An innovative concept for geothermal energy: the Clozed Loop technology aiming for zero emissions

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Keywords: Geothermal energy, Organic Rankine Cycle, associated water in O&G fields, Clozed Loop technology.

ABSTRACT

The use of geothermal steam for the production of electricity has a long track-record, with the first experimental installation built in Larderello, Italy, in 1904. In the last 30 years, 12 GW of geothermal power capacity has been built around the world with the annual installed capacity growing at 4-5% per year. Many countries are coming to appreciate geothermal energy's value as a dependable renewable energy source. Optimizing Geothermal Energy: CloZEd Loop Energy AG (CLEAG) seeks to commercialize a new variant of geothermal energy with technology that fully utilizes the energy potential of hot brines. In contrast to conventional geothermal power plants our hybrid system uses two sources for its energy production: hot water as well as the combustible gases dissolved in it. The gases are separated from the water and burned in a gas engine. The CO_2 from combustion, as well as any brought up with the hot water, is captured at a rate of 98% and safely re-injected into the aquifer, where it stays. The result: remarkably cost-effective, renewable, and near zero-carbon energy. Our technology is cleaner than that of many current geothermal plants, which vent all aquifer gas to the atmosphere. Geothermal power has an important role to play in the energy systems of many countries, as the exploitable potential lies far above its current utilization. The World Bank has estimated that nearly 40 countries possess a geothermal resource large enough to meet their entire electricity demand of which, we estimate the majority also have high natural gas content. With our technology, countries can decrease their energy import dependence and attract industries seeking inexpensive heat and electricity.

1. INTRODUCTION

Typical geothermal power plants generate energy from hot water, underground aquifers. Sometimes, this water contains dissolved natural gases that are treated as waste and vented into the atmosphere, damaging the environment. Furthermore, typical geothermal projects exhibit substantial exploration risks and unfavorable return profiles compared to alternative green energy solutions. CloZEd Loop Energy AG (CLEAG) has developed an innovative and patented technological concept that allows a rational, comprehensive and economically efficient use of underground reservoir of mineral resource in a closed circuit. This concept enables a sustainable and environmentally acceptable approach to geothermal resources in underground aquifers which are used for energy production. Technical features and advantages of the CLEAG technology are described in par. 2. Par. 3 resumes the concept of binary geothermal cycles and the application of Organic Rankine Cycle (ORC) technology in the framework of CLEAG technology. The development of the first pilot project with CLEAG technology is illustrated in par. 4. Finally, conclusions are reported in par. 5.

2. CLOZED LOOP TECHNOLOGY

Typically, geothermal resources contain aquifer gases. These gases are considered a restricting factor because they either decrease energy production efficiencies, or harm the environment if vented into the atmosphere. According to official calculations, aquifer gas resources are huge. They are estimated roughly twice as large as the reservoirs of conventional gas (BGR, 2009). The Swiss company, CloZEd Loop Energy AG (CLEAG), has patented an innovative low-carbon technology - CloZEd Loop Technology - to turn a traditional limitation into a competitive advantage and sustainable solution. The technology is described in fig. 1.

2.2 CLOZED LOOP TECHNOLOGY ADVANTAGES

Many advantages of this technology can be highlighted:

• Within the highly attractive clean energy production market, CLEAG (CloZEd Loop Energy AG) has been very uniquely positioned: energy production is based on geothermal energy. As geothermal energy is permanently available, the most compelling argument for this energy source is its base load character. A geothermal power plant is able to operate 365 days a year, 24 hours a day. Stable energy production creates predictable and controllable revenues.

• Efficiency can be boosted by use of "waste" aquifer gases: in all cases geothermal water contains aquifer gases, for which no technological solution has been developed so far, therefore, these gases are considered as a restricting and environmentally harming factor. CLEAG has developed a compelling solution. By applying CLEAG's technology, it is expected that output, efficiency and sustainability of the geothermal power plants can be significantly increased. As high temperature heat and power is generated separately with gas engines, even geothermal sources with lower temperatures are still economically exploitable. This further enhances the market and revenue potential.

