

# Working Characteristics of Small-scale Absorption Unit with Two-cylinder Design

POSPISIL J., BALAS M., BAXA M., FORTELNY Z.

Faculty of Mechanical Engineering

Brno University of Technology

Technicka 2896/2, Brno 61669

CZECH REPUBLIC

pospisil.j@fme.vutbr.cz <http://www.fme.vutbr.cz>

*Abstract:* - This contribution presents operation of the small-scale absorption units with focus on working stability of the operating parameters. The contribution discusses the long-term operation of LiBr-H<sub>2</sub>O absorption units with consideration of corrosion, slit forming processes and production of incondensable gases. The one-stage experimental absorption chiller with exactly same design of desorber-condenser and absorber-evaporator was built up at the Brno University of Technology in 2008. This experimental absorption unit operates with LiBr-H<sub>2</sub>O working pair. Design of the unit keeps two-cylinder conception, which is common for large-scale absorption units. Heat transfer between the working fluid and the heating/cooling water is realized with utilizing of falling film cooper pipe registers. The cooling capacity of the absorption chiller was designed 6 kW on temperature level 9 °C. The contribution introduces design of the one-stage experimental absorption unit, building, operation experiences and the results of a carried out measurements. The measurements were focused on assessment of heat transfer on the falling film tube bundles and the entire COP evaluation. Four independent pumps enabled to test the influence of a flow rate change in different loops of the absorption unit.

*Key-Words:* - absorption unit, falling film, heat transfer, working stability, tube bundle

## 1 Introduction

Absorption cycles in cooling systems or heat pumps represent an alternative to predominant compressor refrigerating cycles. Advantage of the absorption cycles is their much lower consumption of electricity achieved by replacement of a compressor by so called a thermo-chemical compressor. A thermo-chemical compressor ensures absorption of the refrigerant vapor in an absorption liquid, pumping of the created solution to a higher pressure level, and desorption of the refrigerant vapor from the solution. The main benefits of the absorption cycles are the following: very low consumption of electricity (only up to 5 % of the cooling capacity), possible utilizing of thermal energy obtained from renewable sources (solar radiation, biomass combustion) or whatever source of waste heat energy with temperature above 80 °C for production of cool. Another positive effect of the absorption cycles is utilizing of water as refrigerant. Therefore, using of the absorption cycles cuts down utilizing of harmful refrigerants circulating in the compressor refrigerating cycles (green house gasses). The absorption cycles facilitates the use of renewable sources. Disadvantage of the absorption cycles is necessity to create a assemblies of a bigger size that are more complex if compared with a compressor

cycle. From this reason, the absorption cycles are used predominantly in large industrial applications. Development of the units with smaller capacity is conditioned by better knowledge of processes taking place in the key parts of the absorption cycles. It can help to design small compact units. An absorption chiller assembly commonly contains two key components, namely the desorber with an integrated condenser and the absorber with an integrated evaporator. These two key components have some similar features, but the final design can be significantly different. The one-stage experimental absorption chiller with exactly same design of desorber-condenser and absorber-evaporator was built up at the Brno University of Technology in 2008. Its design details, operation and long term stability of working parameters are discussed in this contribution.

Information about different working mixtures for the absorption cycles can be obtained from accessible studies. One from the basic operation requirements on the working-pair (forming working mixture) is excellent solubility of coolant in an absorbing liquid. Only the working pairs capable to operate in the ranges of convenient pressures and temperature levels are farther utilizable from the group of mixtures fulfilling the requirement of

excellent solubility. Another indicators for selection of the convenient working pair are accessibility, market price and environmental friendless.  $\text{NH}_3\text{-H}_2\text{O}$  and  $\text{H}_2\text{O-LiBr}$  are predominantly used in the absorption cycles with consideration of requirements mentioned above.

In the first mentioned working mixture, ammonium is considered as coolant soluble in water. Strong bed-smell, toxicity, inflammability and explosiveness are the main disadvantages of ammonium. Water is coolant soluble in the mixture  $\text{LiBr-H}_2\text{O}$ . The pure water is clear, environmentally friendly coolant without any smell. Its advantages lead to engagement in office buildings and residences applications. The absorption cycles with  $\text{LiBr}$  operate in a low-pressure atmosphere, deeply below the atmospheric pressure. This is necessary for boiling of water in the temperatures slightly above  $0^\circ\text{C}$ . And the low-pressure atmosphere helps to prevent the system against undesirable leakage of working fluid. The working pair  $\text{LiBr-H}_2\text{O}$  is utilized predominantly in air-conditioned sector. In the following sections, attention will be focused only to the  $\text{LiBr-H}_2\text{O}$  working pair. This working pair is used in the majority of the air-conditioning units.

Design of the key elements (absorber, desorber and evaporator) is commonly based on the falling film tube heat exchangers with horizontally oriented tubes in a vertical adjustment. The absorber and the related processes have been studied in detail recently [1]. However, the problems of heat transfer on the falling film tube heat exchangers working in low pressure atmosphere remained in the shadow of another processes, limited number of works were devoted to it. There are several studies focused on the vaporization of a liquid film from the heated surface [2]. The conditions of the low pressure atmosphere ( $10 - 1 \text{ kPa}$  in the absolute value) corresponding to the working parameters of the absorption cycles yield important specific features from the point of view of the liquid film creation and the related heat transfer.

