USE OF LOW-TEMPERATURE HEAT TO PRODUCE DEEPER TEMPERATURE REFRIGERATION BY MEANS OF A NEW TYPE OF ABSORPTION PLANT (LOTARP)

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1. Abstract

As the demand for cold increases, the requirements to methods of cold production being both economic and also kind to the environment become ever higher. Since at present a major percentage of the cold is produced by means of electrically driven compression plants, the use of "heat-driven" refrigeration plants such as absorption refrigeration ought to be encouraged in the interest of efficient use of energy. The use of absorption refrigeration run on low temperature heat (e.g. district heating or waste heat) represents an ecologically viable and, in economic terms, perfectly competitive alternative.

The primary objective of this project was to achieve the economic use of low-temperature heat to produce refrigeration possible at temperatures from -10°C to - 30°C with the aid of a new absorption refrigeration cycle. The aim was to investigate the principles of the process by means of process simulation as well as modelling of the apparatus planned and to provide proof of its operability by means of a pilot plant with a refrigeration performance of 150 - 300 kW.

A double lift absorption refrigeration plant have been planned and erected with an operation capacity of 260 kW. Tests and the experimental analyses have been carried out in conjunction with a real application (storage of frozen food; warehouse air conditioning). Hot water with a temperature of 70 to 90°C has been used as a source of waste heat. The refrigeration temperature is from 10 to -30°C. The COP lies in the order 0.35.

2. Partnership

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3. Objectives

The primary objectives of this project was to achieve the economic use of low-temperature heat to produce refrigeration possible at temperatures form -10°C to - 30°C with the aid of a new type of absorption refrigeration plant. It has been investigated the principles of the apparatus, as well as the providing of its operability by means of a pilot plant with a refrigeration performace of 150 - 300 kW. Numerical methods have been investigated to calculate the components and the whole process based on theoretical and experimental data. Special models have been developed for process simulation to predict process parameters.

The new plant runs on a NH_3/water mixture. It comprises the following components: desorber, condenser, evaporator as well as a low-pressure and a high-pressure absorber. The heart of the new plant, the low-pressure absorber, is cooled by means of part of the NH_3 refrigerant down to a temperature which lies below the temperature which can be achieved by cooling water. Thus it is possible to reach a higher concentration of the liquid solution, to increase the degasification range and to operate the desorber at lower sump temperature. In this way, it is possible to heat the desorber with low-temperature waste heat.

The plant is connected to a heat source by means of a by-pass system. It has been operated and tested successfully under practicial conditions at the facilities of the IEV.

4. Technical description

The double lift cycle was run on an NH_3/water mixture. The flow sheet in *Figure 1* explains how the process works.

The rich solution 1 is separated in the column K1 into pure ammonia at the head and a depleted ammonia/water mixture (lean solution) at the bottom. The necessary heating takes place by means of supplying low temperature heat to the desorber W1. The ammonia vapor is liquified in the condenser W2 by means of cooling water. A very small part of the condensed ammonia flows back to the column as reflux. The condensed refrigerant is divided into two flow streams: The mass flow 1 used to produce the cold is transported after expansion to evaporator pressure into vessel SW7 and is circulated through the evaporator W7 by the pump P1. There it evaporates by the addition of heat from the cooling liquid. Mass flow 2 is expanded to an intermediate pressure level and evaporates in the low-pressure absorber W5 by taking up the absorption heat from the absorption by the lean solution of the ammonia vapor out of the evaporator. Thus the rich solution 2 is produced. After increasing the pressure by the pump P3, it enters the high-pressure absorber W6 and picks up the mass flow 2 from the low-pressure absorber. The heat which occurs is fed off with cooling water. The rich solution 1 formed as a result is transported by the pump P4 via the heat exchanger W3 into the column K1 and heated up countercurrently to the lean solution. Thus the cycle is completed. The circled numbers represent the thermodynamic states and are presented in *Figure 2* using a lgp, 1/T diagramme.