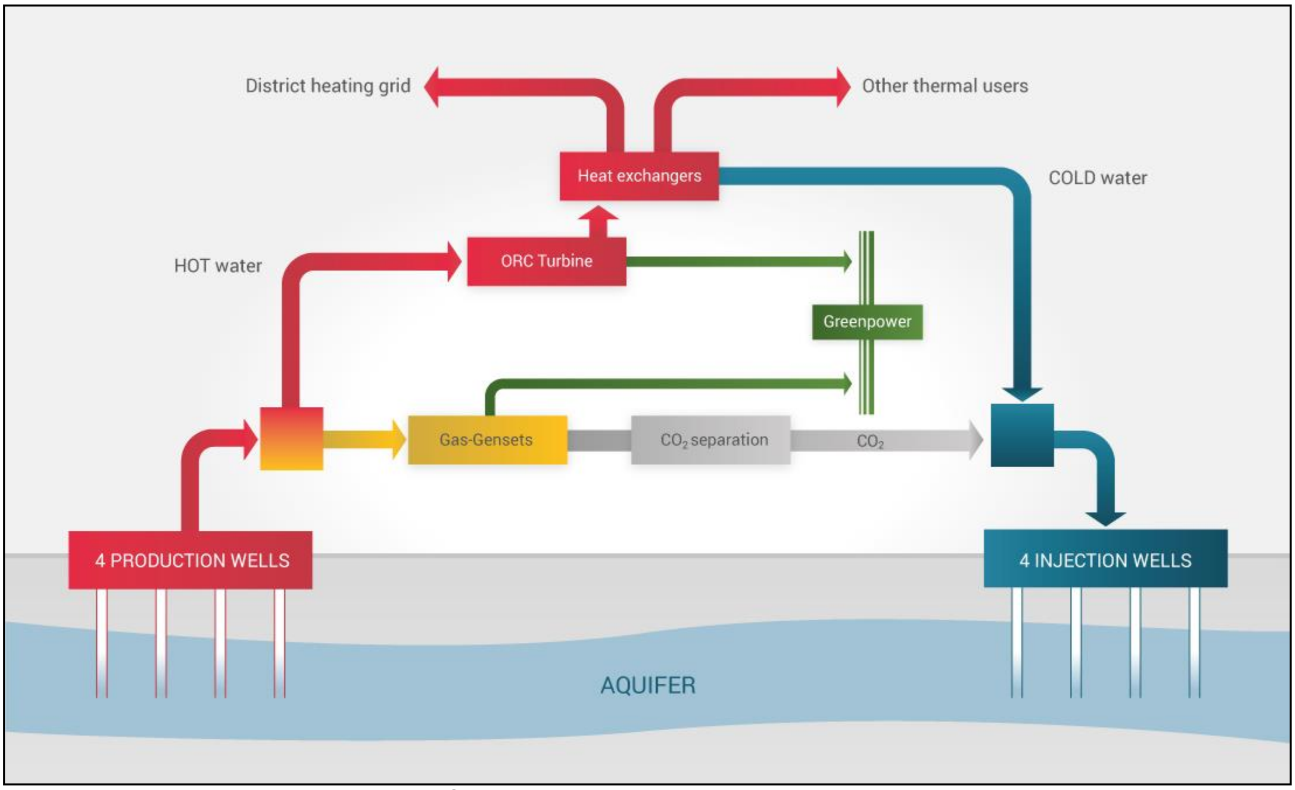

Fig. 1: CloZEd Loop technology simplified scheme

2.1 CLOZED LOOP TECHNOLOGY SIMPLIFIED

The gas is separated from the water using a pressure vessel. Temperature of the water is between 90° and 110° Celsius at surface. The water is fed into the ORC, while the gas is channeled to the CHP gas engines. After combustion, the flue gas is cleaned by an amine-scrubber to obtain pure CO_2. Thermal users can exploit hot water at the bottoming of the ORC (water temperature at about 70°C) or bypassing the ORC during specific period (e.g. winter season). Pure CO_2 cleaned by ammine scrubber are mixed with the cooled geothermal water and re-injected into the same aquifer. The entire process runs in a closed system, therefore having minimal impact on the surrounding environment.

• Energy production based on CloZEd Loop technology can help nations to lower their dependency on oil, gas and electricity imports.

