RIGA TECHNICAL UNIVERSITY
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GAS FIRED COMBINE CYCLE TRIGENERATION UNDER THE TEMPERATE CLIMATE CONDITIONS

Summary of the Doctoral Thesis

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CONFIRMATION STATEMENT

Hereby I confirm that I have worked out the dissertation, which is submitted for acquisition the degree of Doctor of Engineering Sciences at Riga Technical University. The dissertation has not been submitted in any other university for acquisition of scientific degree.

Aivars Cers ______________________

Date ________________________

The dissertation has been written in Latvian: it contains Annotation, Introduction, six Chapters, Conclusions, and References. It consists of 50 figures and 20 tables. It composes 112 pages with 99 reference sources.

ANNOTATION

The full natural gas combined-cycle cogeneration (GCCC) and trigeneration presents one of the most progressive technologies of the modern energy industry that ensures a high level of fuel efficiency, low emissions and the flexible process of changing the load of a power unit.

Within the Doctoral Thesis a special application of the absorption coolers for the transmission of the low potential heat of GCCC to the heat network has been developed. In the result of the study a solution has been found for improving the productivity of the absorption cooler under the conditions of high return temperature.

The introduction of district cooling is proposed as a measure for improving the efficiency of GCCC in the Latvian circumstances and a computer simulation has been developed for determining the costs of cold production. For the purpose of determining the heat flow of the absorption cooler integrated within the operation of the GCCC a non-stationary temperature field within the environment covering cylinder type heat pipes has been described by mathematic methods.

The Thesis proposes solutions for increasing the total efficiency of GCCC in the countries with temperate climate conditions by utilising the low potential heat of the technological process, which was not utilised before and, which was discharged into the environment without any utilisation until now. The proposed solution allows the increase of the total efficiency of GCCC by at least 2%; the savings of natural gas achieved at the EO amount to 1.4 mill. n.m^3 per year. The methodology for introducing the district cooling in compliance with the index of the sustainability of the Latvian energy industry is proposed in the Thesis. The experimental and practical testing of the developed solutions was carried out at the CHP IMANTA of the Joint Stock Company RĪGAS SILTUMS .The gained experience was used for the development of the algorithm of the improvement of the operation of GCCC and the verification of the testing methods. The major results of the Doctoral Thesis have been reported at twelve international conferences and workshops and summarised in 17 publications.

The obtained results of the research have been implemented in the study programs of Riga Technical University, they can be used by the producers, designers, planners and developers of the district heating, cooling and electricity for providing additional heat capacities without carrying out major reconstructions of plants, as well as for evaluating the options for the plant expansion. The technological developments of high capacity heat pumps and coolers can be used for the utilisation of low potential heat from geothermal sources and industrial processes.

Content

1. INTRODUCTION

1.1. Natural gas fired combined cycle cogeneration equipment

The basic principle upon which the natural gas fired combined cycle cogeneration equipment (GCCC) is based is the combination of two thermodynamic cycles in a single energy complex where the gas turbine (GT) cycle operates within a range of higher temperatures and the steam turbine (ST) operated within a range of lower temperatures. A typical GCCC is presented in Figure 1.1. The cogeneration unit (CU) installed at the

CHP IMANTA was used as an experiment object (EO). The single line diagram of GCCC with heat and mass balances is presented in the Figure. The major elements of GCCC are numbered accordingly in the explanatory part of the Figure. The waste potential which is not utilised is used for the provision of a lower temperature cycle, i.e. ST (4). The operation of the cycles within the combined cycle ensures a considerable higher total efficiency of the cycle than it is in case of individual cycles. GCCC consists of three main components: GT (2), a recovery boiler CU (3) and ST. For the purpose of ensuring the operation of the GT, the ambient air (AA) is delivered to the GT where it is pressurised in the compressor (1) for securing the combustion of a fuel which is usually natural gas (NG). The produced hot flue gas expands within the turbine which is coupled to the compressor and the power generator (5).

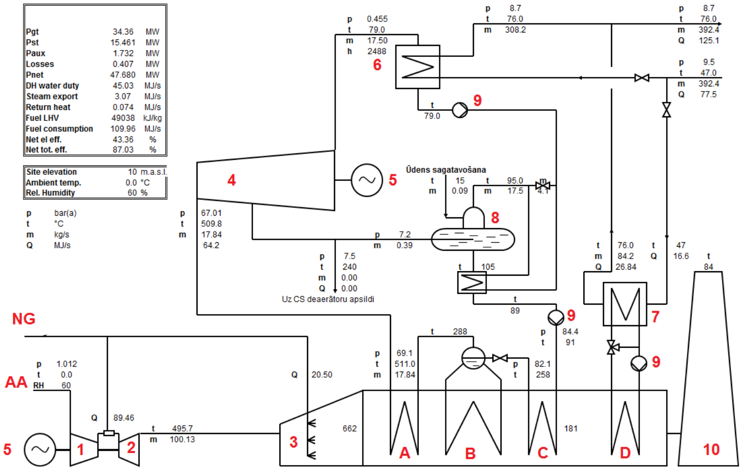

Fig. 1.1 The single line diagram of the GCCC and the heat and mass balances of the process

