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V.1.

SUCCESSFUL COMPOSITION OF THE GEO CO- AND TRI-GENERATION PROJECTS

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ABSTRACT

This paper will present background, objectives and goals of a research necessary to be conducted to get answers on following question: what could and what should be composition of the cost-effective low-temperature co-generation and tri-generation projects. In Central European and Balkan region, reach on low temperature geothermal waters (<100^{0}C), is in growth interest of governmental, public and private investors to participate in funding construction of energy plants which could utilize in a certain way these waters. In addition, current irreversibility of fossil energies/environmental exhaustion increases the importance of R&D search for new technologies of low-exergy sources utilization for higher-exergetic energy production. Hence, it is necessary to explore technical feasibility of efficient/cost-effective use of these waters for co- and tri-generation of electricity and heat for heating and/or cooling by absorption refrigeration. Namely, as a result of global warming a need for cooling, particularly air-conditioning of buildings is in extreme growth. Relevant study of Building's thermal and electrical loads dynamics, and corresponding demands, should be performed based on which potential geo-co- and tri-generation systems could be optimized. It is well known that Kalina thermodynamic cycle can convert relatively low temperature energy, at relatively low temperature difference towards environment, to mechanical power and further to electricity. There are also some other thermodynamic cycles and processes of interest which could be potential solution for utilization of waters of even lower temperatures of those determined as limiting for the implementation of pure Kalina cycle. In addition, challenging question is possible hybridization - the use of these waters additionally heated to higher temperatures implementing other RES before performing co- generation. Finally paper proposes a study/R&D project to be carefully defined, organized and founded, to get reliable answer, based on which future development could be directed.

Key words: Geo co-generation and tri-generation, Kalina, Organic Rankine Cycle, coabsorbent cycles, renewables, hybridization. dynamic optimization.

1. INTRODUCTION

As a result of certain circumstances, this paper author learned about extremely interesting SPA Bardonovo geothermal water project in Slovakia. Aqua Tethys is a Spa community to be built atop the remainder of the Tethys Sea. The water is of exceptional medicinal quality, comparable to the Dead Sea water in Israel. The 22 million year old waters of the ancient sea are currently accessed by three recently completed wells that were financed by the EC. The 82 Celsius waters reach the surface from 2 extraction wells 1800 meters deep at a rate of 100 liters per second; the third well re-injects filtered water. The geothermal capacity of the water produces enough thermal energy for the activities of the water features, the full build out of the resort community and much more. However in addition to thermal energy supply for heating purposes it is important, even in central European region, more and more energy supply for cooling and air-conditioning of commercial and residential buildings and at the community level as a whole, and also electricity. Hence, it is necessary to explore technical feasibility of efficient/cost-effective use of these waters for co- and tri-generation of electricity and heat for heating and/or cooling by absorption refrigeration.

It is well known that except for geothermal (or ground-source) heat pumps, which utilize the heat contained in shallow soil, all existing uses of geothermal energy make use of hydrothermal resources – hot water or a mixture which consist of some combination of hot water and steam located in permeable rock. The hot geothermal fluid is mainly used for direct heating applications such as spas, greenhouses, district heating etc. It is also generally assumed that if the resource temperature is greater than about 90ºC, it can be utilized to generate electricity. However, only a few geo-power plant systems and equipment producers are commercially designing and engineering utilization of the hydrothermal resources with temperatures about 100ºC. Higher temperatures, particularly those significantly above 200ºC are generally more desirable and more suitable for electricity generation efficiency.

An approach to increase geo-power production efficiency is a deep drilling aimed to reach geothermal systems conditions which are known as "supercritical conditions". These are natural systems where underground water can be in super-heated state because of close proximity to almost molten rocks. Supercritical, high-temperature geothermal systems could potentially produce up to ten times more electricity than the geothermal wells typically in service around the world today. Production of electricity from supercritical fluids, requires drilling to depths of 4 to 5 km in order to reach fluid temperatures of 400–600°C. Based on an appropriate study results, at Krafla in north-east Iceland the first wells were planned to be drilled in 2008 and tested this year.

