1986

Application of Nonazeotropic Refrigerant Mixtures in Multi-Zone Heat Pump Room Air Conditioner with Hot Water System

H. Nomura

APPLICATION OF NONAZEOTROPIC REFRIGERANT MIXTURES

IN MULTI-ZONE HEAT PUMP ROOM AIR CONDITIONER WITH HOT WATER SYSTEM

H. NOMURA

Daikin Industries, Ltd. Residential Air Conditioning Designing Department, SHIGA (JAPAN)

1. INTRODUCTION

In recent years, the growing interests in nonazeotropic mixtures for heat pump appliances have been developed.
Several efforts have been undertaken to develop the practical utility of refrigeration systems using nonazeotropic mixtures.
However, their applications remain quite limited. In some cases this is due to the misconceptions developed over the applicability and potential benefits of the systems using nonazeotropic mixtures.

As energy saving is a primary concern when using nonazeotropic mixtures, it should be pointed out that it depends on the characteristics of the application systems.
Multiple tasks can be accomplished by using nonazeotropic mixtures. Therefore it is most important to make special requirements for system design clear.

The object of this paper is to investigate nonazeotropic refrigerant mixtures which will meet the requirements for the combination unit for heating, cooling and hot water supply. This paper includes the concentration variation during operation by means of an electrically driven motorized expansion valve. Possible reasons for the disagreement between the predicted and experimentally observed performance efficiency are also presented.

2. REQUIREMENTS FOR THE COMBINATION UNIT

In this section, requirements for the combination unit are discussed. This system is an air-source heat pump unit with an additional heat exchanger for hot water supply inside the storage tank.

In order to compete successfully with conventional systems, the working fluid characteristics should meet the following requirements:

—Hot water temperature should be as high as possible in order to make a storage tank smaller.
—Loads of compressor closely related to the reliability should be reduced under the conditions of high condensing temperature which are necessary for hot water supply. Consequently the high pressure of the system should be as low as possible during the hot water supply operation.
—Refrigerant should be dense as to increase the capacity for space heating and cooling in order to eliminate the need for excessively large compressor.

Other requirements for the system include the following:

—Capacity control should be taken into consideration. In order to achieve a high coefficient of performance, capacity control is necessary for variation of loads.
—Flow of refrigerant should be controlled continuously under the conditions of variable loads to maintain heat pump operation optimum.

R12 and R22 are commonly-used refrigerants in domestic heat pump devices, but these refrigerants of pure type do not meet the requirements mentioned above. An use of nonazeotropic refrigerant mixtures should be taken into account.
If the circulating refrigerant becomes richer in the higher boiling component under the conditions of high condensing temperature for hot water supply and richer in the lower boiling component under the conditions of space heating and cooling, it becomes possible to meet the requirements mentioned above.

3. CYCLE PERFORMANCE CALCULATION

In order to analyze the refrigerating cycle, a computer program was developed.
An extended BWR equation of state, modified by Nishiumi and Saito /1/ was adopted to perform thermodynamic property calculations for subcooled, two-phase, and superheated nonazeotropic mixtures.

To begin with, combinations of refrigerants had to be chosen which were likely to meet the mentioned requirements. The possible chices were:
1) Adding higher boiling component to R22; a commonly used refrigerant in domestic heat pump devices for space heating and cooling.
2) Adding lower boiling component to R12; a commonly used refrigerant in domestic heat pump devices for hot water supply.
3) The mixture R22/R12.
According to the research carried by Kandlikar /2/, the mixture R22/R12 has the potential of forming an azeotrope. Therefore, R22/R114, R13B1/R12 were chosen as the combinations to be investigated.

A fair performance comparison between a nonazeotropic mixture and a pure refrigerant requires the proper choice of condensing and evaporating conditions for each.
Fig.1 shows the calculated results of the coefficient of performance with concentration change of the higher boiling component. There are two curves indicating the values of COP for each of the combinations.
For the upper curve, dew-point temperature and evaporator-inlet temperature represent the condensing and evaporating temperatures respectively.
For the lower curve, mean condensing and evaporating temperatures represent the condensing and evaporating temperatures respectively.
The mean condensing temperature refers to the average of the dew-point and bubble-point temperatures corresponding to the condensing pressure, and the mean evaporating temperature is the average of the dew-point and evaporator-inlet temperatures corresponding to the evaporating pressure.
The upper curves show the effect of the refrigerant changing temperature in the heat exchangers.