Designations: 1- GK; 2- GT; 3- CU; 4- ST; 5-GTG and STG; 6- condenser unit; 7- disconnectable DH loop ; 8- deaerator; 9- pump units; 10- stack; A- CU overheater; B- CU steam circuit; C- CU economiser; D- closed heat and power production loop.

The above heat exchange elements of the CU are classified based upon their temperature potential. All the groups of heating surfaces (A; B; C and D) are linked by the CU boiler. Taking into account that the flue gas, which is delivered to the CU, has a high air saturation rate $\alpha \div 4$, the potential of flue gas usually is increased by means of a supplementary firing without supplied additional air for ensuring the combustion process.

CU economisers can be either of independent operation (C) or with disconnectable heating surfaces (D) which are used for heat and power production needs in case of full loading and are disconnected under the conditions of minimum load. Waste flue gas is discharged to the environment via a stack (10). For special cases when the use of the GT cycle only is envisaged, a separate GT stack is installed before the CU. The high potential and quality steam which is accumulated and treated in the boiler is transmitted further to the ST, which can be a condensing type or a back-pressure type in most cases, with the extraction of steam or without it. Steam expands and is used for providing the mechanical drive of the ST generator STG (5), and the waste steam is transmitted for further condensation in the condenser (6). The cooling system of the condenser delivers heat for the heat and power production needs. The produced condensate is later returned to the deaerator tank (8) and returns to the ST cycle again. Within the operation of the cycle the water circulation is ensured by means of pumps (9). The efficiency rate η of modern GCCC reaches 84÷88% under the conditions of suitable loading.

1.2. Topicality of the subject

The beginning of the 21st century is marked in the history by the rapid introduction of the combined cycle cogeneration units of gas fired turbines on the global scale. This technology provides an opportunity of generating power with the lowest additionally produced heat volume. Usually this ratio is 1:1 or even better. The operational experience of recent years has demonstrated good efficiency results in the biggest combined cycle power plants of gas turbines in Latvia: Riga CHP-1, CHP-2 and CHP IMANTA. The mean efficiency rate of these power plants is high and amounts to 84 – 86%. In order to achieve even higher improvements in the efficiency indices of GCCC, it is necessary to develop technological solutions for improving efficiency. The absorption cooler (AC) which cools down the technological water of GCCC could be a device which provides this possibility. It would allow the utilisation of up to 2% of the input fuel of GCCC, and at the same time the technology developments would present a solution for introducing the district cooling supply adapted to the circumstances of Latvia and aimed at stabilising the summer production volume of the CHP plants, supplying a new product to consumers and generating additional income. The adaptation and introduction of an absorption heat pump was performed by the JSC RĪGAS SILTUMS in cooperation with the experts of the Heat Supply Department of the Transport and Mechanical Engineering (TMF) of Riga Technical University (RTU).

Foreign scientists: R. Best; V.Dagilis; L.Hargo; T.Hoel; M. Ishimatsu; R.M. Hummelshoj; T. Kashiwagi; J.Ko, R.Linkor; M. Magnusson; R. Marcos; M.Marinova; T.Oda; V.Patnik; J.Stag; R. Ulset; R. Vosken and others have carried out in-depth studies of the energy efficiency and heat supply regimes of cogeneration plants, the application of heat pumps and absorption coolers in the heat supply and the development of trigeneration. Latvian scientists A. Akermanis; J.Barkans; V.Barkans; D. Blumberga; E.Dzelzītis; V.Grivcovs; U.Iļjins; A.Krēsliņš; A.Lešinskis; U.Osis; M.Rubīna; G.Stankeviča; P.Šipkovs; A.Temkins; D.Turlajs; I.Veidenbergs; V.Zēbergs; N.Zeltiņš; Ā.Žīgurs and other have carried out in-depth studies of the efficiency of cogeneration and consumers, the heat supply regimes, the application of heat pumps and absorption coolers for the needs of heat supply and trigeneration prior to the study performed by the author of the present Thesis; they have also developed the mathematic descriptions of the heat physical processes.

