrial heat pumps and absorption chillers that have already been established technically. However, such large-scale surveys of actual exhaust heat in industrial fields had not been conducted since the survey conducted from 1997 to 2000 [3]. Figure 1 shows the estimated amounts of nationwide unutilized thermal energy, by sector and temperature based on the survey result from 1,273 factories of 15 industries. The nationwide estimation of the amount of unutilized thermal energy (exhausted as gas) was based on results of questionnaires, approximation calculated by the correlation between energy inputs to factories and unutilized thermal energy as exhaust gas by industry, and FY2015 energy consumption statistics of manufacturing industries.

The total amount of exhaust gas heat in these 15 industries was 743 PJ / year, and the 76% (565 PJ / year) was occupied by exhaust gas heat of less than 200 ° C. As shown in Fig. 1(a), it can be seen that a lot of exhaust gas from steel industry, non-ferrous metal industry, and transportation equipment industry, with melting and heat treatment processes, is in high-temperature of 500 ° C or higher, and exhaust gas from clean-up industry and other manufacturing industries, with incineration processes, is concentrated from 150 ° C to 249 ° C. On the other hand, when comparing exhaust gas calorific value of 15 industries estimated in 2015 with the result of 2000, as shown in Figure 1(b), it decreased by about 14% from 2000, and it was speculated about 10% energy efficiency was achieved for 15 years.

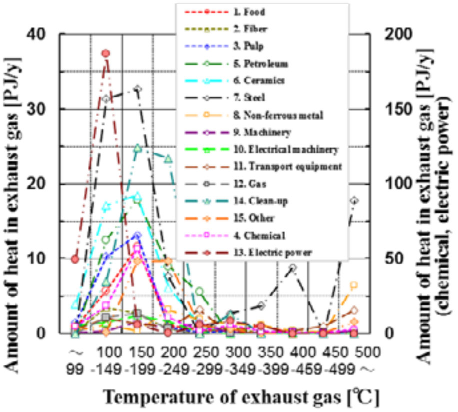

Fig. 1(a). Estimation of amount of heat in exhaust gas from industry by temperature range

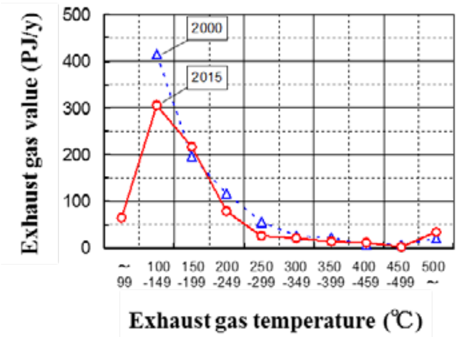

Fig. 1(b). Comparison with survey results between 2000 and 2015

Based on the above, NEDO is promoting an R&D project to effectively reduce (heat insulation, heat shield and thermal storage), reuse (heat pumps) and recycle (thermoelectric generation abd heat power generation) of unutilized thermal energy mainly below 200 ° C or above 500 ° C, with thermal management technologies, led by Dr. Haruhiko Ohara, the project leader, who also serves as the Deputy Director-General of the Planning Headquarters of the National Institute of Advanced Industrial Science and Technology (AIST),

with industry-academia collaboration of the Thermal Management Materials and Technology Research Association (TherMAT) described in Fig. 2. As the oucomet of this R&D and penetration of these technologies, NEDO and they aim to achieve domestic fossil fuel reduction effect of about 6 million kL per year or more in crude oil equivalent and CO_2 reduction effect of over 17 million t-CO_2 per year in 2030 alone. In order to NEDO also aims to realize these effects by reducing or utilizing unutilized waste heat, which is above 500 ° C, mainly with heat insulation and thermoelectric generation technologies, and which is below 200 ° C, mainly with heat pumps, thermal storage and heat power generation technologies. In this way, this R&D project is intended for a wide range, but here it is introduced that an R&D on high temperature heat pumps and its refrigerant, which are the core of this R&D project and can show high energy efficiency effect.

