MECHANIKA
CZASOPISMO TECHNICZNE
TECHNICAL TRANSACTIONS
MECHANICS
WYDAWNICTWO
POLITECHNIKI KRAKOWSKIEJ
1-M/2012
ZESZYT 5
ROK 109
ISSUE 5
YEAR 109

PIOTR CYKLIS, RYSZARD KANTOR*

CONCEPT OF ECOLOGICAL HYBRID COMPRESSION-SORPTION REFRIGERATING SYSTEMS

KONCEPCJA EKOLOGICZNEGO HYBRYDOWEGO SORPCYJNO-SPRĘŻARKOWEGO SYSTEMU CHŁODNICZEGO

A b s t r a c t

The CO_2 application for refrigerating cycles is a growing market due to its environmental friendly characteristics. However, using CO_2 as a refrigerant has some disadvantages due to relatively low critical temperature. For this reason usually two stage compressor cascades are used. But there are alternatives. In this paper the theoretical analysis of the cascade with an adsorption or absorption system as the upper cycle with water as working fluid will be shown.

Keywords: two-stage refrigeration cascade, absorption cycle, adsorption cycle, CO_2 cycle

S t r e s z c z e n i e

Instalacje chłodnicze wykorzystujące CO_2 są coraz popularniejsze. Jednak CO_2 jako czynnik chłodniczy ma także wady. Główną wadą jest niska temperatura punktu krytycznego. Z tego powodu stosuje się dwustopniowe kaskady sprężarkowe. Istnieją jednak inne możliwości. Artykuł zawiera teoretyczną analizę systemu dwustopniowego z obiegiem absorpcyjnym oraz adsorpcyjnym będącym górnym stopniem kaskady chłodniczej.

Słowa kluczowe: dwustopniowa kaskada, obieg absorpcyjny, obieg adsorpcyjny, obieg CO_2

* Prof. PhD. Piotr Cyklis, PhD. Ryszard Kantor, Institute of Thermal and Power Engineering, Faculty of Mechanical Engineering, Cracow University of Technology.

1. Introduction

In nowadays refrigeration systems there is a strong need for environmental friendly and efficient refrigerants. Most friendly are natural refrigerants: water and CO_2. Using CO_2 as refrigerant one has to take into account its very low critical point which limits the COP, and very high pressure requirement in the discharge side of the compressor.

The common way to deal with the problem is to use the CO_2 cycle as a low temperature stage for two stage refrigeration, and another refrigerant for the high temperature stage. This gives reasonable COP for the CO_2 cycle working below critical point and easy to control two stage compressor refrigeration systems. However in this case the environmental friendly CO_2 refrigeration has the addition of another refrigerant in the high temperature stage, and another compressor using electric power.

Water as a working fluid has the temperature limit. It can be used in the air conditioning systems with either absorption or adsorption cycle chillers, having the lowest temperature about 5°C. For the refrigeration purposes this may only be used at the high temperature stage of the cascade, assuming that the condensation in the second (low) stage compression cycle is about 10–15°C. This is below the critical point for CO_2. Therefore combining CO_2 LT (Low Temperature) stage with absorption or adsorption systems as a HT (High Temperature) stage may lead to the environmentally friendly solution.