1.3. Goal of the Thesis

The goal of the present Thesis has been defined as the development of methodological guidelines for improving the efficiency of GCCC by the application of absorption coolers under the temperate climate conditions.

1.4. Tasks to be solved

The goal of the present Thesis is the development of a model for improving the efficiency of the operation of GCCC adapted to the sustainability index of the Latvian energy, the performance of the study of the process of heat and mass exchange of an absorption cooler aimed at the improvement of the efficiency of this equipment. The following scientific tasks were defined for achieving the goal of the Thesis:

- The performance of a study of the impact of the Latvian climate conditions upon the operation of GCCC;
- The development of the plan for introducing the Latvian district cooling supply by utilising the low potential heat of GCCC;
- The development of the model for improving the efficiency of GCCC by utilising the low potential heat suitable to the climate of Latvia;
- The performance of the in-depth evaluation of the efficiency of the absorption cooler and the development of recommendations for the improvement of efficiency under the conditions of a high temperature of the cooling substance;
- The development of the mathematic description for a non-stationary temperature field within the environment covering cylinder type heat pipelines;
- The development of the algorithm for the optimisation of the operation of GCCC and the criteria for evaluating the results.

1.5. Scientific innovation

The performed studies have resulted in the development of several innovative solutions for the improvement of the efficiency of GCCC.

- Within the Doctoral Thesis a special application of the absorption coolers for the utilisation of the low potential heat of GCCC followed by the transmission of heat to the DH network has been developed. A new construction has been developed for the improvement of the productivity of the cooler under the conditions of a high return temperature.
- A study of the experience of introduction of the cooling supply in the Northern Europe has been carried out. The differences in characteristics to Latvia in comparison to the district cooling systems of the Northern Europe have been presented. The methodology of the introduction of the district cooling supply has been proposed. A Microsoft Excel based computer simulation for the identification of the costs of the

production and the cold has been developed for the purpose of the introduction of the district cooling in Latvia. The formula for setting the prices of the service has been developed for the purpose of determining the costs of the district cooling service.

- By performing the analysis of the thermodynamic processes of the operation of the absorption cooler elements, a non-stationary temperature field of the absorption cooler within the environment covering cylinder type heat pipelines has been described by mathematic methods.
- The most optimal solution for the utilisation of the heat of technological and blow-down water of GCCC has been developed;
- A physical picture of the loading of GCCC under temperate climate conditions has been presented. The Doctoral Thesis has been developed by means of the analysis of the factors impacting the operation of GCCC which helped to establish and attest the GCCC optimisation model and to propose the method for testing the simulation results.

1.6. The practical importance of the Thesis

A unique method for the application of absorption coolers for the purpose of utilising the low potential heat under the conditions of the high temperature of the cooling liquid has been developed. The developed equipment presents a valuable solution for the introduction of GCCC, heat supply and geothermal projects in Latvia and the Baltics. The presented application of the absorption cooler allows saving up to 2% of the input fuel of GCCC, which has resulted in the reduction of the natural gas consumption by 1.4 mill. n.m^3 per year at the EO site.

1.7. Approbation

The studies performed within the framework of the present Thesis are based on the author's practical, research and experimental work experience which have been obtained during the employment at the JSC RĪGAS SILTUMS during the time period from 2002 to 2011. This has allowed to carry out in-depth studies on the heat sources of the DH system in Riga and to develop the complex solutions for improving the efficiency of the heat engineering equipment. For the purpose of carrying out the studies the data accumulated on the climate conditions of Riga city, heat sources and their operational regimes, heat recovery devices, the technical economic aspects of the introduction of the district cooling, the long-term experience of the construction and operation of GCCC at the CHP IMANTA, as well as the summary of the experimental measurements and theoretical results implemented by the author as a unified methodology were used. The measures of the utilisation of the heat of flue gas and the improvement of the efficiency of GCCC have been introduced at the CHP IMANTA of the JSC RĪGAS SILTUMS with the participation of the author and the experimental studies of the processes have been performed at the same site. The results of the Thesis have been summarised and reported at 13 national and international conferences. The results of the Thesis have been described in 17 publications.

2. OPERATION OF GCCC UNDER THE CONDITIONS OF LATVIA

2.1. Operational peculiarities of GCCC

In the result of the performed research it has been found that the major causes of accidents and failures in the district heating GCCC are as follows:

- the decrease of the performance capacity of the equipment at low ambient temperature;
- the errors of design and technical solutions within reconstruction projects;
- low quality of repair and service works, non-compliance with the repair technologies;
- errors made by the maintenance and operational staff;
- wear of the equipment and the physical ageing of applied materials during the operational process;
- unscheduled, non-standard damages caused by external circumstances.