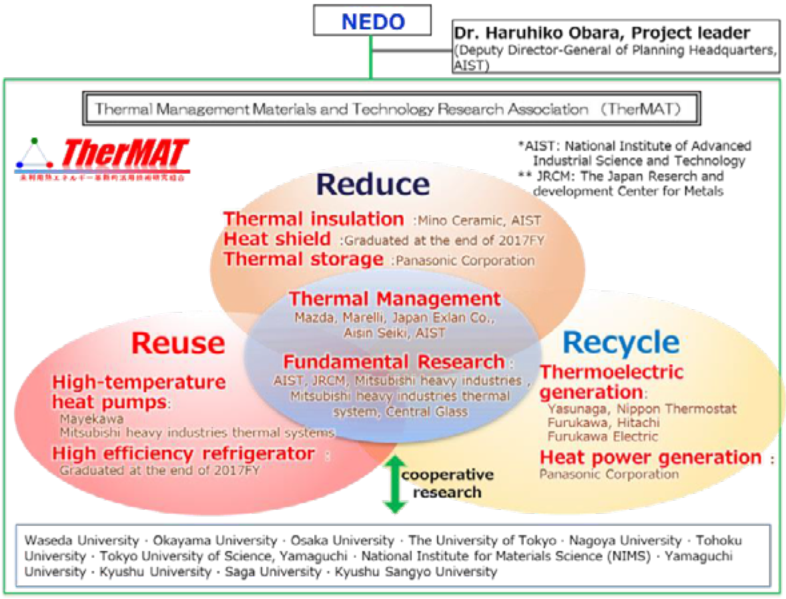

Fig. 2. Organizational chart of "Research and Development Project for Innovative Thermal Management Materials and Technologies"

3. R&D of high temperature heat pumps and refrigerants in NEDO

Currently, boilers using fossil resources are often used as heat sources for industrial heating applications, and a large amount of unutilized thermal energy is discharged from each heating process. By reusing this waste heat as a heat source, it is expected to regenerate it to a higher temperature and replace the heat sources from conventional boilers with high temperature heat pumps, for which NEDO has been promoting the R&D of that. In this project, it aims to develop high temperature heat pumps which can supply high-temperature heat about from 160 ° C to 200 ° C with high efficiency (e.g. COP: 3.5 or higher), recovering from waste heat of 80 ° C or 100 ° C which is discarded from industrial manufacturing processes, and as the result of penetrating them as alternatives to steam boilers, can contribute to use primary energy efficiently and reduce CO_2 emissions. In addition, refrigerants used in the heat pumps are selected, developed and evaluated as compounds which have small GWP (Global Warming Potential) and are suitable for high-temperature applications, in this project.

3.1. Development of industrial high-efficiency and high-temperature heat pump capable of supplying maximum 200 ° C

In this project, Mayekawa Mfg. Co., Ltd. and Mitsubishi Heavy Industries Thermal Systems, Ltd., who are the members of TherMAT, are developing heat pump systems with having the goal that can meet the supply temperature range up to 200 ° C, and achieve COP: 3.5 or higher by heating from 100 ° C to 200 ° C at the end of 2022.

Mayekawa Mfg. Co., Ltd. got the analysis based prospect of achieving COP4.10 by heating from 80 ° C to 160 ° C and the intermediate target (COP3.5) using the developed integrated analysis simulator. Also the ultrahigh-speed turbo compressor was developed, and results by fluid analysis and structural analysis showed achieving the adiabatic efficiency target of 70% or more. In addition, the correlation model necessary for the design was created by the trial model tests of the high-temperature and high-pressure heat exchanger, and the basic design of the heat pump prototype was completed. Based on these, they designed and manufactured a prototype heat pump using R600 refrigerant with a maximum heating temperature of 200 ° C and a heating capacity of 300kW, and started performance verification tests. (Fig. 3) For the purpose of further improving efficiency, they evaluated HFO refrigerants as working media, and they clarified that it was non-flammable, and low GWP, and the rotation speed of the compressor was expected to be lower than that of R600 refrigerants. Based on the above, they have started the development of an oil-free turbo compressor with this working medium.