• Zero Emission, electricity production based on aquifer gas: the most compelling advantage of the technology is the fact that the additional use of gas for energy production – untypically - does not lead to harmful emissions. CO2 can be captured in the internal system, dissolved in water and safely re-injected into the aquifer. As a positive side effect this maintains the stability of the underground aquifer, because all pressures are kept even. In this manner electricity production is – in accordance with what is desired by the society and legislative bodies – completely clean and emission free.

• The technology is highly innovative and relatively easy to implement whilst holding proven elements of state-of-the-art technology. The combination is breaking new ground. This minimizes the development costs and technological risks tremendously.

• Standard components are proven, reliable, and available to buy at attractive prices. A modular containerized concept has been chosen to adapt ideally to local site conditions and further bring down costs through pre-fabrication. Every geothermal site has its own characteristics.

• Flexible energy sources: As an alternative to aquifers, CloZEd Loop technology can also run on water driven oil/gas fields where the water phase has CH4 up to the saturation point. Such an application would prove to be very interesting, as the re-injected CO2 would increase the flow of oil/gas and assure a more constant production. Simultaneously, the power plant would produce sustainable and clean energy.

Dependent on some key criteria (like the availability of gas, gas content, demand for heat, etc.); the appropriate, most economic plant size and design can be chosen and developed in a very flexible, cost efficient way.

3. GEOTHERMAL BINARY CYCLE AND ORGANIC RANKINE CYCLE TECHNOLOGY

In geothermal power plants, binary cycle technology allows the exploitation of low enthalpy geothermal reservoirs – with temperatures below 180°C – that cannot be exploited by other geothermal technologies – i.e. dry steam and flash steam plants.

In 2010, flash steam plants were the most common type of geothermal power generation plants in operation, which use water at temperatures greater than 182°C that is pumped under high pressure to the generation equipment at the surface. With binary cycle geothermal power plants, pumps are used to pump hot water from a geothermal well, through a heat exchanger, and the cooled water is returned to the underground reservoir. A second "working" or "binary" fluid with a low boiling point, typically a hydrocarbon, is pumped through the heat exchanger, where it is vaporized and then directed through a turbine. The vapor exiting the turbine is then condensed by air cooled condenser or cold water and cycled back through the heat exchanger.

The typical thermodynamic cycle and the relevant components of an ORC are shown in fig. 2. The organic working fluid (confined to a closed and leak-free circuit) is pre-heated and vaporized using the heat source in the pre-heater and evaporator. The organic fluid vapor expands in the turbine - which can

