ABSORPTION REFRIGERATION SYSTEMS FOR WASTE HEAT RECOVERY AT THE SILICATE INDUSTRY

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ABSTRACT

The glass, ceramic and cement plants are energy intensive industrial systems, releasing high amounts of greenhouse gases. The dissipation of the waste heat reduces their profitability, energy and ecological efficiency. The absorption refrigeration systems are successful solutions for the recovery of thermal energy at different temperature levels to obtain useful cooling and heating powers for technological needs, and for air conditioning of administrative and industrial buildings. Although the absorption units in a heat pump and refrigeration cycle are currently used in building and industrial systems, they have not yet penetrated widely into the silicate factories.

This paper discusses possibilities for the applications of basic types of absorption cycles at heat pump and refrigeration modes to utilize waste energy at different temperature levels in glass, ceramic and cement plants. The examined variants are demonstrated via examples, diagrams and analyses of the possible energy saving.

Keywords: absorption refrigeration system, waste heat recovery, glass industry, ceramic industry, cement industry, heat pump, air conditioning.

INTRODUCTION

The recovery of the industrial waste heat is a key energy saving activity with positive financial and ecological effects [1]. Waste thermal flows at different temperature levels can be utilized by absorption refrigeration systems (ARS) for heating and cooling applications [2 - 10]. The absorption technologies have lower performances at the heat recovery in comparison to the vapour-compressor refrigeration systems. However, the ARS are thermally driven at negligible consumption of electrical energy and operate silently. In addition, the absorption cycles use binary mixtures of fluids that contributes less to the global warming or ozone depletion in comparison to the freons [6]. Considering these advantages, national and European regulations in the field of the energy efficiency stimulate the integration of absorption cycles in industrial technologies for air conditioning, process cooling and heating [11]. The ARS can be thermally driven by the energy flows of steam, hot water, other technological fluids, exhaust gases and fuels [11, 12]. Absorption technologies have been introduced in the recent decades in ceramic, glass and cement enterprises for utilization of industrial waste heat [2, 5, 10, 13]. However, due to the complexity of absorption cycles and the lack of experience in this direction, the application of ARS is still limited. Currently, a small number of APR are used as chillers for water-cooling for air conditioning of buildings in our country. Absorption units are still lacking in the industrial technologies in Bulgaria, although there are sources of waste heat at different temperature levels, suitable to drive thermally ARS. The aim of this study is to systematize advanced solutions for the utilization of waste heats in the silicate plants via absorption systems, considering the specifics, parameters and features of the available thermal flows and the needs for heating and cooling in the process and the industrial buildings.

EXPERIMENTAL

Absorption refrigerator systems for industrial waste heat recovery

ARS are in the process of continuous development in terms of technologies, designs, binary mixtures and control systems. A brief description and classification of ARS, applicable for recovery of industrial waste energy in the silicate plants, is given below.

The absorption cycles include heat exchangers as generators, where the thermal energy is supplied for boiling of binary mixtures; condenser, where the rich of refrigerant vapour is cooling and condensing; evaporator in which the liquid refrigerant evaporates, heat exchanging with the cooled media, and absorber, where the poor of refrigerant liquid absorbs the evaporated refrigerant vapour, releasing heat (Fig. 1). Expansion valves, circulation pumps, recuperative heat exchangers, rectifiers and other units are used additionally to improve the performance of ARS. The most used binary mixtures are NH_3 (refrigerant) - H_2O (absorbent) and H_2O (refrigerant) - LiBr (absorbent). However, there are another fluid pares, successfully applied in ARS, as NH_3-$LiNO_3$, NH_3-NaSCN, H_2O-KOH, H_2O-LiCl etc. [6].

Depending on the need for pumps for forced circulation of the binary solution in the absorption units, the ARS are divided into pump and diffusion installations. In the diffusion absorption refrigerators, the circulation takes place by means of buoyancy forces created in the generator at the boiling of the refrigerant.

According to the numbers of the levels of the heat input, ARS can be single effect (with one generator) and multi-effect (with two or more generators). The temperature of the hot flows on the generator inlet is between 80°C and 120°C at the single effect absorption systems. Double effect absorption systems work with heat supplied flows with higher temperatures.