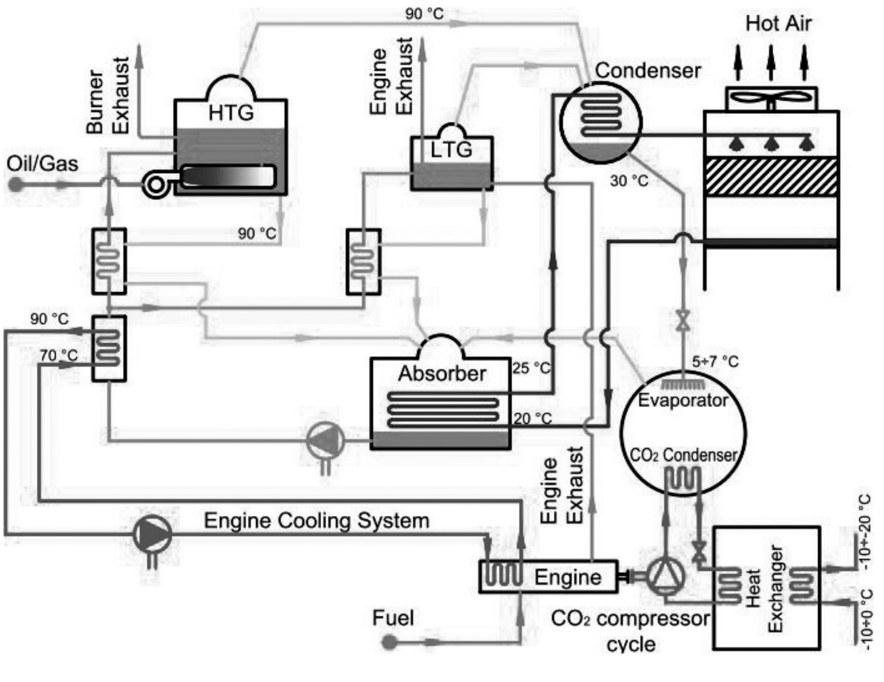

Fig. 1. Two stage hybrid LiBr-H_2O and CO_2 cascade with double effect parallel sorption system using high temperature heat source

Rys. 1. Dwustopniowa kaskada LiBr-H_2O i CO_2 z dwuefektowym układem sorpcyjnym zasilanym wysokotemperaturowym źródłem ciepła

2. Absorption-compression system description

In the Fig. 1 the hybrid system with double effect parallel absorption system is shown. This cycle requires high temperature heat source (about 200°C) (HTG). If the combustion engine driven CO_2 compressor is used the heat generated by engine cooling and combustion gases may be used as shown on the Fig. 1. The engine waste heat is not sufficient for the absorption cycle. So additional gas burner has to be added for HTG (High Temperature Generator) heating. The combustion gases from the engine may be diluted to heat the LTG (Low Temperature Generator) or added to the burning gases for HTG. The cooling water from the engine is used for initial heat up of the solution pumped from the absorber.

In the Fig. 2 the two stage refrigeration cascade is based on the single effect absorption system with low temperature heat source. In this case during summer days solar collectors may be used but during the night the other waste heat source will be necessary. During summer the central heating network in case of cogeneration may be the heat source. What is important in this idea for both cases (Fig. 1, 2) that during cold winter days the CO_2 condenser may be cooled using water/glycol mixture directly from the ambient heat exchanger, and the sorption system may be reversed and used for heating purposes. This solution gives flexibility while applying good control system. For lower temperature sources also half effect absorption may be used, but then COP is relatively lower.

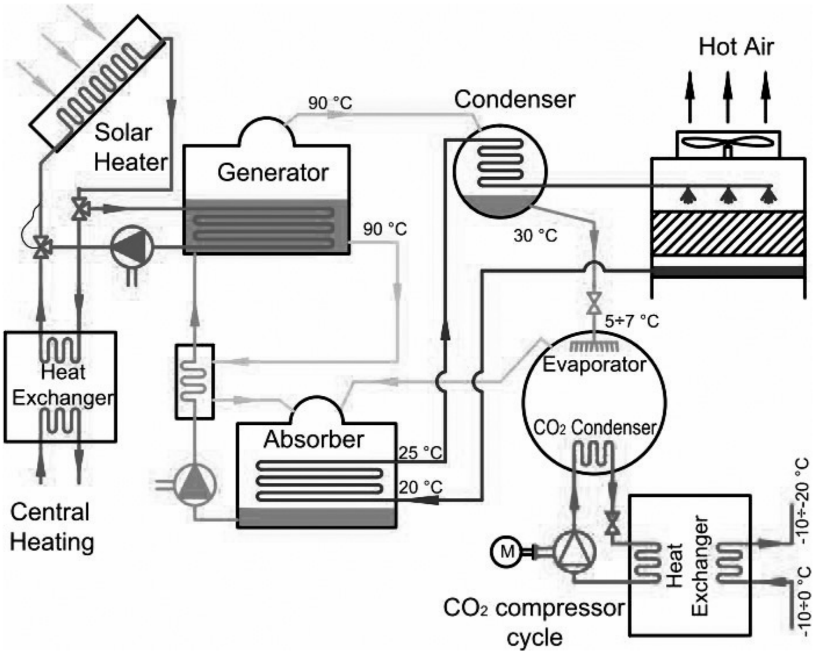

Fig. 2. Two-stage LiBr-H_2O and CO_2 cascade with single effect absorption system, requiring low temperature heat source heated by solar collectors or district heating