For lower quality resource temperatures below about 175ºC, to get efficient performance of power producing thermodynamic cycle, it is necessary to use a secondary volatile working fluid, as for example hydrocarbon type (isobutane or isopentane) that vaporizes absorbing heat received from primary geo-fluid in heat exchanger and produces work during expansion passing through a turbine. Such cycles and plants are known as binary, because a seconddary fluid is performing the power cycle. These types of plants mainly have higher equipment costs than flash plants, as they, after transferring heat from the geothermal fluid, return all the geothermal fluid to the ground, and do not have condensed steam available as cooling water. So, they must use a separate water source or air-cooled condensers.

This paper aim is to try to draw attention on underground geo-waters of temperatures about or even below 100ºC, presenting further background, objectives and goals of a research necessary to be conducted to get answers on following question: what could and what should be composition of the cost-effective low-temperature co-generation and tri-generation projects.

2. ENERGY EFFICIENT AND SUSTAINABLE BUILDING'S ENERGY SUPPLY BY GEO-BASED CO-GENERATION AND TRI-GENERATION

Buildings heating, ventilating, air-conditioning and refrigerating (HVAC&R) systems contribute to GHGs releases directly through commercial, industrial and residential air ventilation and energy-related effects, and directly through the effect of refrigerant losses. The release-related contributions to climate change are addressed by minimizing emissions of refrigerants (that have global warming characteristics) from systems or processes into the atmosphere. The lowest release-related impacts can be achieved by taking care on rigorous refrigerant conservation measures during design, manufacture, installation, operation, service, and recovery and finale disposal. Energy-related impacts - carbon dioxide and other GHGs releases can be reduced by decreasing the energy consumption of equipment, systems, and buildings – by controlling and modifying building operation and user's behavior. Both effects must be considered in a life-cycle environmental analysis.

Primary are those factors that affect the energy consumption in the operation of the building and its HVAC and other technical systems, during its useful lifetime in addition to the selection of energy-efficient equipment. However, very influential factors within the design process are facades concepts and choices in building envelope alternatives, glazing and fenestration, types of building structure thermal mass and insulating materials, lighting and daylighting control, natural ventilation and energy-recovery opportunities, and HVAC systems regimes and operational modes such as temperature control, air volume control, motors and pump types of control, indoor and outdoor air quality and environmental protection.

All of these considerations have an impact on the HVAC&R requirements and resulting CO_2 emission. Additional considerations in the choices (or options) in building design and operation are any excessive environmental consequences associated with the production or manufacture of building components. Decision-makers shall consider all environmental impacts prior to taking actions in response to climate change. It would be counterproductive to require that refrigerant substitutes have low global warming potentials (GWPs), which at the same time may result in higher energy requirements or compromised safety. Thus, integrated assessments and balance are needed in emphasizing environmental issues to avoid solutions that remedy one problem at the expense of another.

There is no doubt that fossil fuels will continue to be the key to satisfy energy needs until well into this century. On the long run, the most important options to delay fossil energy resources total exhaustion, to reduce pollution and to control climate change for all regions are renewable energy sources (RES), geothermal, solar, biomass, wind, etc. and low-carbon energy technologies combined with major improvements in end-use efficiencies. It is mandatory to have fully dispatchable systems, for spreading the use of geothermal and other RES today. The best way to do this nowadays is by hybridization with natural gas, oil or electricity. Most prospective near and mid term applications of RES, are to be foreseen for different hybrid systems or integrated energy system (combines the elements of RES and non-renewable fossil based technology or combines elements of two or more different RES technologies) /1/.

Building performance simulation and energy efficiency optimization. Energy-related impacts - carbon dioxide, and other GHGs releases reduction by decreasing the energy consumption of equipment, systems, and buildings - by controlling and modifying building operation and users behavior, must be considered in a life-cycle environmental analysis. Primary are those factors that affect the energy consumption in the operation of the building and its HVAC and other technical systems, during its useful lifetime in addition to the selection of energy-efficient equipment. Influential factors within the design process are facades concepts of building envelope, glazing and fenestration, types of building structure thermal mass and insulation, day-lighting control, natural ventilation and energy-recovery opportunities, HVAC systems regimes and operational modes: temperature, air volume, motors and pump types of control, indoor and outdoor air quality/environmental protection. All of these considerations have an impact on the HVAC&R requirements and resulting CO_2 emission.