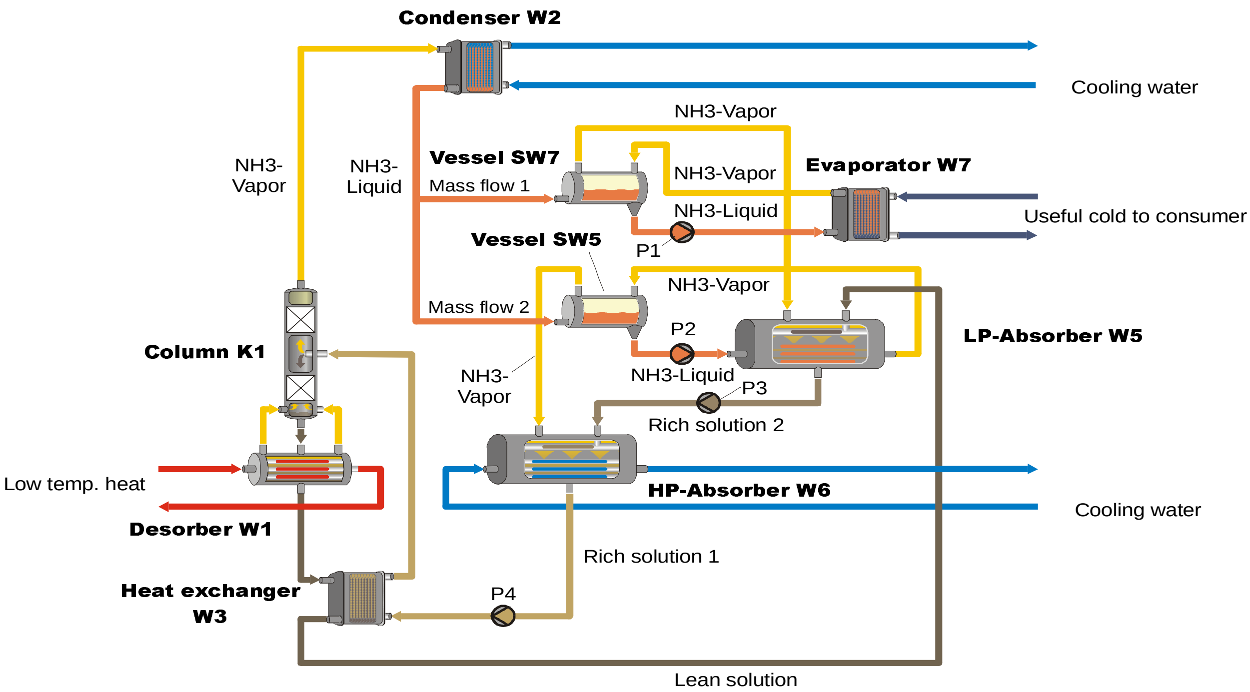

Figure 1.: Flow sheet of the refrigeration plant for the use of district heating

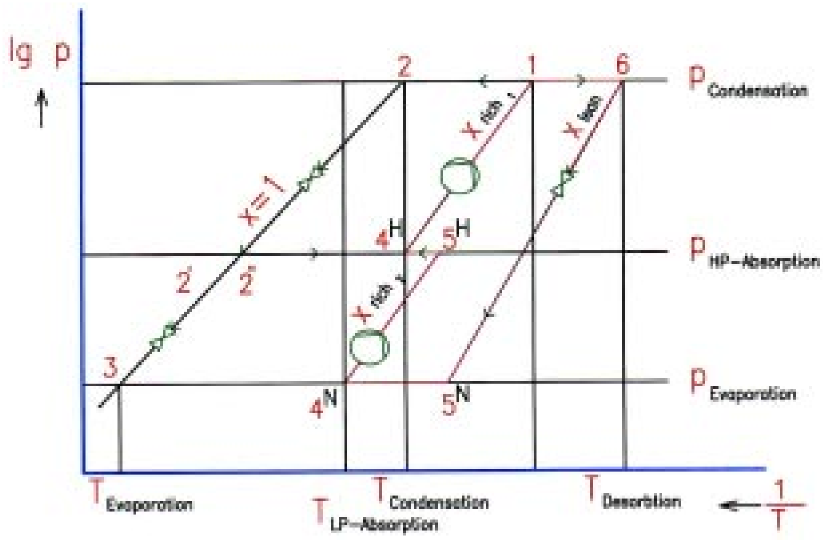

Figure 2.: Process presentation in lgp, 1/T diagramme

The thermodynamic calculation of the process took place with the CHEMCAD-programme. The PPAQ model (Partial Pressure of Aqueous Mixtures) was used to calculate the phase equilibrium. It is a K-factor method which calculates the equilibrium using the partial pressures of the components. The enthalpy values were determined via excess parameters using the latent heat model.