The calculated cooling capacity with concentration change of the higher boiling component is shown in Fig. 2.
Both condensing and evaporating temperatures are based on the mean temperatures.
Fig.2 also shows the calculated condensing pressures corresponding to the mean condensing temperatures.

These calculated results indicate that the mixture R22/R114 is more likely to meet the mentioned requirements from the viewpoints of performance efficiency and reliability.
However, these simulations are based on the assumption that the liquid and vapor remain in equilibrium during the evaporation and condensation process.
In two-phase flow there is always a tendency for the vapor and liquid to move at different velocities.
It should be noted that maintaining equilibrium in the heat exchangers is difficult to achieve.

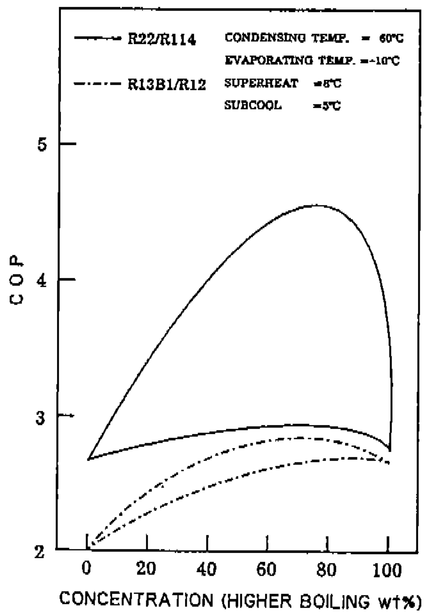

Fig.1 — Calculated results of COP

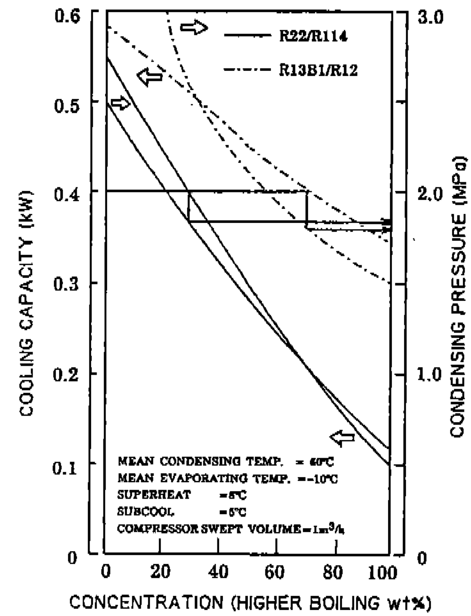

Fig.2 — Calculated results of capacity and condensing pressure

4. DESCRIPTION OF THE EXPERIMENTAL ARRANGEMENT

A schematic diagram of a prototype of the multi-zone heat pump room air conditioner with hot water system is shown in Fig. 3. This system consists of one outdoor unit capable of operating three indoor units and a hot water storage tank. Capacity controlled rotary compressor and electrically driven motorized expansion valves are mounted in the outdoor unit. The system is controlled by means of thermodynamic data, continuously monitored throughout the entire cycle over a range of operating conditions.
Superheat of the refrigerant is controlled by the electrically driven motorized expansion valves. All of these are controlled by means of a microprocessor based control unit.

There are five heat exchangers mounted in this system. All of them are finned coils.
To utilize the changing temperature of the refrigerant in the evaporator and condenser, strict counterflow heat transfer between the refrigerant and external fluid is essential.
But, it is noted by Mori /3/ that the advantage of using nonazeotropic mixtures is relatively a little in devices for domestic use such as room air conditioners due to the small temperature change.
There are also physical problems in configuring the heat exchangers to achieve strict counterflow in domestic heat pump devices.
The flow arrangements of the heat exchangers in this system are shown in Fig. 4.