The results of the research prove that the availability rate of the Latvian GCCC C_{av} is within the range of high global indices and exceeds the worldwide mean l (89.3%).

Figure 2.1 presents the proposed requirements for GCCC under the conditions of Latvia with a high operational safety rate C_{saf} during the heating season, low requirements during the spring flood period and increasing requirements at the end of summer. The C_{av} is above 90% during the whole annual report period of the Latvian GCCC, however, if the split per months is used the availability indices are usually within the range from 75 to 90%. The values exceeding 80% are considered good indices on the global and European scale. This rate is fluctuating due to objective reasons over a few years because of the scheduled overhaul of the equipment.

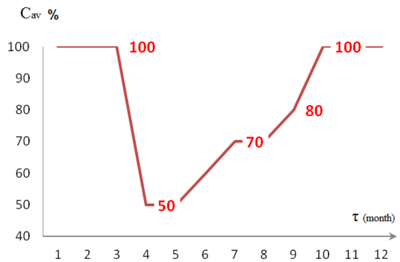

Fig. 2.1 GCCC C_{saf} (%) requirements under the Latvian conditions

In case of water heating boilers, the C_{av} usually is within the range of 95 - 99%. The highest capacity utilisation rate C_{util} at GCCC in Latvia was achieved in years 2006 and 2007 when CHP-1 and CHP IMANTA were commissioned, the high loading was encouraged by the favourable price of natural gas, suitable hydrologic conditions at hydro power plants and the high electricity demand by the manufacturing industry. According to the Eurostat data for year 2010, Latvia was in the leading position in the EU as regards the CHP efficiency (82%) in comparison to the EU mean rate of 50%. Latvia with the result of 45% takes a second position after Denmark (49%) in the EU as regards the volume of heat produced in cogeneration. Latvia has the second lowest (1.8 tons of cond. fuel) specific fuel consumption per capita in Europe, and this is more than twice below the mean consumption in Europe. The loading curves of the basic element of GCCC, i.e. the GT, depend on the ambient temperature and can be described as follows:

$$P_{elmax} \text{ and } Q_{max} = f\,(T_{amb}). \qquad (2.1.)$$

The maximum electrical capacity changes $P_{el\ max}$ is of a linear character: the lowest possible value of $P_{el\ max}$ is achieved at the maximum ambient temperature and at Tamb=+45°C it can reach just 85% of P_{max} at T_{amb} = +15°C. The changes of the maximum electrical capacity of the GT can be described by means of a linear function:

$$P_{elmax} = -0.5108 \cdot T_{amb} + 107.88 \ (\%\ P_{el\ ISO}). \qquad (2.2.)$$

The curves of the maximum electrical and heat capacity intersect at T_{amb} = +15°C, which is the rated capacity reference point of gas turbines. The heat capacity generation of the GT does not have a linear function as the specific heat production tends to increase at a faster rate within the range of low temperatures and at a slower rate within the range of high temperatures. The changes of the heat capacity of the GT can be described by means of a 2nd stage polynomial function:

$$Q_{max} = 0.0007 \cdot (T_{amb})^2 - 0.0399 \,.\, T_{amb} + 100.5 \ (\%\ Q_{ISO}). \qquad (2.3.)$$

Timely washing of the GT and the selection of optimum operational regimes are the major preconditions for ensuring the high efficiency of the GT and GCCC operation. The study also revealed that the quality of the supplied natural gas fully complied with the requirements for the supply of natural gas.

2.2. Specific features of the climate in Riga

The summarised data of the number of hours of ambient temperatures at

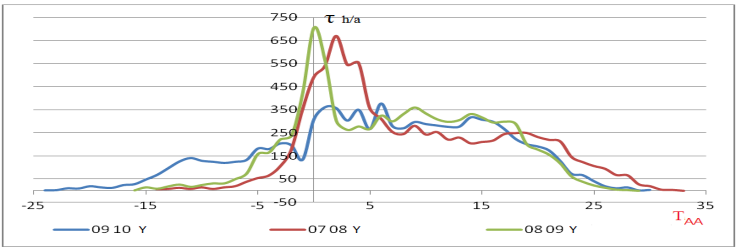

Fig. 2.2 The number of hours of ambient temperatures at Pardaugava district in Riga in the heating seasons of 2007/2008; 2008/ 2009 and 2009/ 2010

Pardaugava district in Riga in the heating seasons of 2007/2008; 2008/ 2009 and 2009/ 2010 is presented in the form of chart in Figure 2.2.

The operational efficiency of GCCC is impacted most by the ambient air temperature and the relative humidity, which can change the operational regimes of the GT dramatically even over a day. The obtained hourly load schedules are presented in Figure 2.3.