The process was designed to include the following main components: Desorber, column, evaporator, low-pressure absorber, high-pressure absorber, heat exchanger and pumps.

Each programme component processes the input flows by means of appropriate models and determines the output flows. The calculation is convergent when the deviations between two systems calculations are below a predefined error limit.

Having completed the thermodynamic calculations, the kinetic design of the apparatus was carried out. The types of apparatus selected is shown in Table 1:

Table 1: Types of apparatus selected

Rectification column K1	: Packing column containing pall rings
Desorber W1	: Submerged tube bundle (solution on the shell side)
Condenser W2	: Plate type
Evaporator W7	: Plate type with forced circulation
LP-Absorber W5	: Spray film tube bundle (solution on the shell side)
HP-Absorber W6	: Spray film tube bundle (solution on the shell side)
Solution heat exchanger W3	: Plate type

5. Experimental results

To test the cycle over a wide range of application, the variation of the following parameters were performed:

- heating temperature 65 - 100°C
- heat input 90 - 230 kW
- temperature of cooling water 15 - 30°C
- pressure of the LP-absorber 5 - 7 bar

The expected cold production lies in the range of 200 - 50 kW at temperatures of –10 to 5°C (in some trials down to –30°C).

All volume flows, temperatures and ammonia concentrations were measured (by means of sampling) prior to and following each piece of apparatus so that each individual component and thus also the entire plant could be balanced. The results were evaluated on-line with the help of special software. Thus it was possible to determine immediately the effects of any change in parameters and to compare them with the mathematical model set up beforehand. Process control is carried out with the aid of an LPC (Simatic S7 400) and visualisation software (In Touch NT). *Figure* 3 shows a photograph of the plant.

In addition to the comparison between the theoretical and experimental values (heat and mass transfer coefficients, concentration widths, COP values etc.), the analysis of the plant's behaviour was of particular interest. *Figure*s 4 to 10 present the results measured during the starting up of the plant and in operation.

Figure 4 shows the heat flows given off over time. More than twice the amount of heat flow is fed off in the condenser in comparison to the HP absorber. The water-cooled cooler W4 is connected after the HP absorber in order to cool down further the rich solution 1 (not presented in *Figure* 1). Relatively small fluctuations can be observed which are mainly caused by varying amounts of condensate in the condenser. The closer the operating level of the column approaches the design state, the sooner these fluctuations disappear. It proved to be very appropriate to control the column pressure by means of the volume flow of cooling water (*Figure* 5). Thus it was possible to achieve a very stable state.

After controlling the pressure by means of the volume flow of cooling water, the column could be gently started up again and the stationary state reached after about one hour, *Figure* 6. The initially low NH_3 temperatures are due to the expansion of the liquid NH_3 in the condenser. In stationary operation, the condensation temperature was about 3°C higher than the exit temperature of the cooling water.
Due to the small storage volume of the evaporator (vessel SW7), steady state conditions could only be reached after about 2 hours, *Figure* 7. Only then was the full cold capacity achieved. The relatively long start-up time can be shortened by a larger storage volume, either by means of a larger vessel SW7 or by using a submerged evaporator.

Dividing the NH_3 condensate between the mass flows 1 and 2 for the evaporator and the LP absorber (*Figure* 1) has a major influence on the stability of the plant. This can be achieved by adjusting the filling level in the vessels SW7 and SW5. The mass flows named above then adjust themselves automatically. *Figure* 8 shows pressures in the condenser and the LP and HP absorbers after adjusting the filling level. Here too a stationary state can be reached after about one hour.

The trials and the simulation calculations have shown that it makes sense to adjust the filling levels in all pieces of apparatus. In order to avoid any control oscillations, sufficient volumes must be foreseen for the liquid ammonia, the lean solution as well as the rich solutions 1 and 2. Certain control oscillations in the volumes of the rich solution 2 can be identified in *Figure* 9. Clearly the sumps of the LP- and HP-absorbers should have been slightly more generous.

Figure 10 presents the balance dimensions of the plant (heat supply and cold capacity). The hot water temperature for heating the desorber was about 75°C. It was possible to achieve COP values of about 0.34 (34%). The COP value was maintained even at evaporation temperatures up to –10°C. After that a steep decline could be observed.