The designers preoccupation to reduce energy consumption and to achieve better thermal ambience levels has favoured the setting up of numerous building thermal dynamic simulation programs – BPS programs. The progress in BPS modelling and its transfer into the professional field has resulted in various numerical approaches. In each of these cases, the objective results, the precision advocated and the time delay of the results are different parameters which call for a multiple-model approach of the building system (/6/ - /9/). Since the initial significant diffusion of simulation and design models, one of the major problems is their appropriateness to a particular user during the design process.

BPS simulations and buildings thermal behavior predictions are reliable foundation for building's energy efficiency intelligence and e-automation, and are to be elucidated as crucial technologies/techniques for design, construction and operation of sustainable buildings, or so called Green buildings integrally with its distributed energy supply system, HVAC, lighting and other technical systems. Specific attention has to be drawn to the energy supply system dynamics, particularly of the integrated clean energy - renewable energy sources including storage, distribution and use.

Chapel on Bezanijska Kosa Case Study. As a BPS energy efficiency optimization and buiding's thermal loads dynamics study, in this paper is presented methodology and results of the performed multidisciplinary, integrated building design of the Chapel on Bezanijska Kosa in New Belgrade, in which energy optimization has been conducted of building construction, of technical and HVAC systems as well as of the utilization of solar energy and ground energy via heat pump. The project is the result of the Agency for Building Land and Construction of Belgrade's decision to design and construct an efficient building from the point of energy efficiency, rational energy use and energy conservation, optimization of utilization of clean technologies and solar - renewable energy source, that means referential green building aimed for demonstration and further dissemination /1/.

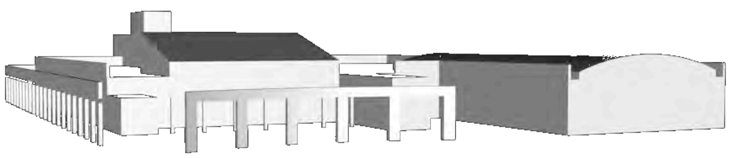

Figure 1. Chapel on Bezanijska Kosa in New Belgrade

Ten scenarios of different combinations of the most effective measures for energy efficiency improvement have been analysed and the best three have been selected for the final optimization, taking in account relevanr constraints as follows: total annual energy consumption, heating and cooling energy use, electrical energy use, new technologies implementation, as well as related investment and operational costs.

Also, it is important to stress that because of cooling and air-conditioning during summer is neccessary more heat then during winter, and it makes very advantageous combination of solar energy utilisation with absorption cooling and trigeneration/cogeneration.

Figure 2. Absorption Cooling's Energy Consumption

Figure 3. Total Gas/Energy Consumption

CHP – Combined Heat and Power, Cogeneration or Trigeneration (when cooling is needed in addition to heating) of heat and power systems normally make effective use of both electric power and heat energy from a generator, by a method that obtains two available forms of energy from a single fuel source. Consequently, in addition to being a promising countermeasure to environmental problems by virtue of its available use of energy, CHP is also effective in dealing with the problem of peak power loads as it can be used as a distributed source of electric power. The key issue in the CHP gas engine system or micro-turbine system design (both types of machines have been encompassed within the design) is the determination of the system and the machine capacity having the excellent economic and environmental characteristics on the electric power and the heat demand. In general, the ratio of electric power demand to heat demand in general buildings varies daily over the course of the year.

Hence, results of the energy efficiency optimization did confirm the importance of minimization of building's loads and annual harmonization of dynamics of different final energy forms demands, before final sizing of co- and tri-generation plant.

Thus, it is necessary to explore technical feasibility of efficient/cost-effective use of geothermal waters for co- and tri-generation of electricity and heat for heating and/or cooling by absorption refrigeration. Namely, as a result of global warming a need for cooling, particularly air-conditioning of buildings is in extreme growth. Relevant study of Building's thermal and electrical loads dynamics, and corresponding demands, should be performed based on which potential geo-co- and tri-generation systems could be optimized.