Rys. 2. Dwustopniowa kaskada LiBr-H_2O i CO_2 z jednoefektowym układem sorpcyjnym zasilanym kolektorem słonecznym lub ciepłem z sieci

3. Absorption-compression system simulation

3.1. The compression system simulation

The low temperature stage of the cascade is a CO_2 cycle. The simulation of the CO_2 cycle is rather known, CoolPack software may be used, or any of the NIST packages, so the method of this cycle simulation will not be here described in details. The COP of the cycle may be simulated as a function of the condensation temperature t_c of CO_2 for different refrigerating conditions (evaporation temperature te). With standard condenser cooling at 35°C the COP range is within 1.4–1.7. Besides usually two stage compressor with inter stage cooling has to be used. With cooling from the absorption system with H_2O where the limiting temperature is 5°C the COP may reach 2.6. It is extremely important to design very efficient heat exchanger coupling directly the H_2O evaporator with CO_2 condenser. Only in this case the lowest possible temperature of CO_2 condensation may be reached. In any case 10°C may be reached where the COP is within the range 2–2.5 for CO_2 cycle.

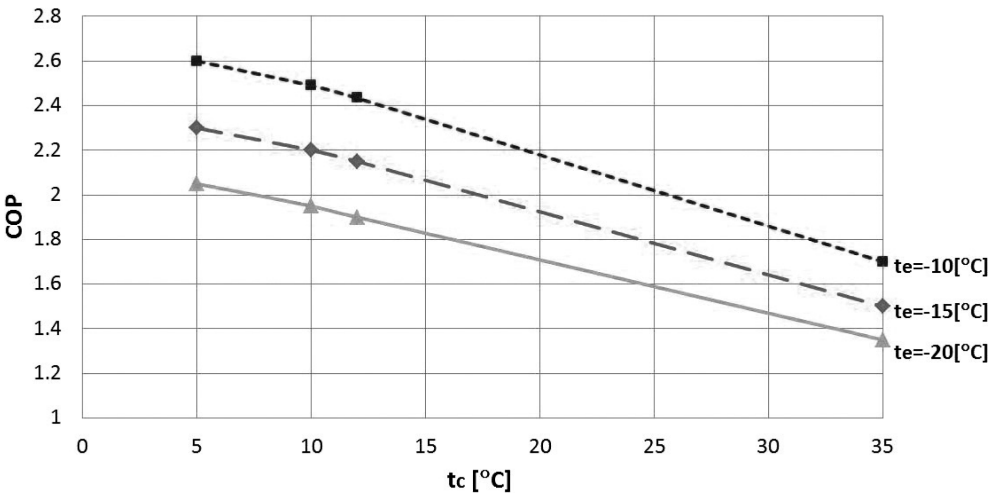

Fig. 3. The COP diagram for CO_2 cycle simulated for different condensation and evaporation temperatures

Rys. 3. Wykres COP dla jednostopniowego obiegu CO_2 dla różnych temperatur kondensacji i odparowania

3.2. The absorption system simulation

The simulation of the absorption system is based on the energy and mass balance for equilibrium conditions. This assumption may be questionable during starting up or closing the system, but in steady state operation it is acceptable. The simulation of the energy balance for the absorption system is based on the equations defining properties of the lithium bromide solution. The results of COP calculations for different cases and cycles is shown on the Fig. 4.