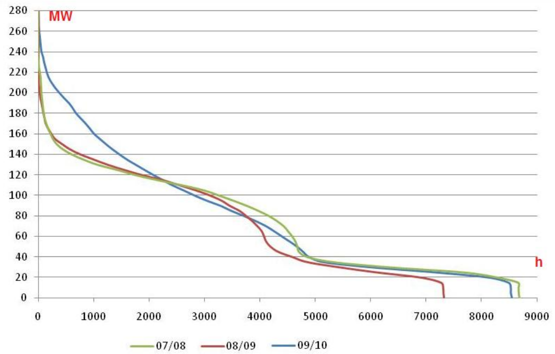

Fig. 2.3 The actual load schedules of the EO in 07/08, 08/09 and 09/10.

In Figure 2.4 the load schedule of the EO which shows the heat production volume at various ambient temperature levels is presented. In the above Figure it can be seen that within the temperature range from +5ºC to -18ºC the load changes are linearly variable depending on the ambient temperature changes, and this can be explained by the fact that within this temperature range the plant complies with the linearity requirements of the temperature schedule. Until now it was deemed that the loading schedule of heat sources under the Latvian conditions consists of a linear load change section during the heating season and the exponential function section during the season without heating. When the ambient temperature decreases below -18ºC, as the supply water temperature is not raised above +118ºC because this is not provided for by the valid temperature schedule, the S-type break point emerges on the loading curve. There is a similar break point at the temperature of +8ºC when the transition from the hot water consumption only to the gradual start of the heating season takes place. Within the ambient temperature range from +8ºC and above an exponential decrease of the heat load takes place and this is encouraged by the lower night time settings of the hot water supply and the increase of the potable water temperature in the summer season

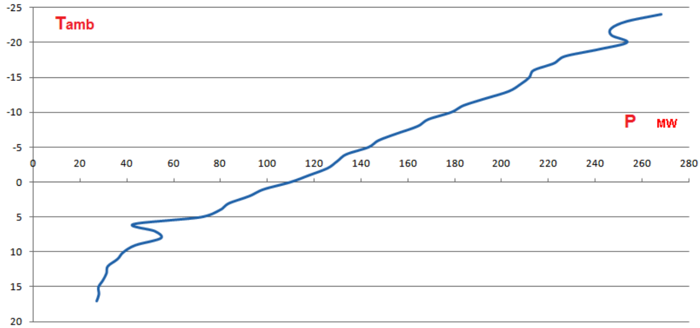

Fig. 2.4 The loading schedule of the EO in compliance with the ambient temperature change

The above schedule was developed based upon the summary of the production statistics data of three years. When the analysis of the operation of the EO during the time period from 2007 to 2010 was performed, it was found that in compliance with climatically levelled data the loading of the CHP generally complied with the theoretical load schedules.

2.3. Introduction of district cooling in Latvia

District Cooling (DC) allows utilising the maximum amount of the locally available resources, to combine various sources of cold depending on the climatic and hydro-geologic conditions. The main conclusions derived from the performed study are as follows:

- The DC can improve the operational efficiency and profitability of district heating companies, in particular, in the summer period by increasing the end production of a company by 5-10% per year. The increase of the efficiency and the production volume is considerable during the season without heating when it is difficult to secure the loading of CHP plants;

- The DC is justified and necessary in the territories with sufficient consumption of industrial cooling capacities;
- Only large scale DH utilities are able to implement the plan of the introduction of the district cooling infrastructure;
- The development of regions is fragmented in Latvia. With the exception of Riga and Riga region (upon the condition that at least the basic infrastructure is present there), the municipal development index is negative in the major part of Latvia. Before the crisis it was positive only in 17 municipalities;
- The measures of improving energy efficiency have to be carried out in CU plants before the commencement of the introduction of the district cooling.

Taking into account the current sustainability index of the Latvian energy industry and the projections based upon the Scandinavian experience of the implementation of the DC, the DC market volume can reach 70 mill. € in 2025, thus becoming an important part of the district heating and trigeneration business. Under the Latvian conditions there is no possibility to ensure the natural cooling from deep water cold sources in summer like it is done in Sweden or Finland where cold sea water is available in the very city centres. The transition from the conventional cooling to the DC can increase the cogeneration production in summer months by up to 30% and divert a part of the electricity consumption intended for ensuring cooling for covering other needs, thus reducing the import volume of electricity.

The DC methodology is based upon the identification of the annual fixed and variable costs of the DC and their verification by comparing to the costs of the construction and maintenance of an alternative local cooling system.