## 2 Absorption cycle

The absorption cycle consists from a generator, an absorber, a condenser and an evaporator, see the Fig. 1. These parts are connected by pipes for transport of liquid mixtures and vapors. The throttle valves are used for depressurizing of liquid mixtures. The pump enables to pressurize liquid mixture.

The liquid refrigerant evaporates in an evaporator. The heat flux  $Q_2$  is taken away from an evaporator surrounding. The refrigerant vapors are led to the absorber, where the poor liquid mixture absorbs the refrigerant vapors. The absorption heat  $Q_4$  is released during the absorption process. The saturated liquid mixture is transported to the generator operating on a higher-pressure level.

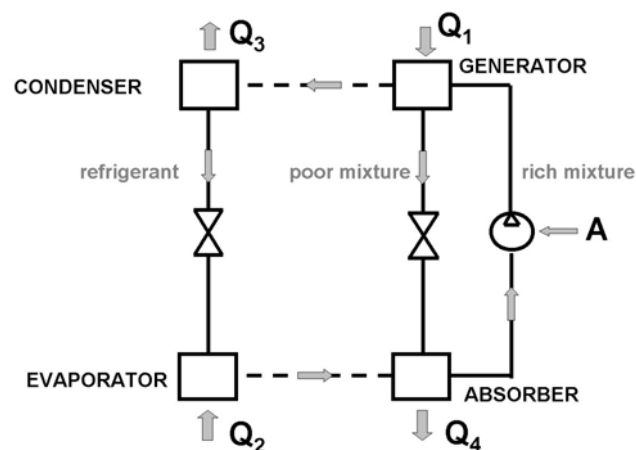


Fig. 1 The simple one-stage absorption cycle

The driving heat  $Q_1$  is supplied to the generator by hot water from a boiler. The refrigerant vapors release the mixture during increasing of the mixture temperature. The poor hot mixture returns to the absorber via a throttle valve. The released refrigerant vapor continues to a condenser. The vapor is cooled to lower temperature and condensate to the liquid form. The condensation heat  $Q_3$  is released during this process. Then the liquid refrigerant passes through another throttle valve and enters an evaporator.

The coefficient of performance (COP) evaluates absorption cycle effectiveness

$$\text{COP} = Q_2 / Q_1. \quad (1)$$

The mixture of water and  $\text{LiBr}$  is considered as the most frequently used working medium in absorption cycles. There is a physical limitation for convenient working temperature of absorption cycles [3]. The COP is approximately constant for all variations of convenient temperatures. The higher driving temperature enables to use the two stage cycle ( $2^\circ$ ) with the higher COP value. Basic parameters of the one-stage and the two-stage cycles are written in the table 1.

The lowest temperature of the driving hot water is required at the temperature level  $90^\circ\text{C}$  for correct operation. The corresponding COP value is 0.7 [3]

for the 1° absorption system. The cooling capacity of the absorption cycle is calculated as

$$Q_2 = Q_1 \times \text{COP}. \quad (2)$$

The temperature of waste heat water leaving the absorption system is assumed 40 °C. Amount of the waste heat  $Q_3$  is calculated as

$$Q_3 = Q_1 \times (1 + \text{COP}). \quad (3)$$

Table 1 Characteristics of the H<sub>2</sub>O-LiBr absorption cycles

	1° absorption cycle	2° absorption cycle
Driving temperature	90-120°C	> 120°C
Cooling temperature	> 5°C	> 5°C
COP	0.7	1.2

### 3 Experimental absorption unit

#### 3.1 Description

The experimental one-stage absorption unit was designed for cooling capacity 6 kW. Mixture of LiBr-H<sub>2</sub>O was used as the appropriate absorption working pair. Another required operation parameters were:

- chilling temperature 7 °C,
- maximal temperature of desorption 95 °C,
- maximal temperature of cooling water 45 °C.

The equations for conservation of mass and energy were used for the design calculation of parameters in all points of the absorption cycle.

Numerous parametrical studies were done for determination of the working parameters with the maximal COP value. The maximal modeled COP value was 0.8165. The ABSIM software tool [3] was used for carried out calculations. The Fig. 2 shows the corresponding temperature of working flows in the designed absorption cycle. The heat exchanger (HEX) is the only external heat exchanger used for improvement of the COP value.

Design of the experimental absorption unit keeps two-cylinder conception.

The desorber, the absorber and the evaporator utilize same falling film tube bundles and the separate circulations loops, see the Fig. 3. Smooth cooper tubes with external diameter 12 mm were

used in all falling film heat exchanges in the experimental unit.