6. Conclusions

The objective of the project was to develop an absorption refrigeration plant for the use of low-temperature heat for cold production. According to the results available this objective has been fulfilled completely. By using an additional absorber/evaporator lower desorber temperatures can be set whereby the temperature of the heat supply can be reduced. Thus it is possible to bring into play waste heat with very low temperatures for the production of cold. The results can be summarised as follows:

- Waste heat at 65°C/60°C (initial and reflux temperatures) can be used for the production of cold at 3°C, even if the cooling water temperatures lie in the range of 30°C/35°C (condensation temperature about 38°C). The COP value is about 0.34. This value is perfectly acceptable for practical purposes since waste heat is frequently available in sufficient quantities.

- Following the start-up phase, the plant's operation is stable. Smaller fluctuations, e.g. in the temperature of the heat supplied, scarcely have any notable influence on the plant's operation.
- The plant can run fully automatically with the aid to the software developed for it. Target values can be changed and adjusted during operation. Direct evaluation of the results is immediately possible.
- The process can be simulated by means of the models specially developed for this purpose. The results of the process simulation provide valuable information for the configuration of the controllers whereby mostly level controllers are used.

  The start-up times are dependent on the filling volume of the individual apparatus. In the case of apparatus based on the spray film principle such as condensor, high-pressure and low-pressure absorber, then changing the guide parameter leads to a relatively significant change in other parameters (e.g. mass flow) since the filling volume is small. In the case of submerged apparatus however, any change which takes place is relatively sluggish. This means that in the case of larger fluctuations (e.g. when there is a major change in the temperature of the waste heat) apparatus with a larger filling volume and in the case of smaller fluctuations apparatus with a smaller filling volume should be used.
- The concentration width should not be adjusted abruptly to the conditions demanded but rather very gently.
- The measurement and control methods can be simplified to a considerable degree. Simple mechanical swimmer regulators can be used for controlling levels as are found in other refrigeration plants. It is important that the pressure in the rectification column is kept constant e.g. via the mass flow of the cooling water. The downstream values then adjust themselves automatically.
- If the heating temperature rises periodically to higher values, e.g. to 90°C, then there is also the possibility to operate the plant in one stage mode, by-passing the absorber/evaporator. In this case the COP value can be almost doubled (on the scale of 0.6 – 0.7).

The following deliverables are available for exploitation:

- Design of prototype and performance data
- Design data and calculation methods

- Research into possible applications (system integration, performance ranges etc.)
- Simulation programmes
- Improved and optimized material data for corresponding sorption processes

The exploitation and dissemination of the results will be organized by the co-ordinator in agreement with all the project partner. Particular attention will be paid to the economic aspect and closeness to market.

7. Applications

The main areas of application of the new absorption refrigeration plant lies in the following applications:

- Cooling and air conditioning in buildings
- Food industry
- Cold storage of meat or fresh fish.

  A frequent temperature range lies between 0 and –30°C. In the case of storage of fruits, the cold temperature could be between 5 and 10°C. There is also a considerable demand in dairies and breweries, where the process off-heat, e.g., from evaporators, dryers or boilers can be supplied as heating energy to operate the refrigeration plant.
- Cooling of warehouses
- Cooling of slaughterhouses and leather goods
- Ice production for skating rinks
- Cold delivery as a service for different users.

  This application concerns for example a container or a fishing port. Cold and electricity can be produced by the same plant consisting of a gas motor and a downstream absorption refrigeration plant.

Market analysis hasn’t been carried out yet. It is forseen to apply the process in connection with a heat co-generation plant.

All partners will exploit the results to increase their competitiveness because they expand their product range with the new developed components and the heat pump.

The consortium partners will use the results as follows:

IEV: IEV is going to use the project results for future applications and compilation of design principles. The results are going to be used for research and teaching. Further, it is planned to commercialise the process with an manufacturer of refrigeration plants.

CNAM: CNAM is going to use the results for further development of the thermodynamics of the material mixtures. Further, the new developed model equations for calculation of processes and material properties will be used in basic research for process simulation.
The visualisation software InTouch will be used for training of students.

IKE: The measuring techniques and model equations will be used for further development and creation of principles for refrigeration plants. Further the results will be used in teaching and training.

Schottke: "Grüner Gedanke" for the production of frozen foods; reducing of consumption of primary energy

8. Exploitation Plans and anticipated benefits

The European market for absorption refrigeration plants is catered for primarily by American and Japanese firms. New techniques can scarcely assert themselves in this market. The necessary parameters for a market-oriented development have been carried out.