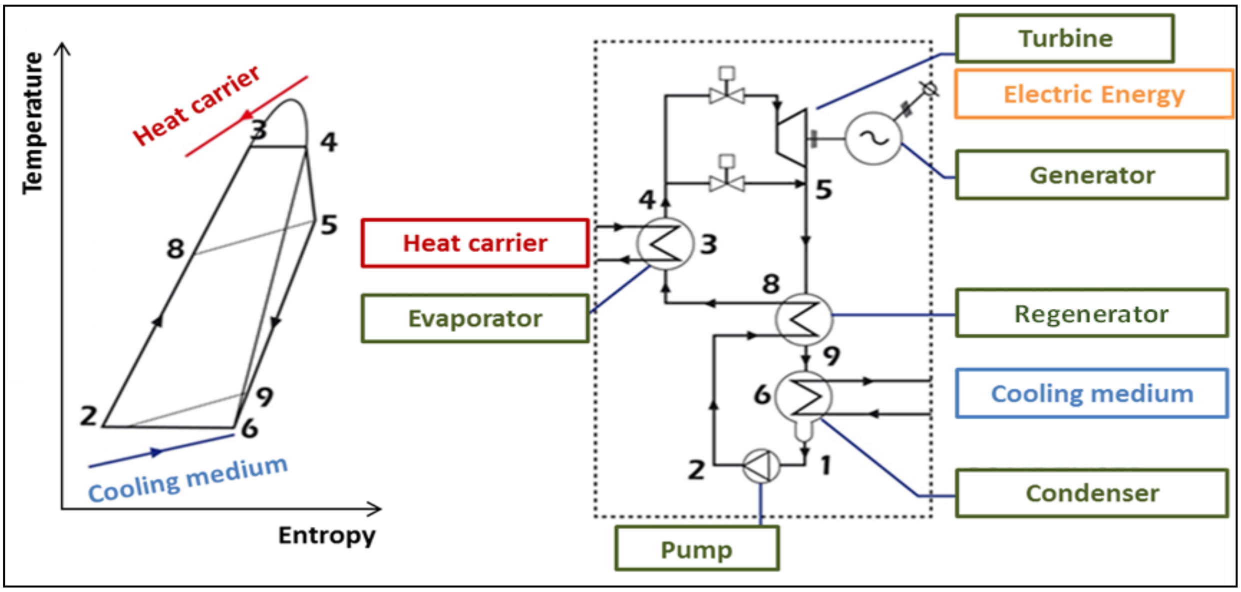

Fig. 2: Thermodynamics and scheme of the ORC

be directly coupled with the electric generator - and is condensed releasing the heat to a cooling media - that can be directly air in air cooled condenser (ACC) systems or water in water cooled condensers (WCC) cases.

The condensate is then pumped back to the evaporator, thus closing the thermodynamic cycle.

Hot and cold sources are neither in contact with the working fluid, nor with the turbine. For high temperature applications, a regenerator (heat exchanger) downstream of the turbine is also added to further improve the cycle performance.

Organic Rankine Cycle (ORC), employing heavy molecular weight working fluids that guarantee dry vapor expansion in all operating conditions, are typically preferred for smaller size heat to power systems up to 20 MW due to the higher efficiencies at lower heat source temperatures and maximum ease of operation at minimum running costs (no dedicated personnel is necessary).

The most widely used organic fluids are hydrocarbons (e.g. pentane, butane, etc.), siloxanes (employed also in the cosmetic industry) and refrigerants (more common in HVAC and refrigeration systems). In fig. 3, saturation curves and the basic difference between traditional Rankine Cycle with Steam Turbine and ORC are reported.

As the shape of T-s curves suggest, if compared to water, organic fluids do not need to be superheated to avoid condensation in the turbine during expanding stage. This feature leads to some very important technical advantages compared to conventional steam cycles in some specific cases: high turbine efficiency (up to 85%), low mechanical stress of the turbine (low tip speed, moderate temperature,) low turbine rotational speed allowing direct drive generator (no gearbox), no blade erosion (no liquid particles during expansion, due to the shape of saturation curve), no oxidation (some organic fluids can even be considered as lubricants themselves), high efficiency with low and moderate temperature sources (e.g. 25% with 300°C hot source).

As a consequence, ease of operation is characterized by:

• simple start-stop procedures, with quiet running and automatic and unattended operation
• high availability
• high flexibility (good efficiency at partial load, with turn-down to 10% or less of nominal power, see fig. 4)
• long life and minimum O&M requirements
• complete automatic / unmanned systems

These advantages are related to the positive working fluid characteristics, allowing to design and build relatively large and slow rotating (thus efficient and