According to the number of absorption and evaporation levels, expressed by pressures and saturation

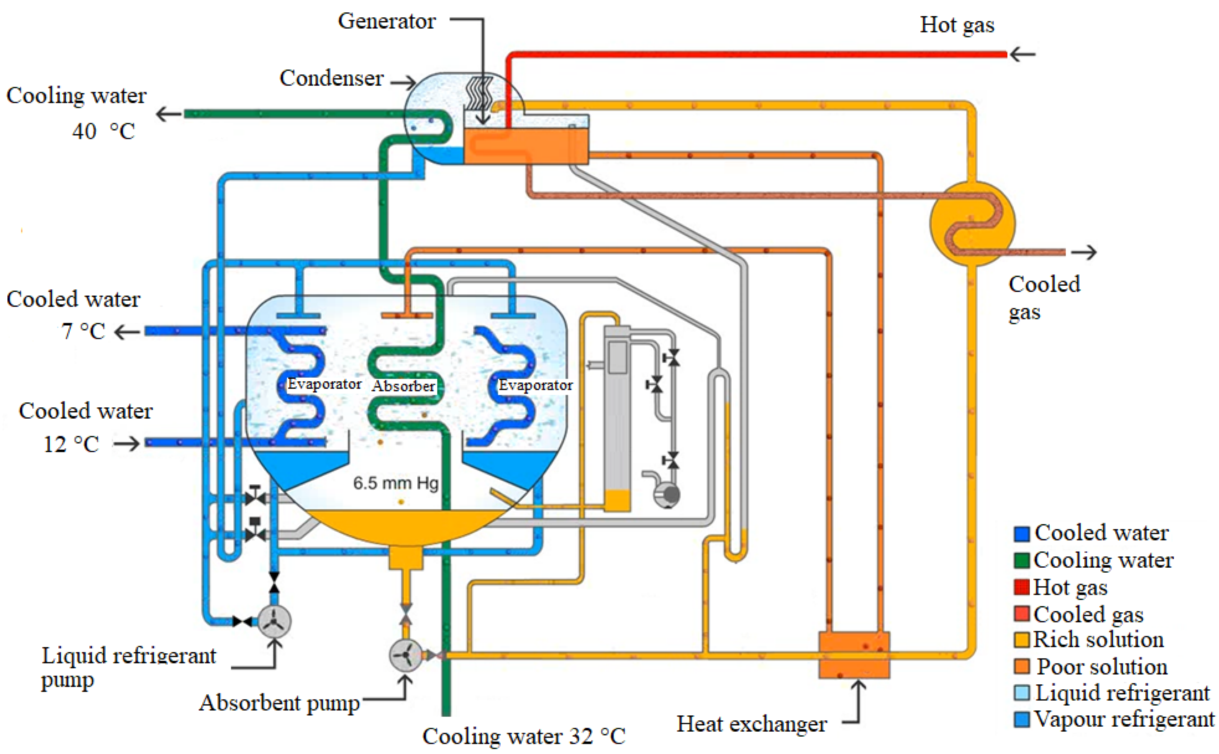

Fig. 1. One stage, single effect absorption chiller with H_2O - LiBr binary mixture for utilisation of the thermal energy of exhaust gases [12].

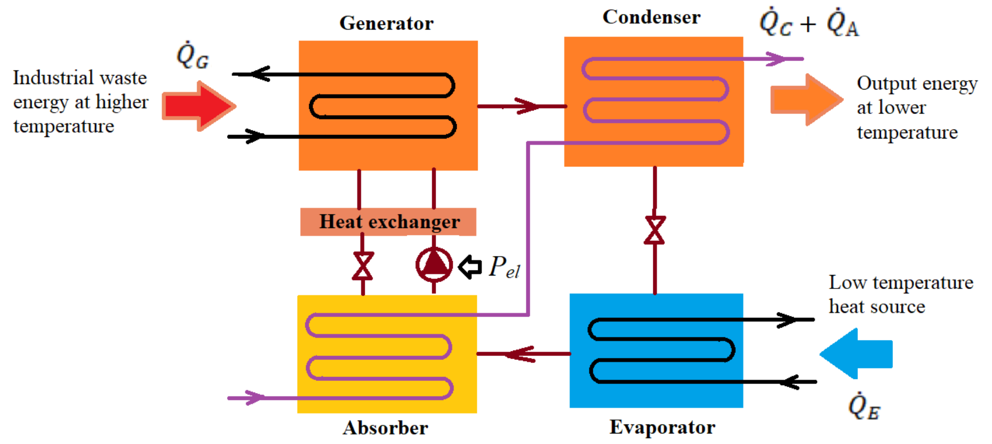

Fig. 2. One stage, single effect absorption heat pump Type 1.