Fig. 3(a). High temperature heat pump prototype unit

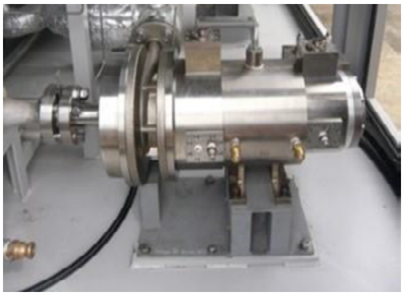

Fig. 3(b). Developed oil-free and ultra-high speed turbo compressor

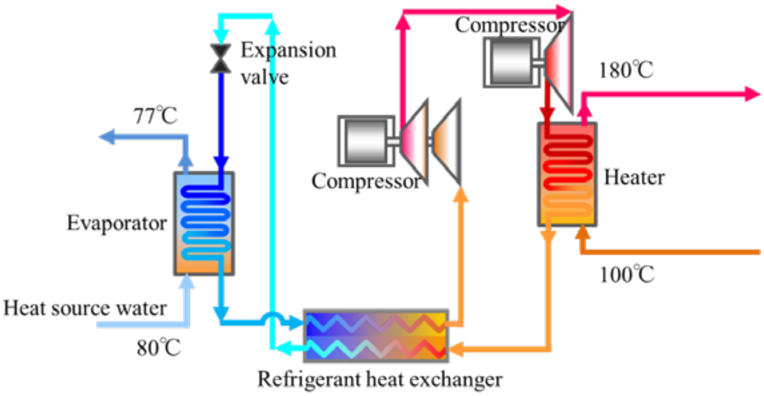

Fig. 3(c). Primary prototype testing machine flow chart of the high temperature heat pump

Mitsubishi Heavy Industries Thermal Systems, Ltd. selected the optimum heat pump cycle as the result of basic heat pump analyses at 160 ° C and 200 ° C. They also decided the refrigerant adopted for the 160 ° C hot water output heat pump, completed their basic plan, and got the prospect for realizing over COP 4.0. In addition, drop-in operation tests using refrigerant candidates in high temperature ranges were performed on an element verification test machine modified an existing product, and the validity of elemental technologies was evaluated. (Fig. 4) At the same time of these R&Ds, they extracted industrial processes that are expected to have high effect including energy efficiency with introduction of high-temperature hot water output heat pumps, and grasped the actual operating conditions including heat balance and energy consumption in each process.

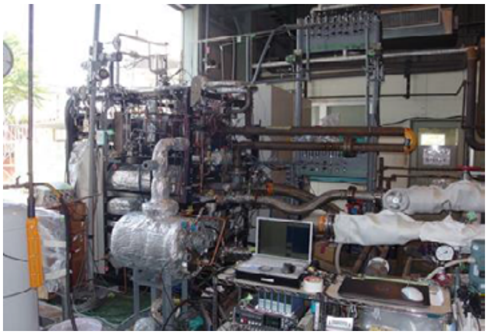

Fig. 4. Drop-in test with low GWP refrigerant

3.2. R&D of refrigerants suitable for high-temperature heat supply heat pumps

In order to be applied to turbo heat pumps with 500kW or more that can be introduced into industries such as machinery and chemical industries, Mitsubishi Heavy Industries, Ltd., Mitsubishi Heavy Industries Thermal Systems, Ltd., Central Glass Co., Ltd. and AIST, who are the members of TherMAT, in collaboration with Kyushu University, Saga University and Kyushu Sangyo University, have been exploring, developing, evaluating physically and selecting several low GWP refrigerants, that meet the requirements for the temperature zone when industrial heat pumps will be used.