3. SEARCHING AN APPROACH TO THE LOW-EXERGY GEO-UTILIZATION FOR HIGHER-EXERGY ENERGY PRODUCTION

In Central European and Balkan region, reach on low temperature geothermal waters (<100^0C), is in growth interest of governmental, public and private investors to participate in funding construction of energy plants which could utilize in a certain way these waters /2/.

In addition, current irreversibility of fossil energies/environmental exhaustion increases the importance of R&D search for new technologies of low-exergy sources utilization for higher-exergetic energy production. Hence, it is necessary to explore technical feasibility of efficient/cost-effective use of these waters for co- and tri-generation of electricity and heat for heating and/or cooling by absorption refrigeration.

It is well known that Kalina thermodynamic cycle can convert relatively low temperature energy, at relatively low temperature difference towards environment, to mechanical power and further to electricity. The **Kalina cycle** is a thermodynamic cycle for converting thermal energy to mechanical power, optimized for use with thermal sources which are at a relatively low temperature compared to the heat sink (or ambient) temperature.

The Kalina cycle uses a working fluid comprised of at least two different components (typically water and ammonia) and a ratio between those components is varied in different parts of the system to increase thermodynamic reversibility and therefore increase overall thermodynamic efficiency. There are multiple variants of Kalina cycle systems specifically applicable for different types of heat sources. Several proof of concept power plants using the Kalina cycle have been built.

Since the phase change from liquid to steam is not at a constant temperature, the temperature profiles of the *hot* and *cold* fluids in a heat exchanger can be made closer, thus making the global efficiency of the heat transfer bigger. For this reason, this cycle is increasingly popular in geothermal power plants, where the hot fluid is very often below 100ºC.

Up to now, in the binary plants (where a heat exchanger is used to produce steam instead of directly employing the steam underground), the commonest cycle had been the *ORC* (Organic Rankine Cycle). Example of this is the Landau-

Pfalz power plant in Germany, rated 3.8 MW of electrical power and 8 MW of thermal power.

The efficiency of the Kalina cycle is depending on the second law of thermodynamics and as a rule of thumb, you can for simple rough evaluations assume for the Kalina cycle an efficiency that is in the range of 40 -50% of the calculated Carnot efficiency.

Although, it has been stressed that heat sources of low temperature like 100ºC can be utilized for power production in a Kalina plant, due to the low efficiency, commercial plant/equipment suppliers normally do not consider this a financially viable option. The minimum temperature limit due to financial restrictions is usually set at 110-115ºC. This can though vary from case to case due to different cooling options for the power plant and also, of course, the electricity price.

That is the reason, this paper states that it is necessary to conduct appropriate research and establish innovative R&D program and re-engineering study aimed to explore reliable technical possibilities to expand the low-temperature geo-water utilization for co- and tri-generation based on synergetic approach - Thermodynamic cycles innovations and RES co-utilization or hybridization with other RES.

Namely, geo-heat source of 100ºC cab be "boosted" by addition of other high temperature renewable heat sources. This a clear possibility and the Kalina cycle has great potential for adaptability for use with heat sources at different temperatures. Naturally all relevant parameters are to be encompassed with that study, including the cooling source and its characteristics (river or lake water, wet cooling tower, or else), as well as local – site climate conditions, beside earlier stressed importance of HVAC and other energy loads demands

4. INSTEAD OF CONCLUSIONS - THERE ARE STILL UNDISCOVERED ROUTES IN THERMODYNAMIC CYCLES AND RES INTEGATION INNOVATIONS

There are available studies reports and scientific/technical papers evidently demonstrating that there are also some other thermodynamic cycles and processes of interest which could be potential solution for utilization of waters of even lower temperatures of those determined as limiting for the implementation of pure Kalina cycle. Also, there are prospective answers on the challenging question on the possible hybridization - the use of these waters additionally heated to higher temperatures implementing other RES before performing co- generation.