The methodology of the introduction of the DC proposes the implementation of the envisaged measures in stages and the six major basic principles to be followed:

- Free and unrestricted competition, according to which the price regulation is determined by the possibility of a business to provide a competitive service and a consumer's alternative of constructing an individual cooling system;

- Setting of the cooling volumes is based upon the proposed specific cold consumption indices;
- Establishment of the fixed costs. During this stage the individual and the design, construction and commissioning costs of the DC are established;
- The stage of establishing variable costs. The operating and service costs are established;
- A customer's alternative solution. During this stage a customer's possibilities to construct an individual cooling source and the structure of the relevant costs are assessed;
- Identification of the profitability of the DC. At the conclusion, the profitability calculation of the project profitability determines the fulfilment of the internal rate of return (IRR) and the net present value (NPV) of the project as per the last year of a contract or a loan schedule. The DC methodology is based upon the identification of the annual fixed and variable costs of the DC and their verification by comparing to the costs of the construction and maintenance of an alternative local cooling system.

It is proposed to use the following formula for calculating the costs component of the specific price of 1 MW of cold of the DC C_k for the compression type cooling without the first instalment:

$$C_K = \frac{C_{el}}{K_K} + \frac{I_k}{T_{eksp} \times \tau} \quad , \qquad (2.4.)$$

where C_{el} – the mean price of electricity (*LVL/MWh*); K_k – the energy transformation rate of the cooler (COP) (*MW/MW*); I_k – specific investment in the cooler (*Ls/MW), T_{ekspl}*- the lifetime of the cooler, τ - the utilisation of the capacity (h/ a)

In the beginning of 2013 for the conditions in Riga *Ck* = 53.45 *(LVL/ MWh)*.

As the annual number of hours of the DC consumption is low and can differ a lot depending on the climate specifics, it is proposed to introduce a capacity fee for the annual operating hours for the purpose of setting a fair rate:

$$C_j = \frac{I_k}{\tau - \tau_{pat}} \quad (2.5.)$$

During the research it was found the major motivations for a customer to use the DC is as follows:

- No high investment in the cold generating equipment is required;
- The ecological situation in the buildings with DC is improved;
- There is no natural gas or a high capacity power connection infrastructure and its construction is unreasonably expensive in the relevant territories.

During the following 10 fiscal years the total investment in the operation of the district cooling of Riga can exceed 25 mill. €. If the conditions are different, each individual project should be evaluated carefully. The main conclusions derived from the study on the introduction of the DC are as follows:

- Only utilities with sufficient financial stability can implement the introduction of the DC, the introduction risk should be covered by the core business, the consolidation of small scale heat supply utilities will improve the conditions for the introduction of the DC;
- The development of the regions of Latvia is fragmented; the large scale introduction of the DC is possible only in the municipalities with a high development index. The target group of the DC covers only the five biggest cities with a positive index;
- In the Latvian conditions no free cooling sources of sufficient capacity which ensure the biggest contribution to the DC efficiency in Scandinavia have been identified. Jurmala, Jelgava, Riga, Valmiera and Ventspils are the cities which are most suited for the introduction of the DC in Latvia. According to the methodology Jurmala and Riga have the most compliant indices.
- The DC is an area of operation for large scale utilities engaged in the heat production and distribution, which possess the required resources for the provision of services in the territories with a high density of the cold consumption, where it is necessary to satisfy the requirements of manufacturing processes and the living standard.

2.4. Experimental Object

Return temperature at the EO, by summarising the mean monthly data on the heating season of 2008/2009 in the DH networks of the left bank of Riga city, it has been found that the return temperature indices exceed the requirements of the temperature schedule.

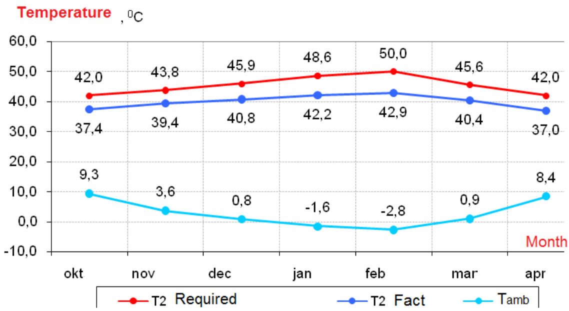

Fig. 2.5 The changes of the actual temperature of the DH network of the left bank of Riga city in the heating season of 2008/2009 in comparison to the settings

The reference values are presented in Figure 2.5. The presented T2 values indicate that there are good conditions for the installation of the flue gas recovery devices and the application of heat pumps or coolers for the utilisation of the low potential heat.