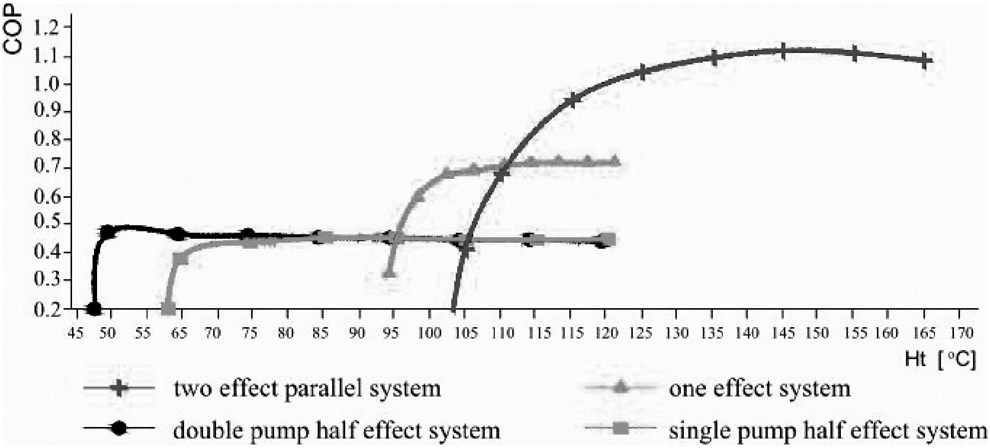

Fig. 4. The simulated COP of the different absorption cycles

Rys. 4. Symulowana wartość COP dla różnych obiegów absorpcyjnych

The two effect parallel system in this comparison is much more efficient than other low temperature cycles. Single effect system may reach COP in the range of 0.7 while two effect parallel system may reach 1.2. However the disadvantage is of course the high temperature heat source required for double effect.

What is important while using absorption system that the COP rises with the capacity and supply temperature. During design process the economy of the system shall be considered. Multi-effect systems are more expensive than single effect but they use less energy, so there is an advantage to use multi-effect cycle. The multi-effect system proposed here is double effect parallel one. It is more complicated than two effect series system because of the solution distribution cycle but is safer to use. There is less possibility of crystallization compared to series cycle.

The basis of the system is the single effect cycle. It can be used during the whole summer. A single effect LiBr/H_2O absorption system, with water as an refrigerant and lithium bromide as absorbent can operate with a heat source temperature from 90 to 120°C, and COP about 0.7 (with condenser cooling water temperature 30°C and the chilled water temperature 7°C).

The single effect consists of four components that exchange energy with surroundings, one internal heat exchanger, two flow controllers that are expansion valves and a pump. When the heat source is really low temperature, it is necessary to use half effect cycle. The half effect systems own its name thanks to achieving values of COP. It is a half of single effect units (COP~0,38 with t_c = 32°C and t_e = 9°C). There are two kinds of half effect systems: the first one called Double Pump Half Effect – DPHE containing two absorbers and two generators and the second one called Single Pump Half Effect – SPHE and containing two generators but one absorber.

For the high temperature stage of the refrigeration system the DPHE cycle which contains two single effect circuits is proposed here. The driving temperature is in range from 50–100°C. All values shown in the Fig. 4 are obtained by simulation of the equilibrium state.

4. Adsorption-compression system description

The general scheme two-stage adsorption-compression cascade system with silica gel adsorption chiller and CO_2 compression cycle is shown on Fig. 5. The hybrid system shown here is designed in the way that the solar power or other low temperature source (65–95°C) is used for the adsorption cycle. The re-cooling system is also needed. At our plant the wet tower heat exchanger will be used, however the ground heat exchanger may be also considered. The advantage of the sorption system is that it can be used as a heat pump during cold season, when the CO_2 condenser may be cooled directly by the ambient air. The high power adsorption systems are commercially used in Japan for air conditioning, utilizing waste heat sources. The idea presented in this paper shows new possibility, widening the adsorption and CO_2 systems application. One of the disadvantages of the simple adsorption cycle is the periodicity of its work. In fact in industrial applications the periodicity is avoided, because two or more adsorption beds are utilized. Reduced periodicity for second stage CO_2 subcritical compression refrigeration cycle is acceptable, and can be compensated, using automatic control system, coupling the CO_2 cycle load with reduced periodicity of the adsorption cycle operation shown on Fig. 5.