Finally, this paper will present background, objectives and goals of a research necessary to be conducted to get answers on following question: what could and what should be composition of the cost-effective low-temperature co-generation and tri-generation projects.

Potential R&D Project objectives

- Kalina cycle reexamination and study of some other thermodynamic cycles and processes of interest which could be potential solution for utilization of waters of even lower temperatures of those determined as limiting for the implementation of pure Kalina cycle.
- Searching new technological routes of RES, implementation/integration to increase exergy value of low-exergy geothermal waters. Here, particularly great potential lies in the solar radiation intrinsic high exergetic character, which is mainly by all terrestrial solar utilization technologies degraded.
- Investigation of possible advanced geo co- and tri-generation by the co-utilization of Geo-waters and solar or/and biomass for example is to be investigated.
- Energy conversion research is aimed at reducing the delivered electricity cost by improving performance, lowering equipment cost, and reducing O&M costs of geothermal power plants.
- Low temperature geothermal power plants operate at low temperatures and thermody-namic request is to reject to the environment as much as 90% of the heat extracted out of the ground – hence research is to focus improvement of the heat rejection equipment, and new designs of both water-cooled and air-cooled condensers are necessary.

- Development of heat exchanger linings that protect low-cost heat exchanger materials from corrosion and scaling when subjected to geothermal fluids.

Follows a short review of current R&D topics which could be more in depth elaborated and certain aspects of those also introduced in the proposed R&D project.

Coabsorbent technology (CT) was publicly disclosed recently /7/, (Staicovici, 2006a-2008e). As one of applications, CT can be coupled with thermal power plants (e.g. Steam (Organic) Rankine Cycle (S(O)RC), or Diesel engine type), in order to produce efficient district combined cooling, heating and power (CHP, i. e. Trigeneration), (e.g. Staicovici, 2008f). In this work, ammonia/water further research results are added to this topic. First, district coabsorbent heating vs. heating in classic S(O)RC cogeneration of power and heat are comparatively assessed. Second, S(O)RC-CT vs. S(O)RC-MVC (Mechanical Vapour Compression) trigeneration systems are modelled. After CHP coabsorbent candidates selection, trigeneration systems are evaluated with respect to electrical power output for same cooling and heating district loads, within a common range of cooling and heating temperatures. Finally, comparative results are given and paper conclusions are formed.

The plant's design and components' selection are commonly based on user specified or estimated distributions between heat, power and refrigeration capacities and are crucial for the economical success of the cogeneration plan. A basic approach is given by Weber (2005). Therefore a shortcut selection and sizing method shall be explained as a tool for early design stages.

Based on real components' performances for a combination of combined heat and power plant and single stage absorption chiller a graphical method was developed for the assessment of combined-heat-power-refrigeration-plant applications for various user-specified demand profiles /6/.

An effective-energy-trigram was introduced with its three axes representing heat, power and cooling effect. The components' performances determine an operation area; the user's demands specify a demand point in the trigram.

A demand point within the operation area means that all energy demands can be met by the CHPR-plant. A demand point outside of the operation area can be met by supplementary effective energy and a properly designed CHPR-plant which capacities meet the requirements at a corresponding operation point. In both cases there is no overgeneration of any of the three effective energies.

Demand point and corresponding operation point of an adequate CHPR-plant can be easily connected by subsidiary lines in the effective-energy-trigram. The pre-dimensioning method introduced here helps to get a realistic view on a total-energy system's potential at an early design stage. It is a tool for consultants to give their customers a clear perspective on feasible component combinations and economic possibilities of combined energy generation.

The U.S. Department of Energy (DOE) has developed a spreadsheet model to provide insight as to how its research activities can impact of cost of producing power from geothermal energy. This model is referred to as GETEM, which stands for "Geothermal Electricity Technologies Evaluation Model". Based on user input, the model develops estimates of costs associated with exploration, well field development, and power plant construction that are used along with estimated operating costs to provide a predicted power generation cost. The model allows the user to evaluate how reductions in cost, or increases in performance or productivity will impact the predicted power generation cost. This feature provides a means of determining how specific technology improvements can impact generation costs, and as such assists DOE in both prioritizing research areas and identifying where research is needed.

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