By FY2017, they selected refrigerants that were promising for using at 160 ° C hot water output heat pumps. Specifically, among the compounds for which some thermophysical property data are known, three compounds were selected as new refrigerant candidates, and their performance (normal boiling point and critical temperature), thermal stability, safety (toxicity and flammability), environmental impact (GWP <20) were evaluated, and also thermodynamic properties and transport properties data (PVT properties, thermal conductivity and viscosity) were obtained. In addition, they conducted synthesis studies using cheaper catalysts, confirmed the high selectivity and long life of the catalyst and revealed the low toxicity as the result of subacute toxicity tests.

New refrigerant candidates suitable for use for 200 ° C hot water output heat pump have not been studied yet, including other applications, and had no REFPROP FLD files. Therefore, they have developed a method for preliminary toxicity test and synthetic method with high yield for new refrigerants candidate corresponding to 200 ° C, and they evaluated five screened candidate refrigerants from points of view of thermal stability, basic thermophysical properties, safety and environmental impacts, and as the result of that candidate refrigerants were narrowed down to two. They developed equation of state based on sound of speed in gas phase, PVT property measurements and vapor pressure measurement for the refrigerant candidate, and confirmed that it was almost the same as the actual measurement value of physical property. Also, they have also found a catalyst with high selectivity, high conversion and long life in the synthesis process.

3.3. Next steps

Based on above R&D, materials can be selected by analyzing thermodynamic characteristics and heat exchange characteristics of the 200 ° C output heat pump cycle using new refrigerant candidates, and evaluating elastomer compatibility suitable for the refrigerant candidate. Then, toward the final goal, they will conduct element verification tests of high temperature heat pumps using new refrigerant candidates suitable for 200 ° C output machines, confirm the each component performance of heat pump cycles, together with evaluation of the soundness, evaluate overall performance of the heat pumps, and determine basic specifications.

On the other hand, toward introduction of the heat pumps after the end of R&D, it can be difficult to see the effect or value when they apply to actual heat utilization equipment in factories. Especially it will be even more difficult to conduct verification to grasp the energy efficiency effect in the actual environment using the existing systems. Therefore, it will be proceed with activities of model cases studies, assumed actual heat utilization facilities, and based on the results of this studies, calculation and quantitatively evaluation of the effect or value including energy efficiency, cost merit and heat pump system configuration post introduction. As the result of the activities, "visualization" of introduction effect will be progressed and it will be possible to share the installation image of heat pumps in industrial heating processes with customers, which will be able to lead to acceleration of the introduction. It is planned to construct equipment utilizing systems with high temperature heat pumps including attached facilities, proceed with model case verifications that examine optimal applied processes and clarify economic effects, and studies on "visualization" of introduction effect with TherMAT and all Japan in this R&D project. Through these activities, the newly developed industrial high-efficiency and high-temperature heat pumps will be properly arranged and used for process heating instead of boilers, thereby promoting energy efficiency in factories and contributing to solving energy and environmental problems in the future.

4. Conclusion

"Energy efficiency" is the primary expectation for the realization of "3E + S" (simultaneously achieving Energy Security, Economic Efficiency and Environment, with coming Safety always at first) in Japan and global long-term decarbonization, but most of primary energy is still discharged as unutilized thermal energy without being effectively used, even though various measures have been taken so far. Among energy forms such as fuel, electricity, and hydrogen that are expected to be used in the future, the last remaining form is heat, and decarbonization of all sectors that use this heat can be the key to construct the sustainable recycling society. Now all the relevant people are required to promote to implement technologies for effectively reducing or recovering a large amount of unutilized thermal energy discharged into the environment including high-temperature heat pumps, to the society with economic rationality, realize significant energy efficiency of the entire society and a "circular economy", and there can be no doubt that this R&D project has been a driving force for it.

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