Research into new energy-saving technologies low in emissions is of benefit both in terms of environmental policy and national economy. The objective of the European Union is to use processes and products in new investment projects where pollutant emissions and energy consumption are as low as possible in order to reduce primary energy demand and above all CO_2 emissions. The project LOTARP is a contribution to this. Higher performance factors in comparison to conventional plants were achieved.

The following main results are available for dissemination:

- Experimental results of a new kind of absorption refrigeration plant
- Design of the prototype including economic feasibility
- Research into possible applications (system integration, performance ranges etc.)
- Simulation programme
- Improved material data about working media

It has been developed a new absorption refrigeration plant. These kinds of plants will be build and sold by a company, which is well involved in planning and manufacturing of conventional refrigeration plants. Universities and research institutions also profit from the results. Thus the results published can be used as the basis for other developments and applications.

All partners co-operate with various industrial representatives in Europe and beyond. A distribution network will be set up via these partners. An information brochure will be printed and appear as an insert in publications.

The scientific and technical results of the project will be published in Europe and beyond. By means of participation in international congresses and specialist seminars, the results will be and have been presented to a wide audience of scientific and technical experts. The following can be mentioned:

- International Sorption Heat Pump Conference, 24-26 March 1999 in Munich, Germany
- ASHRAE Conference (American Society of Heating, Refrigeration and Air-Conditioning Engineers)
- International Congress of Refrigeration
- DKV-Conference (DKV = Deutscher Kälte- und Klimatechnischer Verein)
- International Energy Agency Heat Pump Conference
- International Colloquium on Refrigeration and Air-Conditioning

Apart from seminars and congresses, articles have been published in specialist national and international journals. Apart from the actual process, the results of the material characteristics investigated will also be published. Important specialist journals include:

- IZW Reports (Informationszentrum Wärmepumpen und Kältetechnik)
- ASHRAE Journal
- Luft- und Kältetechnik
- Chemical Engineering Process

Responsible for the dissemination of the results will be IEV in agreement with all the project partners.