Specific electricity consumption for the production of heat is considerably lower at a lower ambient temperature. The EO is operating at a higher efficiency level at a lower ambient temperature, i.e. a higher load. The specific consumption of electricity increases when the heat load in the DH network decreases. The electricity consumption of the CHP plant is highest at night hours in summer. As the DH system is operating at a constant network water supply temperature T_1=70ºC during the summer period, it is not possible to impact electricity consumption for the provision of the network water circulation in the DH network. In winter T1 changes in compliance with the temperature schedule, and in this case, when the supply water temperature is higher the volume of the circulation water in the DH network is lower, thus $P_{el\ aux}$ required for the pumping of water is reduced.

Gas consumption at the EO during the whole year is fluctuating. Fuel costs have a considerable impact upon the price of the produced energy and these have increased dramatically over a period of the last 10 years.

Conclusions: In the Latvian conditions, due to the rapid increase of the purchase price of gas and the imposing of the excise tax to this type of fuel, the continuous long-term operation of GCCC becomes complicate. The situation is aggravated even more by the relocation of the manufacturing industry to the developing low costs countries in Europe and the stagnation of the power consumption by the manufacturing industry, caused by the prolonged economic depression. The situation can be returned to stable by reducing the price of natural gas for ensuring that the electricity and heat produced by natural gas are competitive products.

3. HEAT EXCHANGE PROCESSES IN ABSORPTION DEVICES

The main feature of an absorption device is a circulating mixture which consists of at least two substances, i.e. the cooling liquid and the absorbent. The selected substances are with different boiling temperatures at equal pressure values. Usually, a cold agent is one of the components and an absorbent is the other. The concentration changes of absorbent and the cooling agent is reflected in Figure 3.2. The light blue stands for water, the orange and the red stand for the cold agent of various concentrations.

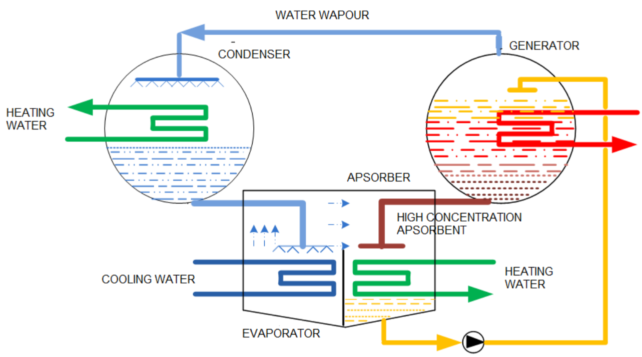

Fig. 3.2 Visualisation of the absorption process

The heat exchange processes ongoing in the absorber and the condenser, as well as their calculations are quite complicated. The calculation depends on a number of factors, including the type of flows (laminar, turbulent), the concentration of the liquids, the temperature fields, etc. Within the analysis of the heat exchange processes it is important to identify the volume of the heat flow from the environment to the enclosing heat pipeline or register of pipelines, carrying the liquid, or access the task from a different perspective – from the pipeline or register of pipelines to the enclosing environment. The volume of the heat flow depends on a number of factors, including the heat physical properties of the enclosing environment, the stability of the heat volume of the above environment, the heat inflow possibilities from further enclosing environment section, as well as temperature field cyclic of occasional changes of characteristics.

In the present Thesis the expression of the calculation of a non-stationary temperature field enclosing a cylinder type heat pipeline - a pipe carrying a cooling liquid with a constant temperature, was found.

$$\Theta_1 \; \rho, F \; = 1 + \frac{2}{\pi}\int_0^{+\infty} e^{-u^2 F} \, \frac{\psi_1(u)}{\varphi^2(u) + \psi^2(u)} \frac{du}{u}, \tag{3.1.}$$

where non-dimensional variables are introduced to complete the calculus:

$$\frac{r}{r_0} = \rho; \qquad \frac{T_1}{T_0} = \Theta_1; \qquad \frac{T_\infty}{T_0} = \Theta_\infty;$$

$$F = \frac{a\tau}{r_0^2}; \qquad Bi = \frac{\alpha r_0}{\lambda}, \tag{3.2.}$$

as well as introduced designations:

$$\varphi(u) = BiJ_0(u) + uJ_1(u); \tag{3.3.}$$

$$\psi(u) = BiY_0(u) + uY_1(u); \tag{3.4.}$$

By means of applying the Laplace transformation, an expression for the assessment of the temperature field within the environment enclosing the heat pipeline was found.