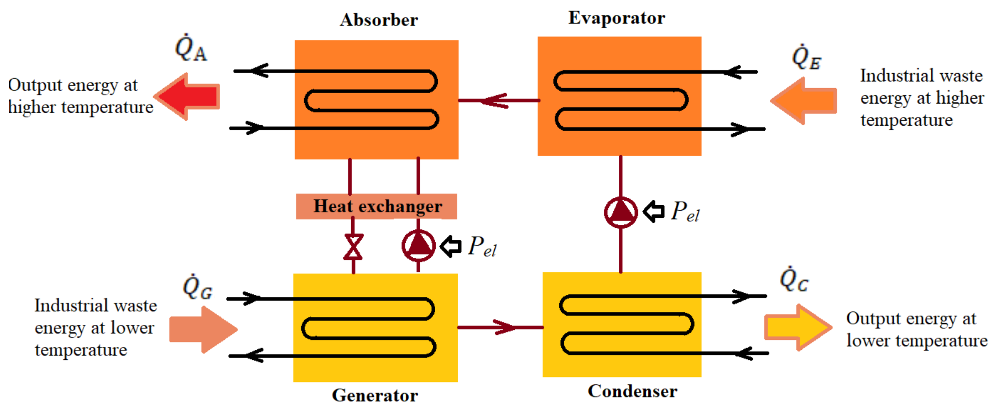

Fig. 3. One stage, single effect absorption heat pump Type 2.

temperatures, ARS can be one, two or more stages. In both cases, the number of generators can be one or two. These systems are appropriate when two different refrigeration temperatures must be achieved and the capacity requirements for the stages are large. The refrigeration temperature range is between 5°C and -55°C.

The cooling of a chosen media due to the absorbed heat in the evaporator is the useful effect at refrigeration cycles. The absorption chillers collect waste heat from different industrial processes to cool water for air conditioning of buildings (Fig. 1). The binary mixture, predominantly used in absorption cycles for building air conditioning, is H_2O - LiBr solution.

The thermal energy, released in the condenser and the absorber is utilized in the heat pump cycle. Two variants of the absorption heat pumps have been developed, depending on the levels and the locations of the heat inputs and outputs [6]:

- Type 1 (conventional technologies): the pressure and average temperatures in the condenser and generator are higher compared to those in the evaporator and absorber (Fig. 2);

- Type 2 (so-called inverse absorption heat pumps or absorption heat transformers): the pressure and average temperatures in the condenser and the generator are lower than those in the evaporator and the absorber (Fig. 3).

Additionally, ARS can work as thermal energy storage system (Fig. 4). In the thermally charging of ARS, the rich of refrigerant solution is generated and stored in the solution tank. At the same time, liquid refrigerant is stored in the refrigerant tank after the