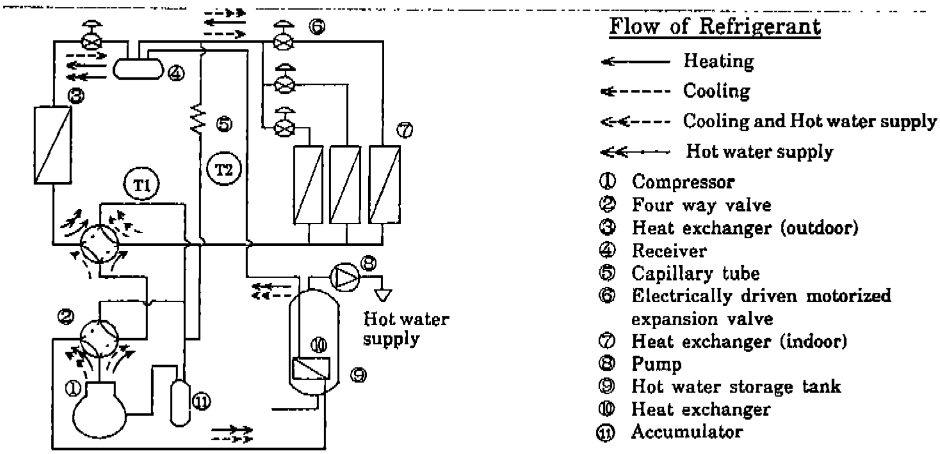

Fig. 3 — Schematic diagram of the multi-zone heat pump room air conditioner

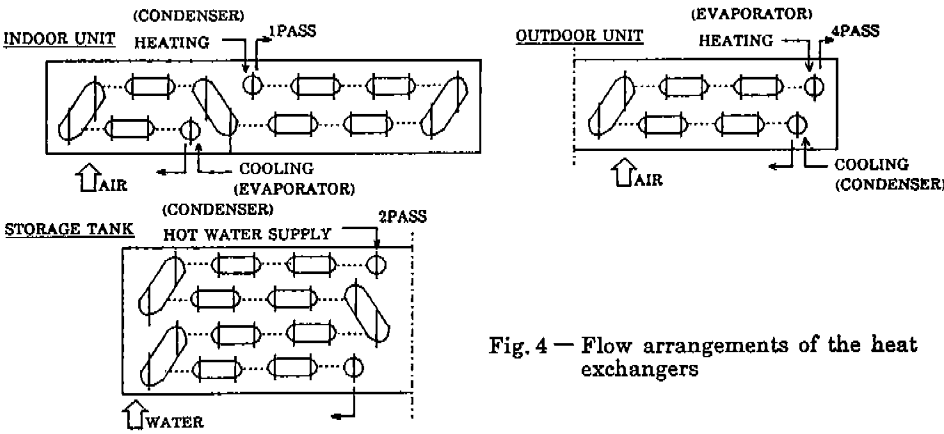

Fig. 4 — Flow arrangements of the heat exchangers

5. EXPERIMENTAL RESULTS

In order to investigate the possibilities of nonazeotropic refrigerant mixture R22/R114, measurements were made on the test plant shown in Fig. 3 with various concentrations.

5.1 Cooling and Heating

Table I shows a typical comparison between calculated results and experimental data for cooling cycle with R22/R114 at 75/25 weight percent and pure R22.
The table shows that predicted calculated and experimental results are in good agreement except condensing pressure and the COP with R22/R114.
Table II also shows a typical comparison for heating cycle.
The table shows differences in the results for heating capacity as well as in the COP due to the increase in power consumption which results in an increase in heating capacity.

When comparing between a nonazeotropic mixture and a pure refrigerant, there are different ways according to the condenser and evaporator conditions.
In general the required heat transfer surface area for the mixture will be somewhat greater. In all test results reported here, the heat transfer surface area remained unchanged. Consequently the conditions are likely somewhat advantageous to the pure refrigerant as is noted by Berntsson /4/.

However, the capacity influences on the COP due to the substantial differences between the characteristics of the refrigerants are greater.
In this system, COP with mixture R22/R114 should be greater than that with R22 as the calculated results in Table I ,II show.
Actually, COP with mixture R22/R114 decreases.
This results from non-equilibrium change in the condenser.
Possible methods of maintaining equilibrium are noted by Burr and Haselden /5/, but it is very difficult to achieve good heat transfer with the liquid and vapor remaining in equilibrium.

Fig. 5 shows an example of temperature profiles in the condenser.
Temperature change was evaluated by measuring surface temperatures of return bends with insulated thermocouples.
Temperature change in the condenser did not behave exactly as the theory estimates. The theoretical change for condensation from dew point to bubble point corresponding to the measured condensing pressure is shown in the figure.
It is evident from Fig.5 that condensing pressure should be raised higher than the theory estimates to get desired mean condensing temperature.
This causes an increase in compressor work which results in an decrease in the COP.