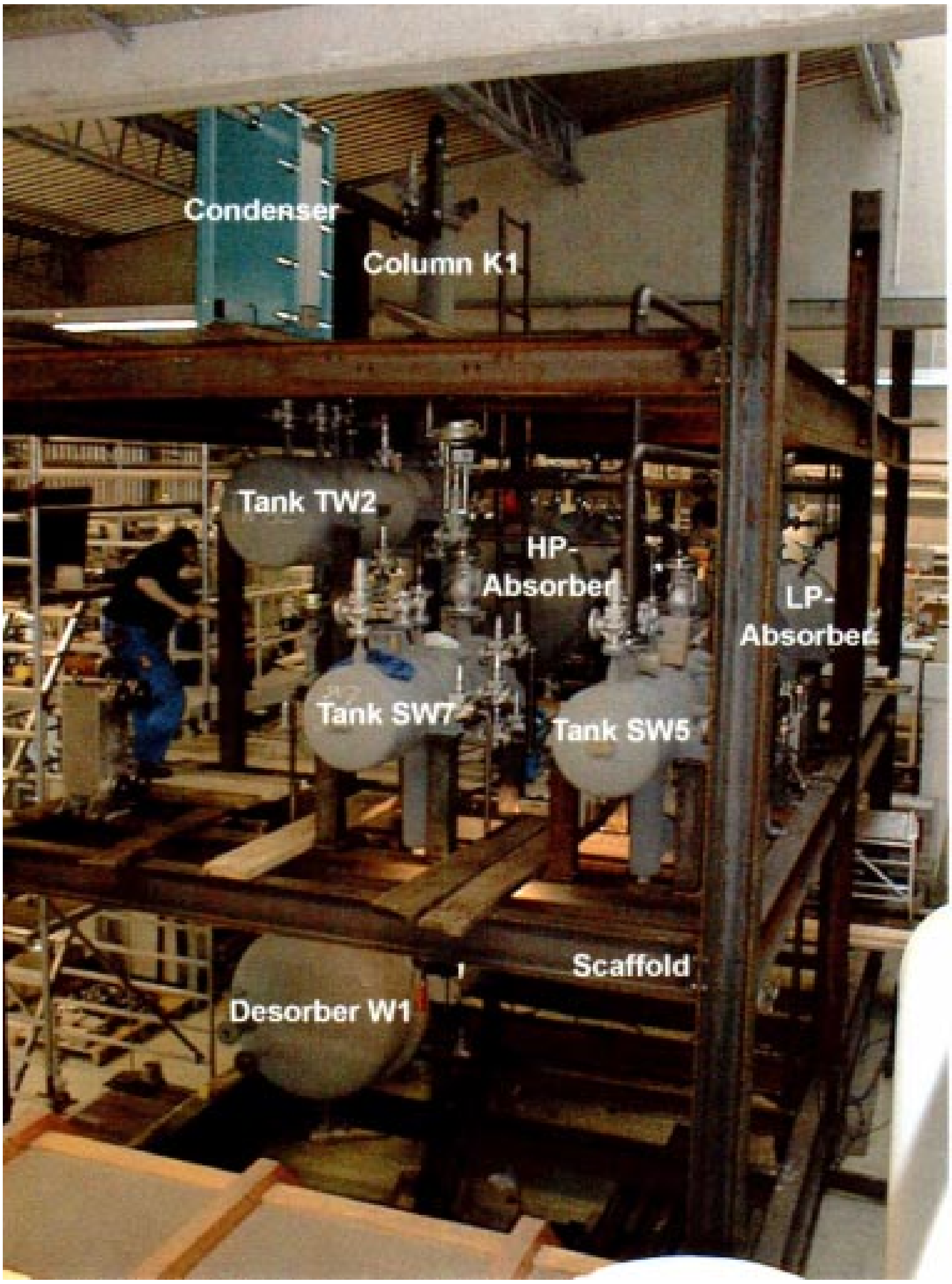

Figure 3: Photograph of the double lift plant

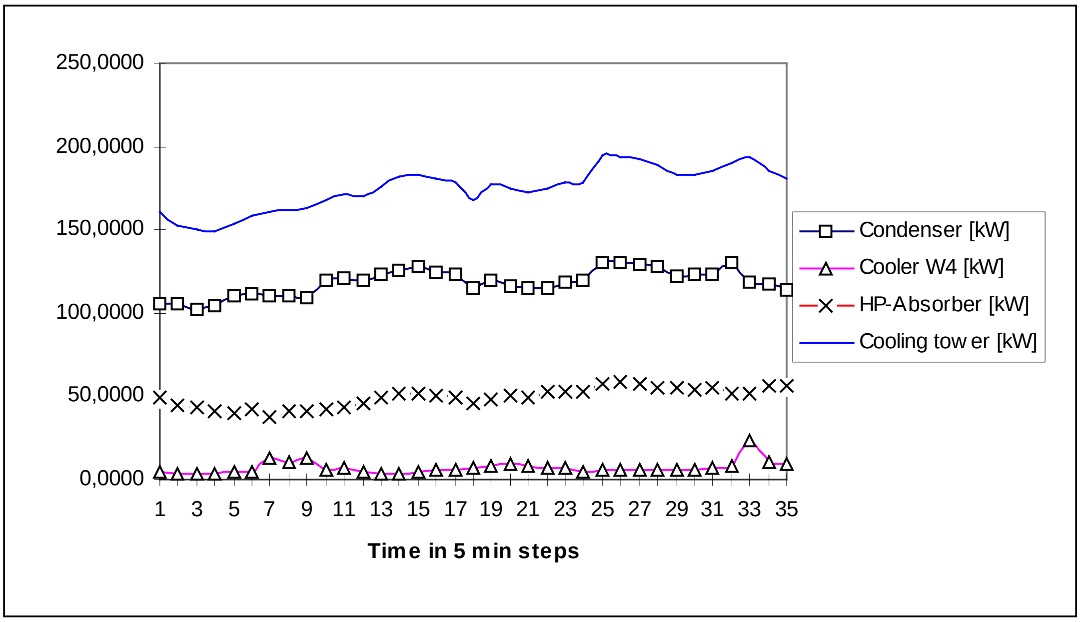

Figure 4. Rejected heat flows over the time

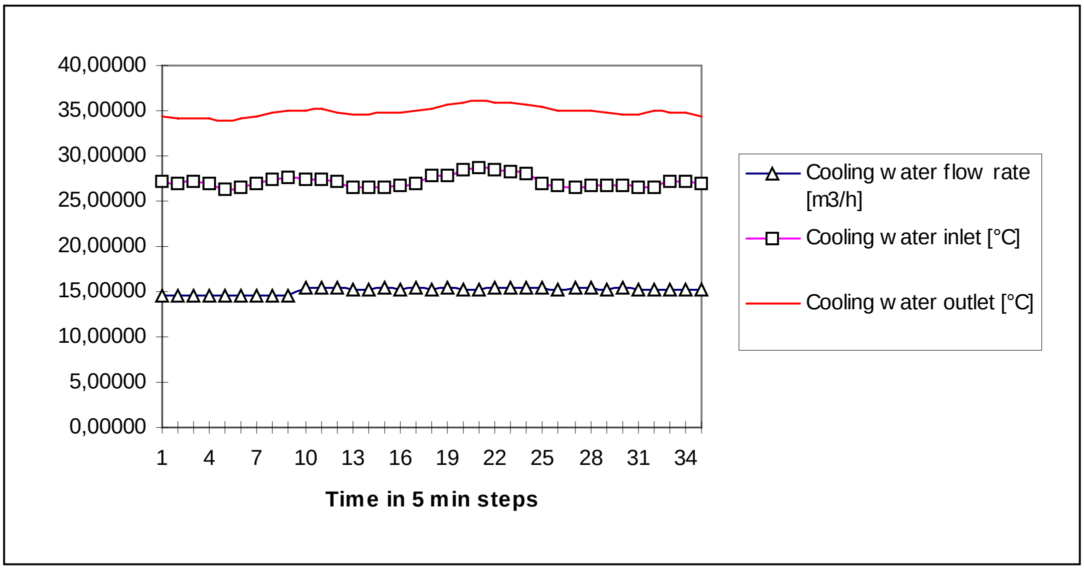

Figure 5. Conditions of cooling water