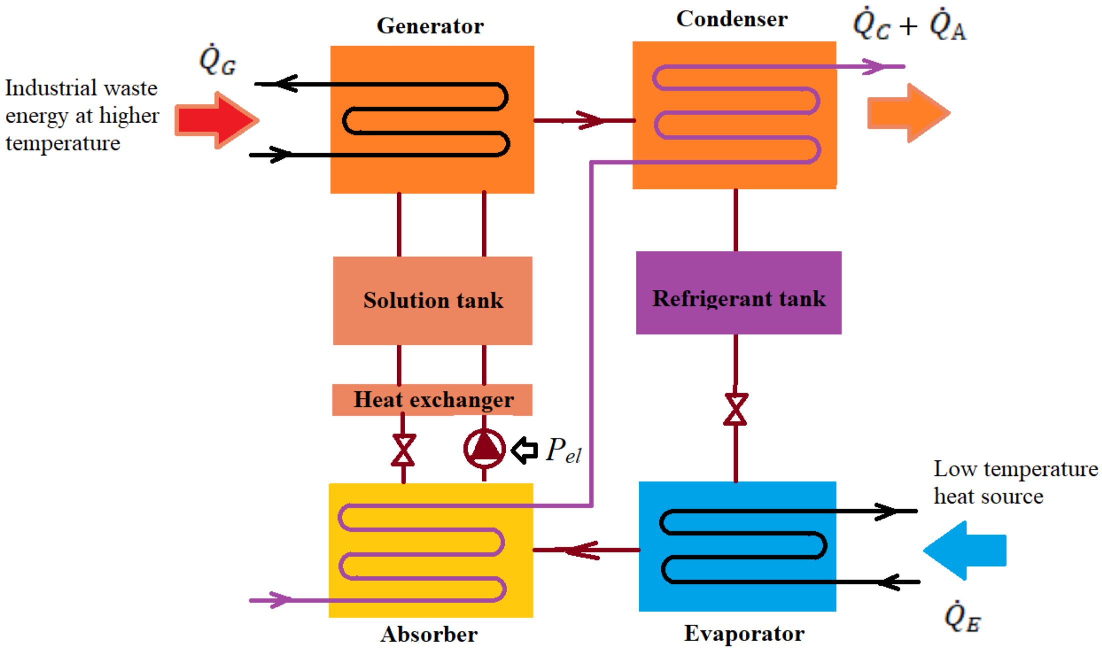

Fig. 4. Absorption heat storage system.

condensing. In the thermally discharging process, the liquid refrigerant evaporates in the evaporator, and the vapour refrigerant is absorbed in the absorber by the strong solution.

The absorption units operate most efficiently at so-called hybrid cycle when the cooling and heating effects are simultaneously utilized [14, 15].

The respective coefficients of performances of ARS are:

Cooling mode:

$$COP_c = \frac{\dot{Q}_E}{\dot{Q}_G + P_{el}} \quad (1)$$

Heating (heat pump) mode:

$$COP_h = \frac{\dot{Q}_C + \dot{Q}_A}{\dot{Q}_G + P_{el}} \quad (2)$$

where $\dot{Q}_G$, $\dot{Q}_E$, $\dot{Q}_C$, $\dot{Q}_A$, and P_{el} correspondently are the input heat flows in the generator and the evaporator, the released heat flows in the condenser and the absorber, and the electrical power of the circulating pumps [W].

A classification of most used ARS for industrial waste heat recovery is given in Table 1. Higher coefficients of performance of ARS at heat pump cycle are obvious. However, the temperatures of the heated fluids are similar or smaller in comparison to the driving temperatures on the generator inlets. The coefficient of performances at cooling mode are higher at double, triple effect and double stage ARS, but the investments for these systems are also higher. The Type 2 absorption heat pumps allow obtaining of higher temperatures in comparison to the driving ones, but at relatively small COP_h.

RESULTS AND DISCUSSION

Possibilities to recovery the waste thermal energy in silicate plants via ARS

Information about waste thermal energy flows in the silicate factories is summarized in Table 2. The temperature levels of the heat carriers are determined according to the data of the relevant enterprises and the literature for the design of thermal equipment in the silicate industry [16, 17].

The industrial buildings in the cement and glass factories with high-temperature equipment, mentioned in the table above, need cooling to maintain appropriate room conditions, especially during the summer period.

Table 1. Coefficients of performance of ARS for industrial waste heat recovery and required hot gas temperatures t_g on the generator inlet.

	Heat pump mode for heating applications	Refrigeration mode for cooling applications	Absorption heat storage system for heating applications
Single effect	COP_h є (1 - 1.8) t_g є (50 - 120)°C	COP_c є (0.3 - 0.75) t_g є (80 - 120)°C	COP_h є (0.4 - 0.6) t_g є (80 - 120)°C
Double effect	COP_h є (1 - 1.8) t_g є (50 - 180)°C	COP_c є (0.8 - 1.3) t_g є (80 - 180)°C	COP_h є (0.4 - 0.7) t_g є (80 - 180)°C
Triple effect	COP_h є (1.2 - 1.8) t_g є (50 - 180)°C	COP_c є (1 - 2.1) t_g є (130 - 230)°C	COP_h є (1.1 - 1.7) t_g є (50 - 180)°C
Single stage	COP_h є (1- 1.5) t_g є (50 - 120)°C	COP_c є (0.3 - 0.75) t_g є (80 - 120)°C	COP_h є (0.4 - 0.6) t_g є (80 - 120)°C
Double stage	COP_h є (1.2 - 1.8) t_g є (50 - 120)°C	COP_c є (0.3 - 1.8) t_g є (50 - 180)°C	COP_h є (1.1 - 1.6) t_g є (50 - 120)°C
Absorption heat pump Type 2	COP_h є (0.2 - 0.6) t_g є (50 - 120)°C	Non-Applicable	Non-Applicable

However, the high temperature waste heats on positions 1 - 3 in Table 2 are impossible to be recovery via refrigeration systems and heat pumps without pre-mixing of the hot flows with colder ones, as the maximal operating temperature of the metal heat exchangers of ARS is about 500°C [16]. Even more, these waste energies are successfully utilised to heat the combustion air and the raw materials at the cement factories.