TABLE I
Comparison between calculated and experimental (Cooling cycle)

	R22		R22/R114	
	Calculated	Experimental	Calculated	Experimental
Capacity [kW]	4.87	4.77	4.29	4.21
COP	2.18	2.14	2.46	2.06
Condensing Pressure [MPa]	1.97	2.01	1.53	1.89
Evaporating Pressure [MPa]	0.49	0.50	0.45	0.43

TABLE II
Comparison between calculated and experimental (Heating cycle)

	R22		R22/R114	
	Calculated	Experimental	Calculated	Experimental
Capacity [kW]	5.37	5.26	4.30	4.67
COP	2.56	2.48	2.79	2.46
Condensing Pressure [MPa]	1.88	1.90	1.29	1.73
Evaporating Pressure [MPa]	0.46	0.44	0.37	0.36

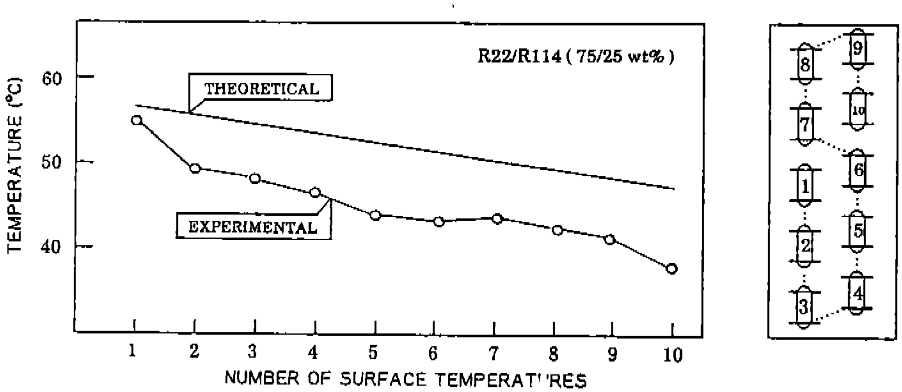

Fig. 5 — Example of temperature profiles in condenser

5.2 Hot water supply

The tests for hot water supply were conducted under the condition of air dry bulb temperature 15°C. COP and condensing pressure with hot water temperatures were measured with R22, R12 and mixture R22/R114.
The results of the measurements are shown in Fig. 6.
Fig. 6 shows the decreasing pressure levels in the condenser, when using the mixture R22/R114. Consequently the bearing loads of the compressor can be lowered remarkably by enriching the concentration of the circulating refrigerant in higher boiling component R114.

It is noted at the same time that capacity control of the compressor is also effective to reduce pressure levels in the condenser.
Although decrease in the loads of the compressor is achieved with a certain loss of the COP due to the possible reasons mentioned above, it is still significant in the viewpoint of extension of the application limit of a refrigerant compressor.