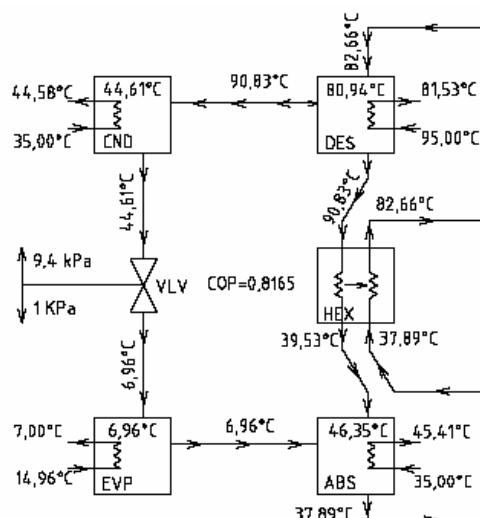


Fig. 2 Designed parameters of the absorption cycle

The pressure difference between the desorber with the integrated condenser and the absorber with the integrated evaporator is controlled by the hydraulic siphon. The hydraulic siphon utilizes static pressure of the mixture column to keeping the required pressure difference. Vapor can pass through the hydraulic siphon when the pressure difference between the desorber and the absorber rise above the required value. A vacuum pump serves for initial decrease of working pressure in the system and it periodically removes incondensable gasses from the absorption cycle during long-term operation. A plate heat exchanger is used as the recuperative heat exchanger for repetitive utilizing of heat with respect

to an actual temperature level and the necessary temperature drops. The absorption system was designed as self-controlled as possible. The liquid mixture level in the desorber is controlled by an overflow outlet. The working pressure level in the desorber is controlled by cooling power of the condenser. The cooling power is directly influenced by amount of cooling water flowing through the condenser tubes. From this reason, the working pressure level in the desorber can be controlled by actual cooling water flow. The pneumatic thermo-valve was installed in the cooling water circuit. The same pneumatic thermo-valve was used to control the required pressure level in the absorber. Operation of the pumps was without real-time control. The flow rates in all circulation loops were constant during operation periods.

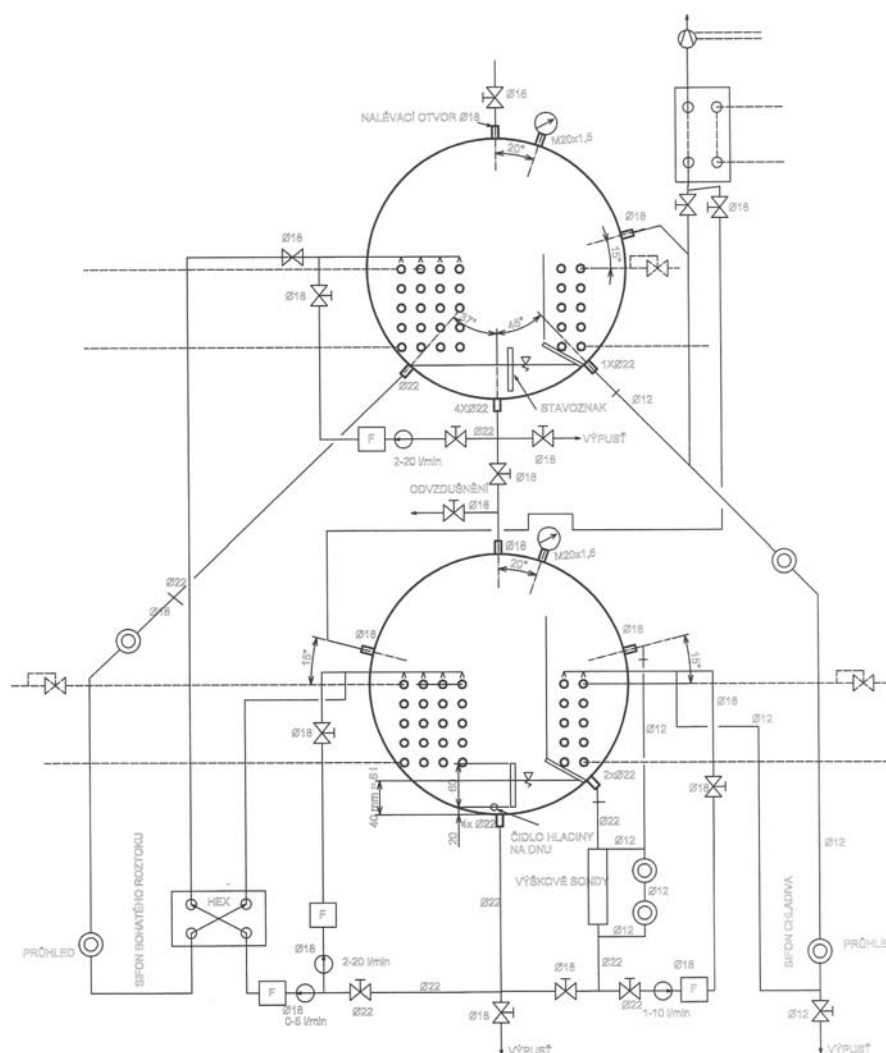


Fig. 3 Working schema of the 1° experimental absorption unit

The final design of the experimental absorption unit shows the Fig. 4 in form of 3D drawing with component description.