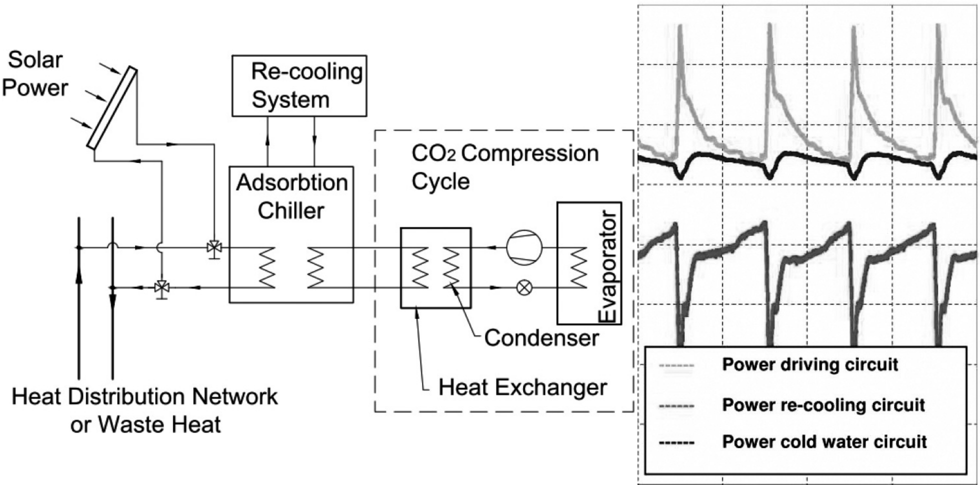

Fig. 5. Two-stage adsorption-compression cascade with silica gel adsorption chiller and CO_2 compression cycle

Rys. 5. Dwustopniowa adsorpcyjno-sprężarkowa kaskada z adsorpcyjnym chillerem i obiegiem sprężarkowym CO_2

The HT stage being analyzed is this case utilizes the Sortech ACS 08 machine. The ACS 08 has two adsorber beds working in combination, to achieve continuous cold production. The adsorbent in this case may be Silica Gel or Zeolite for adsorption prepared in Sortech patented coating technique. The maximum cooling capacity is 11 kW with COP of the stage related to the driving heat 0.65. Producer claims that even 55°C temperature of the heat source is sufficient to generate cold.

An important advantage of adsorption chillers, compared to absorption chillers, is their ability to generate cooling power at very low driving temperatures – starting at 55°C up to 95°C. Seen from this aspect, the adsorption cycle may be powered by low temperature renewable energy or waste energy generated by many industrial processes. It is often the case in the food processing plants that this kind of waste energy is present and free to use. The cold water circuit operates within temperature range of 5 to 20°C. At temperatures below 5°C both the cooling power and the COP are reduced significantly. The adsorption chiller requires re-cooling. The heat that is generated has to be released to the surrounding area at the MT (middle temperature) level. The re-cooling water temperature shall be at 20–35°C. This can be achieved by e.g. a wet tower. There are also other possibilities: for example, to use heat exchangers in swimming pool for water heating, working as MT cooler. A ground heat exchanger may also be used, having two functions as re-cooler in summer or a heat source for a heat pump, since the adsorption cycle is easily reversible and may be used as a heat pump in winter time.

The total system has potential also for refrigerating purposes using the city central heat distribution system in summer. This is one of the possibility to increase total efficiency of the CHP (Combined Heat and Power) working in Rankine cycle in summer time.

5. Adsorption-compression system description

One example of the ACS 08 characteristics is shown on the Fig. 6 for 75°C temperature of the heat source (Driving Temperature).