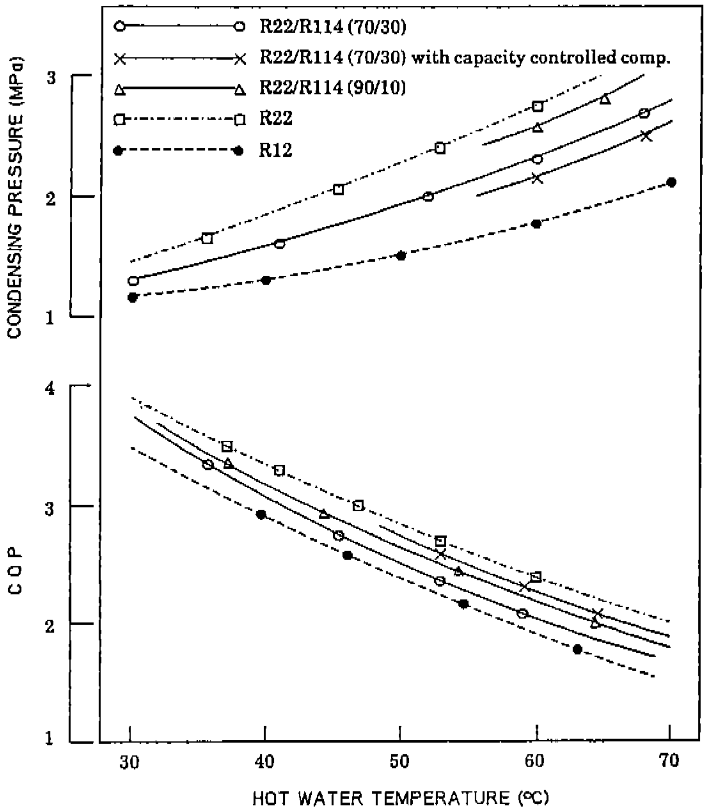

Fig. 6 —Results of the operation for hot water supply

5.3 Varying the concentration of a mixture.

The results of the measurements show that enriching the concentration of the circulating refrigerant in higher boiling component is essential for high temperature hot water supply.
In order to change the concentration of the circulating mixture, possible methods were investigated including accumulation of a portion of the original charge.
In conclusion, accumulating a portion between the evaporator and the compressor, as was investigated with mixture R13B1/R152a by Cooper /6/, is more suitable for this application because of simplicity and low cost.

In this system an electrically driven motorized valve is utilized as an expansion valve in the outdoor unit which must operate three indoor units and a hot water tank. It is favorable to use electrically driven valves over the required range of load which varies extremely.
By continuous monitoring of the condition of the refrigerant at the outlet of the evaporator and using a control algorithm, it is possible to constantly maintain a desired degree of superheat.

Fig.7 shows the amount of liquid collected in the accumulator between the evaporator and the compressor with change of the superheat. As is shown in the figure, at the load point where the system reaches 7°C superheat not 0°C superheat as is seen with single refrigerant system, liquid will begin to leave the evaporator and will collect in the accumulator due to a temperature rise in the evaporator.
The superheat described here means the temperature difference between T1 and T2 which are measured at the points T1 and T2 in the schematic diagram Fig. 3 respectively.

Enrichment of the circulating concentration in the lower boiling component is proportional to the amount of accumulation.
Fig. 8 shows the example of the test results with 25% charge accumulation and with no accumulation to provide significant decrease in pressure levels in the condenser when the accumulator becomes empty. Fig.8 also shows that discharge gas temperature can be lowered with enrichment in the higher boiling component under the conditions of high condensing temperature for hot water supply.
The electrically driven motorized expansion valve for hot water supply provides liquid accumulation through the conditions of the hot water temperatures up to about 55°C to increase the capacity of the heat pump.
To obtain temperatures up to about 65°C, liquid in the accumulator is added gradually to the circulating mixture by increasing the degree of superheat.

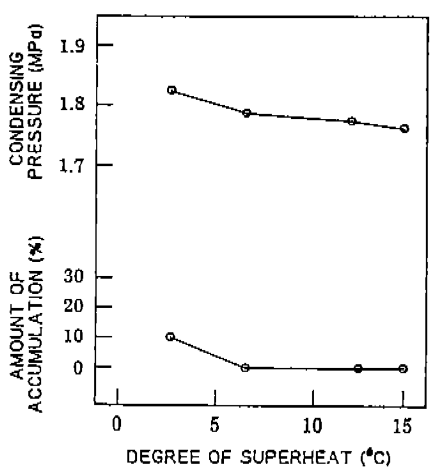

Fig.7— Example of accumulation with change of superheat

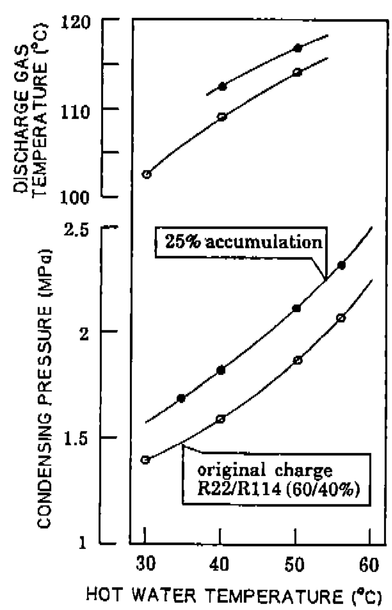

Fig.8— Example of the effect of accumulation

6. CONCLUSION

In order to find out a working fluid which will meet the requirements for the combination unit for heating, cooling and hot water supply, theoretical analysis and experimental measurements were carried out. The mixture R22/R114 was found to be the best suited fluid.