Solid particles (dust) exist in the exhaust flue gases and the hot air at the raw material drying and treatment, especially in the heat exchangers in the cement factories. So unwanted material deposits on the heat transfer surfaces on the generator are expected to be formed. These fouling deposits would decrease the performance of ARS and require higher operating costs for repairing and changing of the heat exchangers.

The energy of the exhaust gas flows at the periodically kilns and ovens with non-stationary temperatures could be recovery via absorption heat storage systems (Fig. 4) for heating of the administrative and industrial buildings or for drying processes. However, the cost of the energy storage ARS is higher and a detailed analysis of the profitability of investments is required before their implementation.

The exhaust air flows at the thermal aggregates for annealing, tempering and strengthening of glass products do not contain dust and have suitable temperatures to be used as heat source in ARS. According to [18], the amount of the energy, consumed in the post-forming operations in the glass factories, generally ranges from 13 % - 17 %. The energy consumption for the air conditioning of the industrial buildings in the same sector is about 3%. The thermal losses of the post-forming glass systems, including the waste energy, carried by the exhaust gases, depend on the efficiency of the equipment. For example, the efficiency of the annealing glass furnaces is between 16 % and 25 % [19]. At average efficiency of 20 %, the thermal loses are 80 % of the energy input in the annealing furnaces and minimum 9 % of the total energy, consumed in the glass factory. Therefore, if the waste energy flows of the annealing furnace is converted into cooling power via absorption chiller, it is enough to cover the energy needs for the air conditioning of the factory building even at ARS with lower COP_h. Additionally, the waste heat at the post-forming processes of the glass can be successfully utilized using absorption heat pumps to obtain hot water for heating, domestic and technological needs.

Table 2. Waste heat flows at ceramic, glass and cement factories at different temperature levels.

№	Thermal equipment	Thermal energy carriers	Flow temperature and remarks
	High temperatures		
1	Clinker kilns	Exhaust flue gases at the kiln outlet	1000°C - 1200°C
2	Continuous glass furnaces	Exhaust flue gases at the furnace outlet.	Non-stationary temperatures at the regenerative furnaces. 1300°C - 1450°C
3	Periodically kilns for firing of ceramics	Exhaust flue gases at the kiln outlet.	Non-stationary temperature following the maintained temperature curve. 1000°C - 1700°C
	Average temperatures		
4	Regenerative and recuperative heat exchangers for flue gases heat recovery at glass furnaces	Exhaust flue gases at the heat exchanger outlet.	Non-stationary temperatures at regenerative furnaces. 200°C - 300°C
5	Thermal equipment for post-forming processes in the glass factories (annealing, tempering and strengthening of glass)	Exhaust airflow at the outlet of the units.	230°C - 600°C
6	Clinker coolers	Exhaust airflow at the outlet of the coolers.	300°C - 600°C
7	Heat exchangers for flue gases heat recovery at rotary clinker kilns	Exhaust flue gases at the outlet of the heat exchangers.	200°C - 350°C
8	Kilns for raw materials treatment	Exhaust flue gases at the kiln outlet.	200°C - 650°C
9	Heat exchangers for heat recovery at periodically kilns for firing of ceramics	Exhaust flue gases at the exit of the heat exchangers.	Non-stationary temperatures, following the maintained temperature curve. 200°C - 650°C
	Low temperatures		
10	Dryers of ceramics	Exhaust flue gases or air flows	40°C - 70°C
12	Dryers of raw materials	Exhaust flue gases or air flows	40°C - 120°C
13	Continues ceramic furnaces	Exhaust flue gases at the furnace outlet.	85°C - 120°C
14	Condenser heat exchangers	Exhaust flue gases at the outlet of the heat exchangers.	32°C - 88°C

CONCLUSIONS

The advanced absorption refrigeration technologies allow industrial waste heat recovery for variety of heating and cooling application. However, their application in the silicate industry requires detail life cycle cost analysis due to the dusty exhaust gases in the cement and raw materials technologies, and the non-stationary temperatures of the exhaust flows at the periodically operating equipment in the glass and ceramic factories.

The energies of the exhaust gases at the thermal equipment for post-forming processes in the glass plants are suitable to be utilized through absorption chillers and heat pumps for air conditioning of the industrial building. This will allow maintaining of comfortable working conditions in the factory buildings at nearly zero energy input for the air conditioning.

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