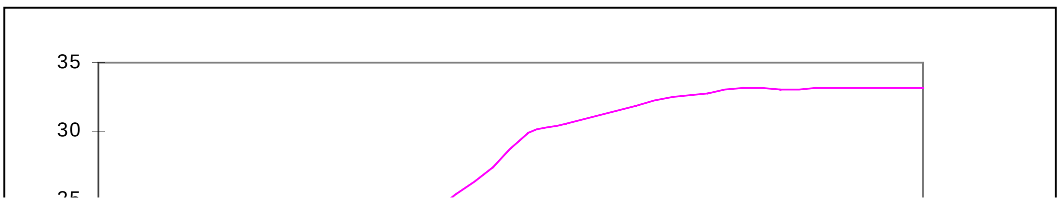

Figure 6. Conditions at the column head after controlling the head pressure

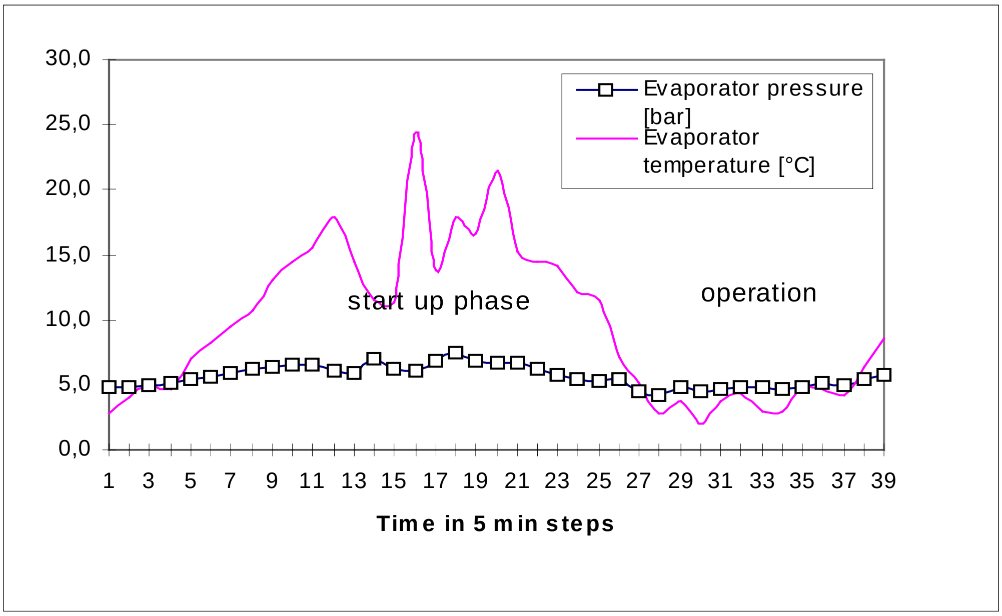

Figure 7. Evaporation temperature and pressure

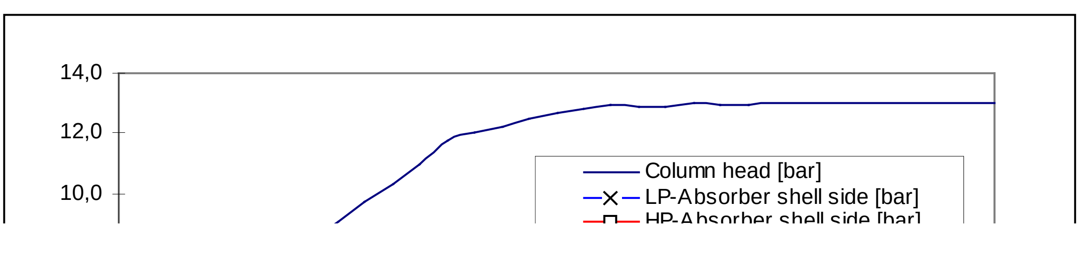