By varying the circulating concentration of the mixture, requirements for the system can be fulfilled adequately as follows:
1) extension of the application limit of a compressor.
2) hot water supply up to 65°C.
3) completion of the system with a small-sized compressor.
Varying the concentration can be accomplished by controlling the amount of accumulation in the accumulator between the evaporator and the compressor.
The use of an electrically driven motorized expansion valve has been shown to be a feasible method of achieving this control.

Practical utility of the combination unit has been developed successfully.
However, improvement in performance efficiency is less than predicted from theory due to a non-equilibrium change in the heat exchanger.
Future work includes a heat exchanger optimization.

REFERENCES

1. Nishiumi, H. and Saito, S,: J. Chem. Eng. Japan. 8, 356 (1975).
2. Kandlikar, S. G., C. A. Bijlani and S. P. Sukhatme,: Predicting the Properties of Mixtures of R-22 and R-12, Part I -Thermodynamic Properties. ASHRAE Trans., Vol. 81, Part I, (1975) PP. 266-284.
3. Mori,S. :Refrigerants and Refrigeration Cycle. Reito(Refrigeration)649, (1981) PP 892-902.
4. Berntsson, T., Ljungkvist, K., Moser, F. and Schnitzer, H.,: High Temperature Working Fluids and Nonazeotropic Mixtures in Compressor Driven Heat Pumps. Final Report, AnnexVI, IEA Implementing Agreement on Advanced Heat Pumps, (1984).
5. P. S. Burr and G. G. Haseldon,: A Non-Isothermal Mixed Refrigerant Cycle for Air Conditioning Duties. Proc. of Inst. of Refrigeration, Vol. 71, (1974) PP. 18-25.
6. Cooper, W.D.: The Use of Mixed Refrigerants in Air-to-Air Heat Pumps. ASHRAE Trans., Vol. 88, Symposium Paper HO-82-11 NO.2, (1982) PP. 1159-1169.

SUMMARY

In order to investigate the possibilities of applying nonazeotropic refrigerant mixtures to the combination unit for heating, cooling and hot water supply, a computer program has been developed based on an extended BWR equation of state.
The mixture R22/R114 was found to be the best suited mixture from the viewpoints of performance efficiency and reliability.
Experimental investigations have shown that varying the concentration of a mixture can be accomplished by the control of accumulation in the accumulator between the evaporator and the compressor. To achieve this control, an electrically driven motorized expansion valve has been utilized. Enrichment of the circulating refrigerant in the lower boiling component can make it possible to get desired capacity for space heating and cooling without a need for excessively large compressor, and enrichment in the higher boiling component for hot water supply can extend the application limit of a refrigerant compressor.
Requirements for the system can be fulfilled adequately with use of nonazeotropic refrigerant mixture. However, improvement in performance efficiency is less than predicted from theory due to a non-equilibrium change in the heat exchangers. This result shows that scope exists for further development.

RÉSUMÉ

Afin de déterminer les possibilités d'applications des mélanges réfrigérants non azéotropes aux unités mixtes de chauffage, de climatisation et de distribution d'eau chaude, un programme d'ordinateur a ete mis au point à partir d une généralisation de l'équation d'état B.W.R.

Le mélange R22/R114 apparaît comme le meilleur compte tenu des performances et de la fiabilité.

L'analyse expérimentale a mis en evidence que l'on pouvait faire varier la concentration du mélange en contrôlant l'accumulation dans l'accumulateur situé entre l'evaporateur et le compresseur, pour effectuer ce contrôle on utilise une valve d'expansion actionnée par un moteur électrique. L'augmentation de la circulation en réfrigérant dans le compartiment inférieur de chauffage permet de chauffer ou de refroidir un volume suffisant sans faire appel à un grand compresseur, de plus un enrichissement dans le compartiment supérieur de chauffage, pour la production d'eau chaude, permet d'utiliser à l'extrême le compresseur refrigérant.

Les conditions requises par le système sont atteintes en utilisant un mélange refrigérant non azeotrope. Cependant l'amélioration du rendement est moindre que ce que prévoit la théorie; ceci résulte d'une transformation de non équilibre dans les échangeurs de chaleur. Ce résultat indique que d'autres développements sont à prévoir dans le futur.