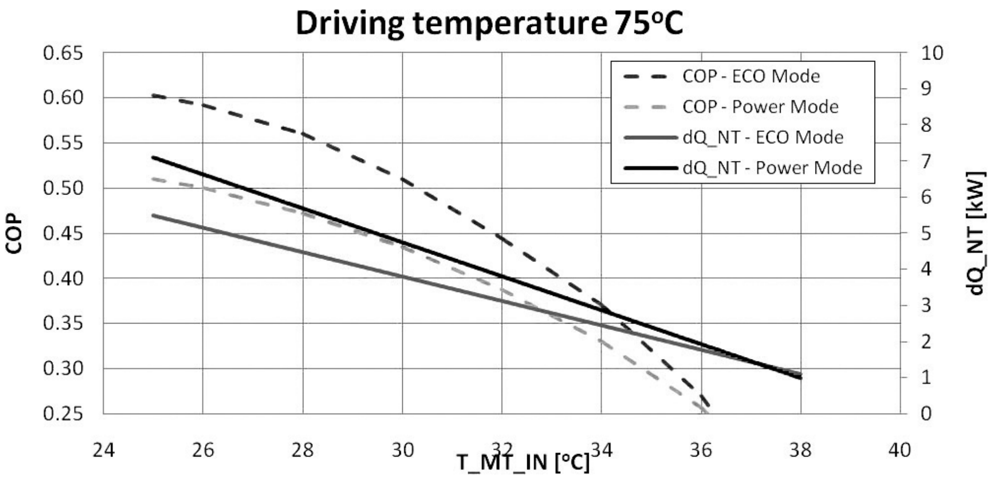

Fig. 6. The COP diagram for SORTECH ACS08 adsorption chiller

Rys. 6. Wykres COP dla adsorpcyjnego chillera SORTECH ACS08

Combining both cycles adsorption as HT, and CO_2 compression as LT cycle the total two stage hybrid system parameters may be calculated (Fig. 7, 8).

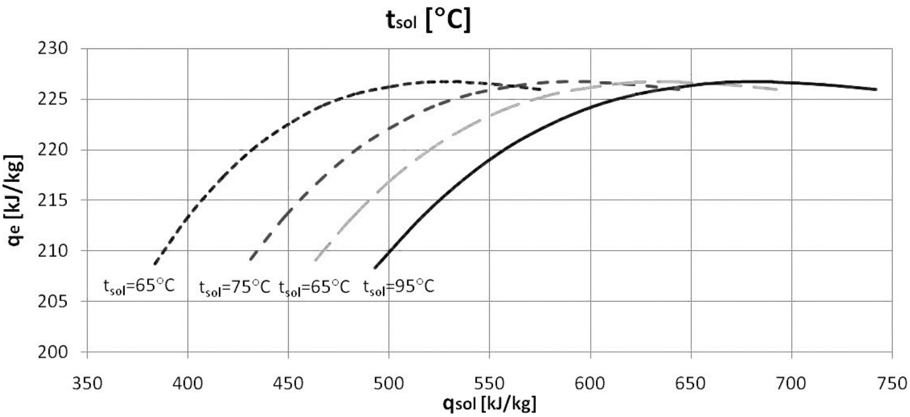

Fig. 7. The specific cooling energy diagram for hybrid adsorption-compression system simulated for different specific energy and desorption temperatures

Rys. 7. Wykres chłodniczej energii właściwej hybrydowego adsorpcyjno-sprężarkowego systemu dla różnych wartości zasilającej energii właściwej i temperatur desorpcji

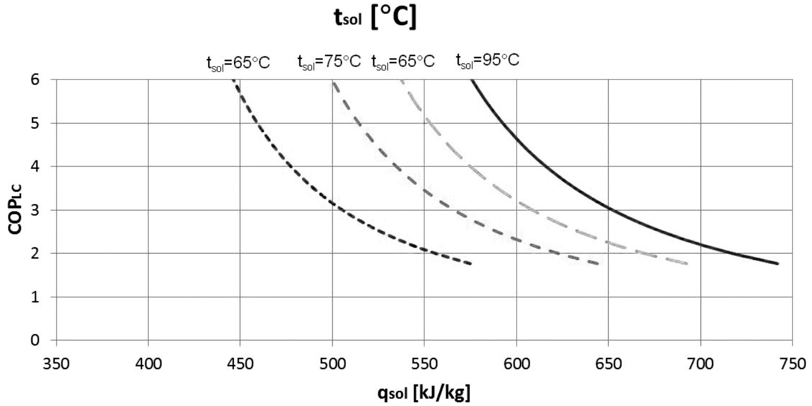

Fig. 8. The COP diagram for hybrid adsorption-compression system simulated for different driving temperatures related to the solar heat