Figure 8. Pressures in the Column head, LP- and HP-Absorber

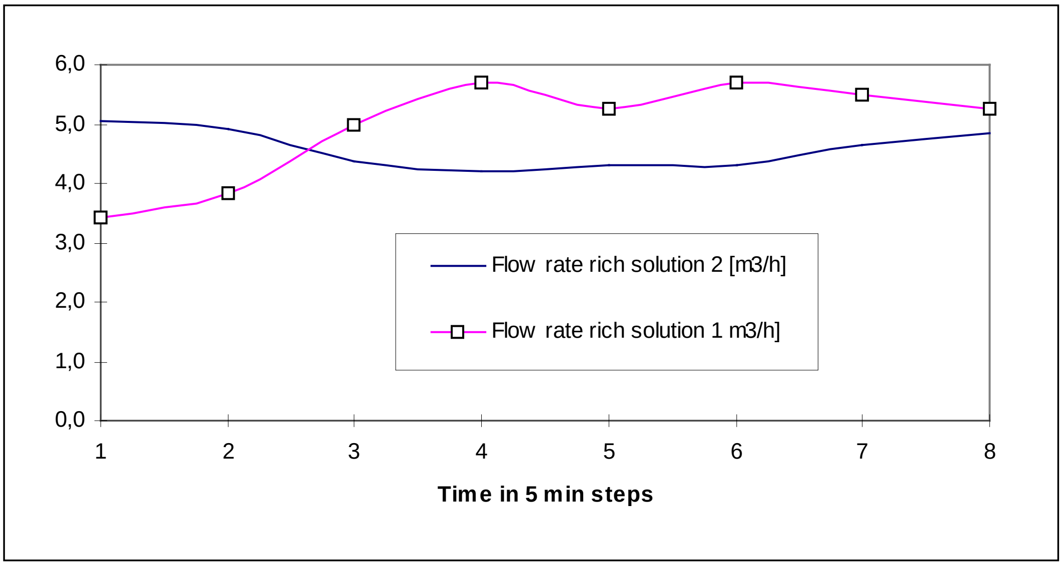

Figure 9. Fluctuations of solution flow rates

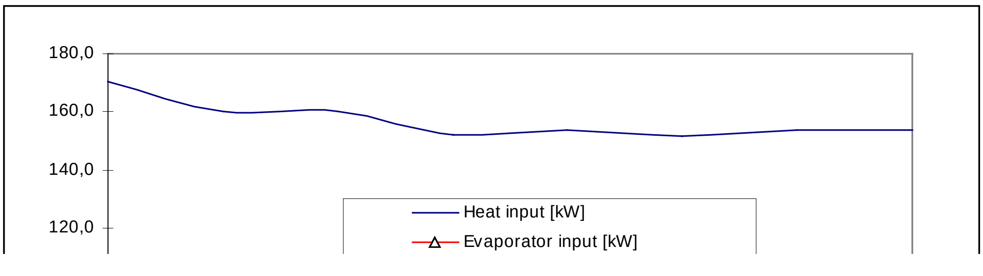

Figure 10. Heat input and cold capacity