4. METHODOLOGY OF THE OPERATIONAL INDICES FOR THE ABSORPTION COOLER

A solution was found for the application of the absorption cooler at GCCC under the temperate climate conditions with an increased return temperature. When the temperature of the cooling water in the condenser increases above +47°C, the productivity of the cooler decreases rapidly and thus the risk that the technological water

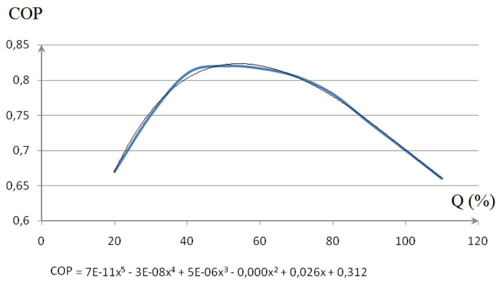

Fig. 4.1 The actual efficiency of the absorption cooler

is depending on the loading of GCCC will not be cooled sufficiently and the CU will experience an emergency shutdown increases. The dependence of the productivity within the DH network return temperature T_2 range +47 ÷ +67°C can be described by means of a polynomial of a 2nd stage:

$$Q_{cooling} = 0.0428 \cdot T_2^{\,2} - 7.3829 \cdot T_2 + 352.58. \qquad (4.1.)$$

When the testing of the absorption cooler was performed under the normal cooling conditions, the curve of the changes of the efficiency rate COP depending on the discharged load was obtained: Figure 4.1 presents the curve of the change of the cooling efficiency for single stage absorption cooler. This figure presents the dependence of the COP changes on the loading of the absorption cooler. Within the capacity range 20-110%, this COP change can be quite well described by the means of the polynomial which is added to the chart presented in the figure.

4.1. Possibilities for improving the operational efficiency of the absorption cooler

Taking into account that the capacity problems of the cooler emerge at the ambient temperature below -12 ÷ -15°C, this would permit to solve the cooling capacity deficit within the range of ambient temperature up to -22°C ÷ -24°C, which is observed very rarely, and the annual number of operating hours at this temperature is below 100. The proposed connection diagram of the absorption cooler is presented in Figure 4.2.

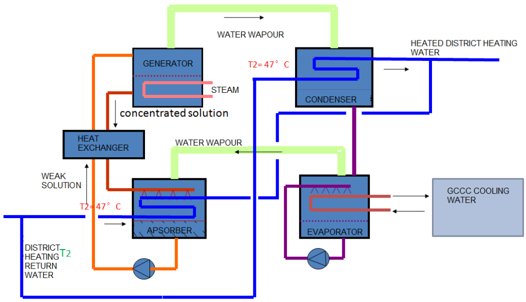

Fig. 4.2 The parallel connection of the absorption cooler

The proposed connection diagram requires the rebuilding of the hydraulic system of the heat supply return water of the cooler. In the result, the input cooling water temperature both in the absorber and the condenser will be equal, which permits to maintain the high COP and the cooling capacity of the device at increased DH network water temperature T_2.

CONCLUSIONS

1. The methodology for improving the efficiency of GCCC under the temperate climate conditions by applying the absorption coolers based upon the in-depth study of the heating season climatology data of the ambient temperature and the analysis of the operation of coolers has been developed in the present Thesis.
2. The methodology for the plan of the introduction of the district cooling in Latvia by utilising the low potential heat of GCCC has been developed for the district heating businesses which have introduced the energy production in the cogeneration process. This plan requires the compliance with a high national energy sustainability index and it can be implemented in municipalities with a positive development index. The perspective locations of implementation are the following: Jurmala, Riga, Valmiera, Jelgava, and Ventspils.
3. The method for improving the efficiency of GCCC by utilising the low potential heat of the technological water which is suitable for the Latvian and Baltic climate has been developed and proposed. During the course of the development of the above method several problems were solved and prevented, including the decrease of the capacity of the cooler under the conditions of the increased return of the DH network.
4. The developed GCCC technological solution is unique and it has been approbated at the CHP IMANTA of the JSC RĪGAS SILTUMS. It permits to save up to 2% of the input fuel of GCCC, which has resulted in the reduction of the natural gas consumption by 1.4 mill. n.m^3/ year at the EO.
5. The development of the mathematic description of a non-stationary temperature field within the environment covering cylinder type heat pipelines.
6. The long-term operational tests have proven that the efficiency of the absorption cooler integrated with GCCC can be improved by means of installing an additional closed air cooler or changing the connection of the cooling water of the cooler from series to parallel.
7. The optimisation algorithm and the criteria for assessing the results have been developed in the course of the analysis of the optimisation measures carried out during the study for the economic improvement of the GCCC operation.
8. The research of the technical economic operation of the district cooling and GCCC coolers has been carried out by performing the evaluation of the financial profitability which revealed the economic aspects of the operation of the compression and absorption coolers.

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