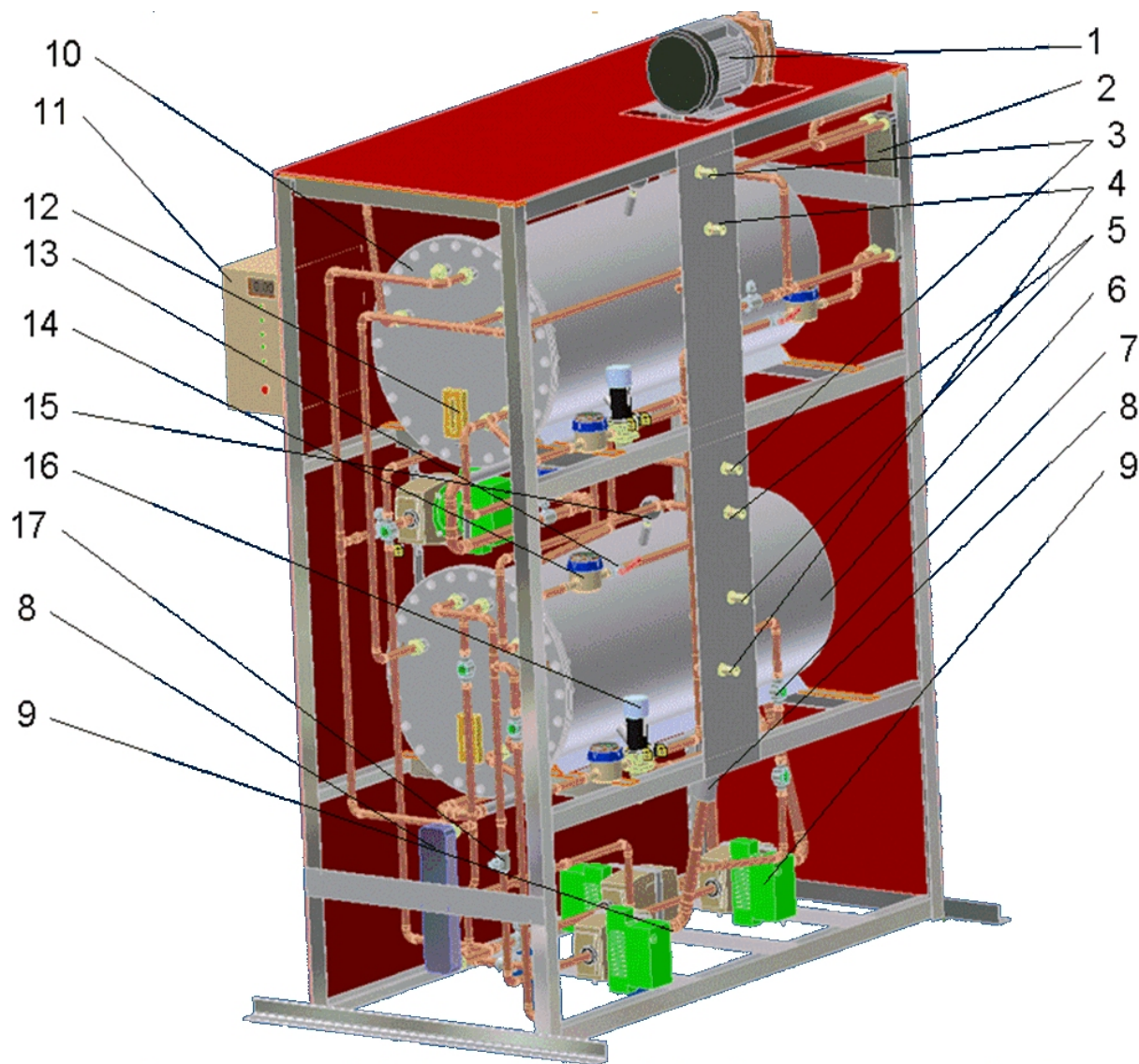
Crystallization of salt (LiBr) is one of the crucial points of the LiBr absorption unit operation. The Fig. 5 shows the absorption cycle in the p-t-x diagram.

The right hand border line denotes the crystallization line, identifying parameters with height potential to form crystals of LiBr. The suggested absorption cycle operates far enough from the crystallization line to prevent the unit against crystallization.

### 3.2 Heat transfer on falling film tube bundles

Film of the liquid phase flowing off the tubes of the falling film heat exchanger must cover as much tube

surface as possible. This helps to maximize the use of the heat transfer surface. During the heating of the liquid film and the vaporization, the heat is transferred from the liquid circulating in the tube via its wall into the falling film on the tube. The liquid film therefore needs to be continuously present at the widest possible surface of the falling film tubes, and at the same time, an intensive transfer of heat energy between the tube walls and liquid film must be ensured. This is a very demanding task because the initial creation of the film on the tube wall is connected with the distribution of the liquid on the tube, and in particular, with the size of drops, their frequency and impact velocity. The falling drop must have a sufficient velocity so as, after it falls down, the liquid film opens widely. When flowing off, this film extends into the whole outer perimeter of the tube. If the velocity of the falling drop is not



1 - vacuum pump, 2 - plate heat exchanger, 3 - connections for driving heating water, 4 - connections for cooling water, 5 - connections for chilled water, 6 - absorber with integrated evaporator, 7 - glass eye, 8 - separator, 9 - circulation pumps, 10 - desorber with integrated condenser, 11 - control unit, 12 - working mixture level identification, 13 - ball valve, 14 - flow meter, 15 - vacuum meter, 16 - temperature controller, 17 - GBC ball valve, 18 - plate heat exchanger

Fig. 4 3D visualization of the experimental absorption unit

sufficient, the liquid film spreads out only a little, and it does not reach the whole surface of the outer tube wall. In some cases, it can fall down over one half of the tube only.