Rys. 8. Wykres COP dla hybrydowego adsorpcyjno-sprężarkowego systemu dla różnych wartości temperatur czynnika grzewczego z kolektora słonecznego

In the Fig. 7 the relationship between specific evaporation enthalpy and heat consumption by the adsorption system is shown, for different temperatures of the heat source. In fact the total COP of the hybrid system shall be calculated only for LT cycle. The COP for the adsorption system is not really important assuming that the free waste or solar heat is used.

Finally the COP of the LT stage is shown in the Fig. 8 for different driving temperatures with the relation to the solar heat.

The highest values of COP are calculated for evaporation temperature -5°C. In this case the compression ratio is relatively low and so is the compressor work and COP.

6. Conclusions

6.1. Absorption-compression system

The low COP of the one stage CO_2 refrigerating system working with the condensation temperature above the critical point was the basis of the idea of hybrid system presented in this paper. The LiBr/H_2O absorption gains nowadays a lot of applications. There are several papers on the simulation and experimental analysis of the use of solar heated lithium-bromide air conditioning and heat pump systems. There are no experimental or theoretical analysis of such a hybrid system as presented here in the published articles. In this paper the extension of the application of the lithium bromide absorption system for two stage hybrid refrigeration use is presented. The total COP of the presented hybrid system is relatively low. For the high temperature heat source of desorber the total COP for the hybrid system is within 2–2.5. With low temperature waste heat source total achievable COP is within the range 1–1.4.

This idea may be useful on two conditions:

– the waste or renewable heat source is available, the temperature in the lowest case may be above 55°C when applying half effect system for absorption with COP 0.3–0.4,
– the evaporator H_2O/condenser CO_2 is designed individually for maximum performance.

Although there are disadvantages of the hybrid system, there is a possibility to use it as a part of a complete heating/air conditioning/refrigerating system, utilizing waste heat or solar collectors, with ground heat exchanger. In this case this would be energy friendly and efficient solution.

6.2. Adsorption-compression system

The idea of hybrid two stage (H_2O adsorption)-(CO_2 compression) system is new. The designed system is currently under construction in the Laboratory of Thermodynamics and Thermal Machines Measurements at the Cracow University of Technology. The simulated results of the system work will be the basis of the real system analysis. The results shown in the paper are based on the simulation and producer's data.

The reduction of the compressor work comparing to the conventional one-stage or two-stage compression refrigeration system using CO_2 as a working fluid is significant. There is also significant reduction of the discharge pressure in the system.

The idea of coupling two systems is also interesting because of the future development possibilities. The source heat used here: solar collectors may be easily substituted by the engine and compressor cooling heat, when using engine driven compressor.

During cold seasons or in the nights the direct cooling circuit for CO_2 condenser using ambient conditions may be used, and then the adsorption cycle may be reversed and used for heating. The re-cooling system can be used for swimming pool heating.

The system shown here, as it is, is very expensive, but the possibilities of the total integration: refrigeration, air conditioning, heating in one system will reduce unitary costs and increase the system usage time.

This paper is a part of development project N R06 0002 10 0936/R/T02/2010/10.

References

[1] Florides G.A., *I Design and construction of a LiBr – water absorption machine*, Energy Conversion and Management, 44, 2003, 2483-2508.
[2] Mandani F., Ettouney H., El-Dessouky H., *LiBr-H2O absorption heat for single-effect evaporation desalination process*, International Compressor Desalination, 128, 2000, 161-176.
[3] Grzebielec A., *Experimental study on adsorption heat pump*, Archives of thermodynamics, Vol. 30, Wydawnictwo IMP, Gdańsk 2009, 189-200.
[4] SorTech Adsorption Chiller ACS 08/ACS 15, Design manual, Version 2.2, July 2009.