The amount and the type of distribution of the liquid in the upper part of the heat exchanger have a crucial impact on the time behavior of the tube surface wetting. With a very small amount of liquid, the frequency of the falling drops is small too, and a

significant part of tubes remains non-wetted between the single impacts. With increasing amount of the distributed liquid, the area of a non-wetted surface is getting smaller. If the frequency is being raised, the next drop will fall on a sufficiently thick liquid film created by the spread of the previous drop, and as a result of insufficient absorption of the momentum in the boundary layer at the surface of the tube, it slides quickly off over the wetted tube

surface. Further increase in the amount of the falling film liquid results in creation of streams. These streams are wetting a smaller part of the tube surface. The liquid moves on the tube wall with higher speed in such conditions, which causes its separation on the bottom of the tube in direction that significantly turns away from the required vertical. In similar cases, the falling liquid can completely leave the bundle of horizontal tubes in a vertical adjustment. The characteristics of the liquid film, its stability, and the heat transfer from the tube wall in the liquid film are considerably influenced by the tube surface. In commercial applications, the use of falling film heat exchangers composed of plain tubes still prevails. However, tubes of different surface structures have appeared recently (micro ribbed, cross and bias grooving, corrugated surface etc.). Based on the available literature, these can increase the heat transfer by 1.5 – 5 times if compared with the plain tubes [5].

The experimental study was carried out on the falling film tube bundle with cooper tubes (external diameter 12 mm). Vertical distance of the tubes was set to 25 mm. The distribution leaks were circular with diameter 1.5 mm and spacing 10 mm. The experiments provided the optimum flow rate of the 1 m long distribution tube as 3.8 liters per minute. This flow rate was used in the experimental absorption cycle.

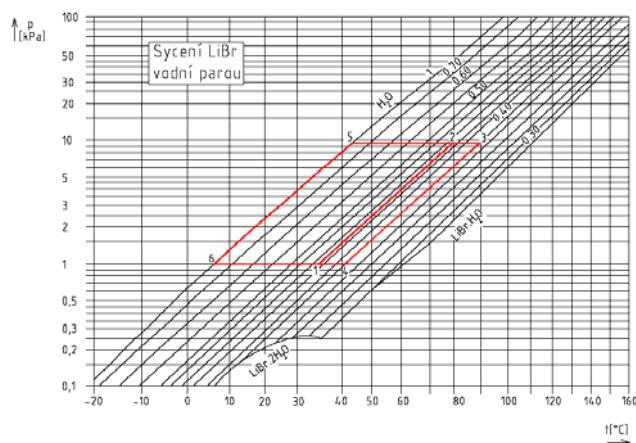


Fig. 5 Parameters of absorption cycle in the p-t-x diagram

### 3.3 Testing of the experimental unit

Long-term measurement of the operation parameters were carried out on the experimental absorption unit. Temperature and flow rate was monitored in all external connection loops (cooling water, chilled water, driving hot water). The Table 2

compares the designed temperature and the operating temperatures of the experimental absorption unit in all connection loops. Real COP<sub>c</sub> value reached averaged value 0.58.

Table 2 Designed and averaged operation temperatures of outlet flows

Outlet flow from component	Designed temperature [°C]	Averaged operating temperature [°C]
Desorber	82	89
Condenser	45	38
Evaporator	7	10
Absorber	45	36

Comparison of the outlet flows temperatures shows significant working temperature deviations from designed values. Lower level of the cooling water temperature leaving the absorber and condenser results from lower temperature of cooling water in the entire cooling water loop. Higher temperature of the chilled water leaving evaporator was caused by problem with stability of the low pressure atmosphere in the absorber. Higher temperature of the driving heat outlet flow indicates under-sizing of the desorber.

The parametrical studies were carried out with target to assess influence of main parameters on the entire cycle effectiveness. During these studies, particular studied parameters were changed to appreciate their influence on the entire efficiency.

The first, the influence of the working solution concentration was tested. In the absorption cycle the rich solution (LiBr-H<sub>2</sub>O) is pumped from the absorber to the desorber via the solution heat exchanger. The poor solution (less of water) comes back to the absorber from the desorber. The difference in water content of the rich solution and the poor solution influences the cooling capacity per unit of mass flow. This parameter influences consumption of pumping power. Smaller difference in the concentrations requires more energy for pumping and the solution heat exchanger of bigger size. Increase of the solutions concentration difference enables to use the smaller solution heat exchanger, less pumping power, but it requires higher desorption temperature. Influence of the solution concentration was tested by experiments and mathematical simulations. Obtained results are shown in the Fig. 6.

Significant influence of the concentration difference appears up to value 4 %. Another increasing of this parameter does not influence the entire cycle efficiency.

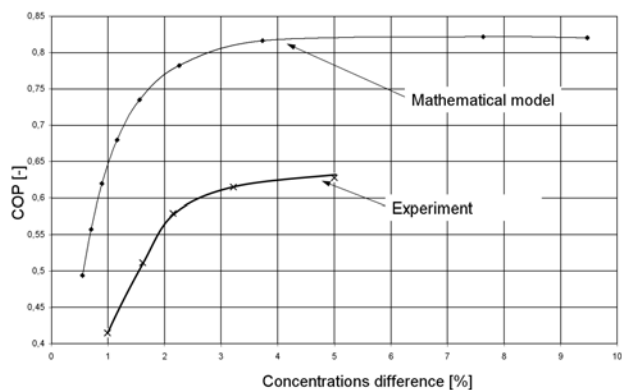


Fig. 6 The relation between the solution concentration difference and COP of the entire absorption cycle

The solution heat exchanger “HEX” (see the Fig.2) serves as the recuperative heat exchanger utilizing heat of the poor solution leaving the desorber to preheating of the rich solution entering the desorber. Design of this heat exchanger influences the entire cycle efficiency, too. The Fig. 7 and the Fig. 8 show relationship between the entire cycle efficiency and the solution heat exchanger power/efficiency.

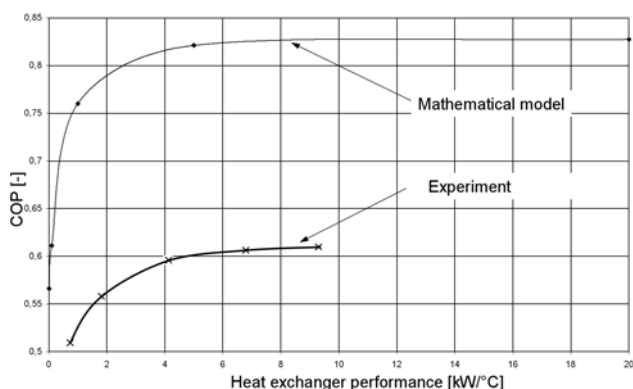


Fig. 7 The relation between the solution heat exchanger power and COP of the entire cycle

The chilling temperature level is one of the most important parameters significantly influencing the entire cycle efficiency. The presented absorption cycle uses water as coolant. Such system can be used only for the chilling temperatures above 0 °C to avoid freezing of water. Air-conditioning systems require temperature of chilling medium up to 15 °C. The influence of the chilling medium temperature was tested in the temperature range from 2 to 15 °C. The obtained results are presented in the Fig. 9. Generally, increase in temperature of the chilling medium improves the entire cycle effectiveness.

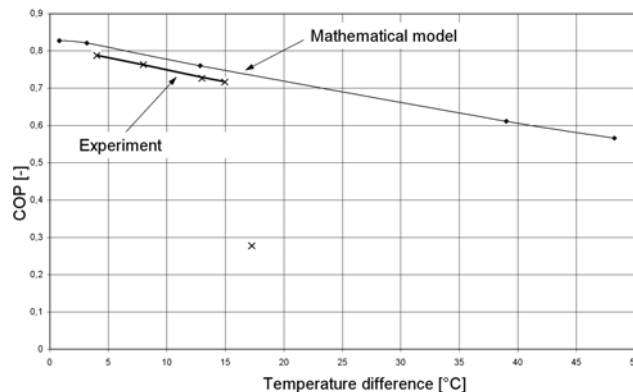


Fig. 8 The relation between the solution heat exchanger efficiency and COP of the entire cycle

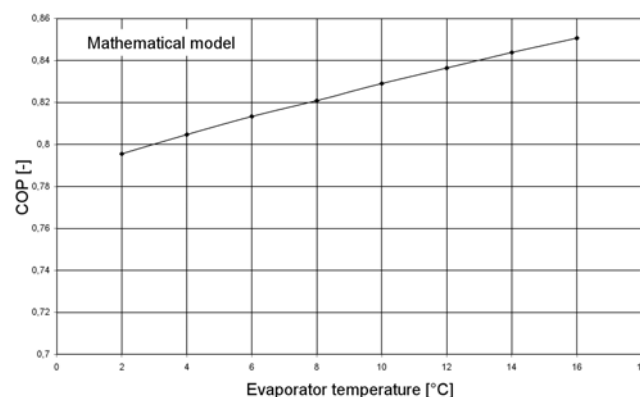


Fig. 9 The relation between the temperature of the chilled water and COP of the entire cycle

The temperature of condensation and the temperature of absorption are other important parameters influencing the entire effectiveness. Low temperature heat released during condensation and absorption is transported by cooling water to users or cooling towers. The Fig. 10 shows the relation between the cooling water temperature and the entire effectiveness of the cycle.

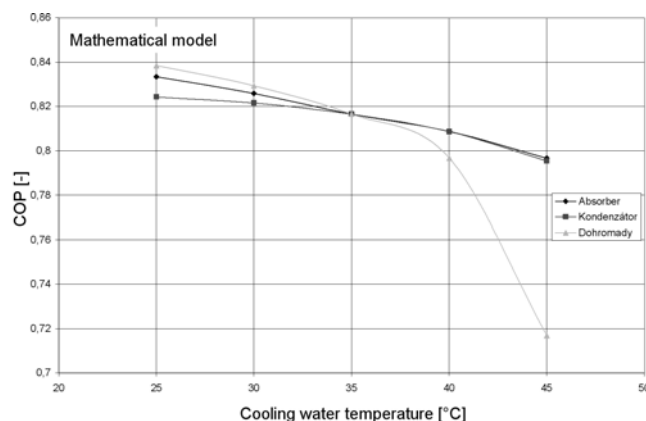


Fig. 10 Relation between the cooling water temperature and entire effectiveness of the cycle

## 4 Long-term operation

Long-term operation of absorption units is the basic requirement for meaningful utilizing of this technology. Therefore, long-term stability of working parameters has to be under close attention. Small-scale absorption cycles are more sensitive to change of working parameters in comparison with large-scale cycles. Stability of sequential circuits connected to the absorption cycle directly influences the entire cycle stability. Instability of the sequential circuit parameters cause temporary decrease of the entire COP, But it can't causes a no returnable damage of the absorption cycle. A control unit monitors working parameters and prevent the unit against no returnable damage. From this point of view, the desorber represents the most crucial point of the absorption cycle. Detail monitoring of pressure and temperature is necessary to prevent cycle against crystallization of the LiBr-H<sub>2</sub>O solution in the desorber. Mechanical dirt is another from the monitored parameters. Its existence significantly influences the working stability of absorption cycles. Mechanical dirt connected with manufacturing of components and the assemble process must be removed by proper washout before the final sealing of the cycle. This process removes so called "free mechanical dirt". But the cycle still contains mechanical dirt in the form of oxides covering surfaces of heat exchangers and other surfaces in contact with the working pair. These oxides can be removed by chemical way with utilizing of an appropriate solvent. If the oxides remain in the absorption cycle until filling the system by working mixture, the oxides are early or later released or dissolved by working fluid. The released oxides circulate in the system in form of scales and form the silt in the lowest part of the cycle. Generally, existence of oxides presents potential danger for stable operation of the cycle. Release of oxide scales can results in obstruction of components of the cycle. Dissolving of the oxides is danger due to chemical transformations of the working pair resulting in change its physical-chemical properties.

Mechanical dirt arises inside the hermetic cycle during operation period, too. Working mixture LiBr-H<sub>2</sub>O is partially aggressive, namely in high temperature range. It causes corrosion of steel and other materials in oxygen rich atmosphere. Then, the formed oxides are released from surfaces and subsequently create significant slit in lower parts of the cycle. Protection of the cycle against corrosion

is realized with utilizing of inhibitors passivating surface layers of the component material. Presence of incondensable gases is the most serious problem for long-term operation of absorption cycles working in low-pressure atmosphere. At this moment we can exclude incondensable gases penetrating in the system during assembly process and by accidental leakage.

Presence of incondensable gases has origin in technical imperfection of the system and can be excluded by appropriate technical solution. Strong vigilance must be kept to inner sources of incondensable gases. The hydrogen production is most important inner source of incondensable gases during passivating of surfaces by inhibitor dissolved in the working mixture. The passivating process is not single-shoot action, but this process occurs during all operation periods of the absorption cycles. Passivation process involves several chemical changes in steel surface structure. The chemical changes produce hydrogen as secondary product. A hydrogen production rate depends on type of used inhibitor and component material. But we must consider hydrogen production in all absorption cycles. Hydrogen production causes increase of partial pressure of incondensable gases in hermetic sealed absorption cycle and it decreases the absorption cycle efficiency. General effort to build up absorption cycle as absolutely hermetic assembly is unrealizable due to necessary to remove incondensable gases from the cycle. Removal of the hydrogen is convenient to realize as periodical manual or automatic process with respect to small hydrogen production rate. For this purpose, hydrogen must be separated and accumulated in an appropriate part of the cycle.

## 3 Conclusion

This contribution introduces design, building, operation parameters and long-term operation limits of the experimental one-stage absorption unit for cooling application. Design of the unit utilizes the two cylinder conceptions with exactly same geometry of the desorber-condenser and the absorber-evaporator. This experimental absorption unit operates with LiBr-H<sub>2</sub>O working pair. Increased attention was focused on a basic component of the unit – the horizontal tube bundle with vertical adjustment. From the carried out study, the optimal cooper tube vertical spacing in tube bundle is 25 mm for tubes with external diameter 12 mm. Self



regulation control was successfully engaged in the absorption cycle for control of the pure mixture outlet flow rate from the desorber and the pressure difference between low-pressure and high-pressure loops of the absorption cycle.

Numerous parametrical studies were done for determination of working parameters with the highest COP value, 0.8165. The falling film tube bundles need to be continuously wetted for intensive transfer of heat energy from the tube walls into the liquid film. The optimal falling film liquid flow rate was determined as 3.8 liters per minute on each 1 meter of the tube.

The main advantages of the absorption cycles are: their much lower consumption of electricity and a cut down utilizing of harmful refrigerants. Exactly same design of the absorber and the desorber confirmed decrease of the producing price and realistic achievement of the COP value 0.58, only with consideration of the solution plate heat exchanger.

Utilizing of absorption cycles offers new potential for effective utilizing energy sources. At the present time, absorption cycles are engaged predominantly in large-scale applications. Progress of this technology in small-scale applications is limited by numerous problems where the most important role plays long-term stability of working parameters. Long-term stability is technically reachable, but necessary solution is connected with significant increase of investment and necessary periodic service.

#### Acknowledgements:

This work is part of research supported by the Ministry of Industry and Trade of the Czech Republic under grant FI-IM4/059 and the Ministry of Education of the Czech Republic under the grant MSM 1350003.

#### References:

- [1] Killion J. D. and Garimella S., Simulation of Pendant Droplets and Falling Films in Horizontal-Tube Absorber, *ASME Journal of Heat Transfer*, Vol. 126(6), 2004, pp. 1003-1013.
- [2] Thome J., Falling film evaporation: State-of-the-Art Review of Recent Works, *Enhanced Heat Transfer*, vol. 6, 1999, pp. 263-277.
- [3] Pospisil J., Lisy M., Fiedler J., Chroboczek L., Small scale combined production of electricity, heat, cool and process steam, *International Journal of Energy and Environment*, Issue 4, vol. 1, 2007, pp. 211-219.
- [4] G. Grossman: Advanced modular simulation of open absorption systems. Keynote Lecture, *Proceedings, the 7th International Sorption Heat Pump Conference*, Shanghai, China, September 24-27, 2002, 19-25.
- [5] Feng Zhang, You-Ting Wu, Jiao Geng, Zhi-Bing Zhang, 2008, An investigation of falling liquid films on a vertical heated/cooled plate, *International Journal of Multiphase Flow*, Volume 34, Issue 1, Pages 13-28
- [6] S. Smolen, M. Budnik-Rodz, Economical analysis of energy conversion and use by cogeneration system with microturbines, *IASME Transactions*, Issue 8, Vol. 2, October 2005,
- [7] M. Hansen, M. G. Rasul, Performance Assessment and Improvement of an Existing Air Conditioning System of a Supermarket: A Case Study on Bi-Lo Supermarket, *Energy and Environment III: Proceedings of the 3rd IASME/WSEAS International Conference on Energy and Environment*, Vol. 1, 2008, pp. 55-60
- [8] A. Zamljic, D. Goricanec, J. Kropce, Economical Analysis the Recuperation of Waste Heat in the Air-Conditioning Systems, *IASME TRANSACTIONS*, Issue 8, Vol. 2, WEAS, 2005, pp. 1401-1408
- [9] Neil Petchers, *Combined heating, cooling & power handbook*, Lilburn: The Fairmont Press, Inc. 2003
- [10] Gherhardt Ribatski, Anthony M. Jakobi, 2005, Falling-film evaporation on horizontal tubes a critical review, *International Journal of Refrigeration*, Volume 28, Issue 5, Pages 635-653
- [11] Killion J. D. and Garimella S., 2004, Simulation of Pendant Droplets and Falling Films in Horizontal-Tube Absorber, *ASME Journal of Heat Transfer*, Vol. 126(6), pp. 1003-1013,
- [12] M. El Haj Assad, Markku J. Lampinen, 2002, Mathematical modeling of falling liquid film evaporation process, *International Journal of Refrigeration*, Volume 25, Issue 7, November Pages 985-991
- [13] Yong Tae Kang, Hiki Hong, Young Soo Lee, 2007, Experimental correlation of falling film condensation on enhanced tubes with HFC134a; low-fin and Turbo-C tubes *International Journal of Refrigeration*, Volume 30, Issue 5, Pages 805-811

- [14] Herold, K., Radermacher, R., Klein, S.: *Absorption Chillers and Heat Pumps*. CRC Press, Inc. 1996, pp. 329, ISBN 0-8493-9427-9
- [15] J.Patek, J. Klomfar, Simple functions for fast calculations of selected thermodynamic properties of the ammonia-water system, *Int. J. Refrigeration*, 18(4), 1995, pp. 228-234
- [16] Tillner-Roth, R., D. G. Friend, Survey and Assessment of Available Measurements on Thermodynamic Properties of the Mixtures, *J. Phys. Chem. Ref. Data*, 27(1), 1998, pp. 45-61
- [17] Sassen, C. L., R.A.C. van Kwartel, H.J. van der Kooi, J. de Swan Arons, Vapor - Liquid Equilibria for the System Ammonia + Water up to the Critical Region, *J. Chem. Eng. Data*, 35, 1990, pp. 140-144