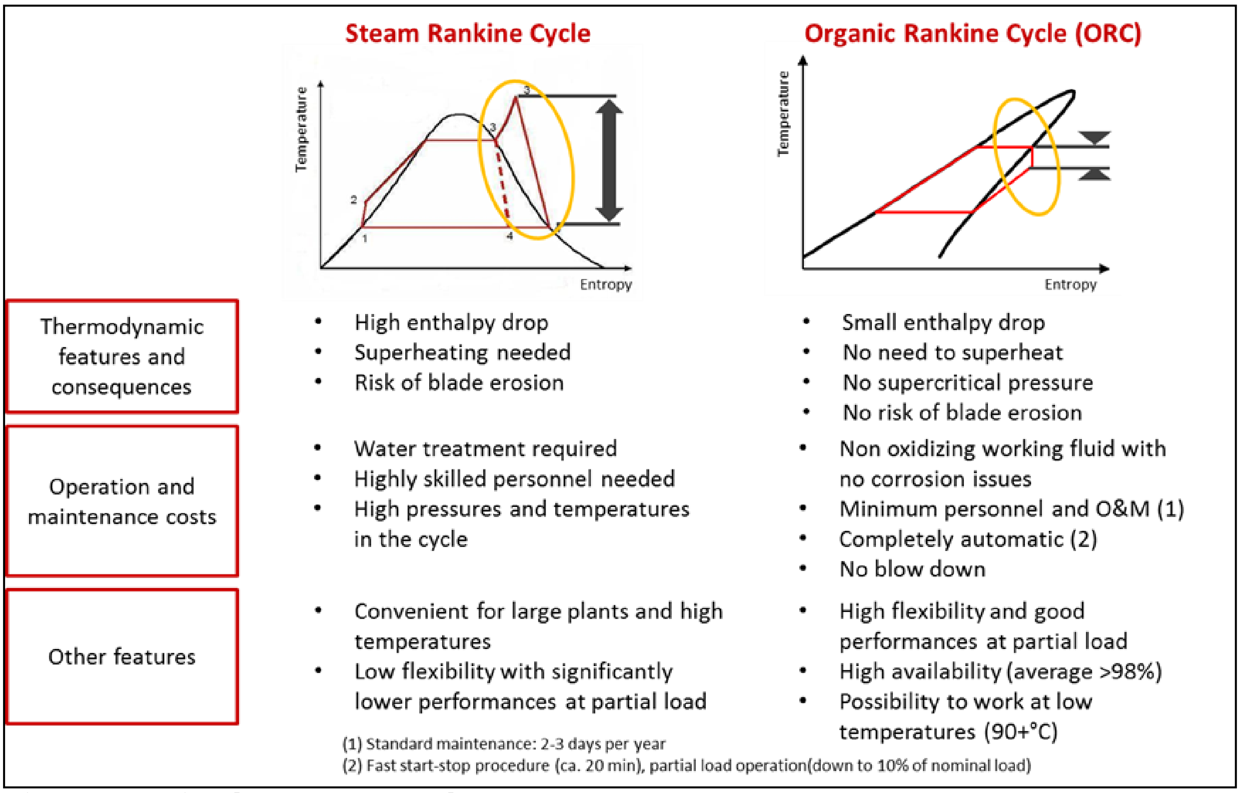

Fig. 3: Comparison between Steam and ORC

reliable) turbines, making ORC one of the best choices for small scale applications (up to 5-20 MW). For these reasons, the ORC technology is expanding its list of potential applications for distributed generation in geothermal power, other renewables in general (especially biomass based), in small combined cycles (bottoming gas turbines or internal combustion engines) and for waste heat recovery in industrial processes.

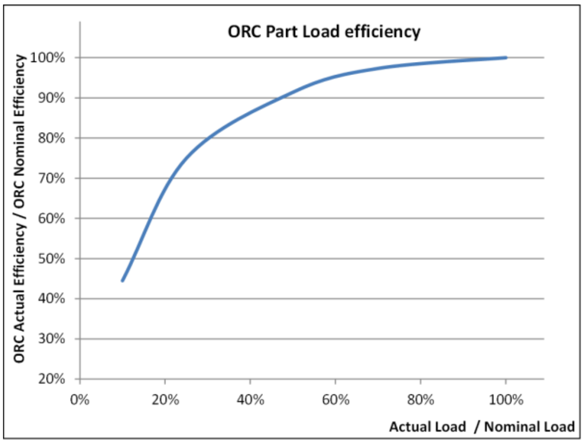

Figure 4: Performances at partial load of the Organic Rankine Cycle

Depending on the specific project features and requirements, several ORC technical solutions are possible. Three main variables are selected from case to case to optimize the final heat recovery plant scheme:

• the selection of the working fluid, done to maximize the ORC power output while achieving an optimum cost and system reliability;
• the materials used for the heat exchangers between the geothermal brine and ORC working fluid. Tradeoff between cost and performances (resilience to corrosion and fouling) must be achieved.
• how the ORC condensing heat is released to the ambient, either via a water cooled condenser in cases in which water for cooling is available or directly to air in Air Cooled Condensed cases.

4. CLEAG PILOT PROJECT

CLEAG is developing its first power plant in Draškovec, Croatia through the company AAT Geothermae d.o.o. (AATG). AATG is wholly owned by CLEAG and owns a license to develop and operate CLEAG power plants throughout Croatia. Draškovec is in the Pannonian Basin, a geological formation that extends under Hungary and parts of Hungary's neighbors. It is particularly suited to geothermal projects:

(1) reliably offers a water temperature of 100°C at a depth of only 2,500 m
(2) extensively researched in the past 30 years (5000 research wells).

Exploration is not difficult and the cost of drilling to such a depth is not prohibitive. In addition, the water under the Draškovec site is rich in natural gas. One cubic meter of geothermal water on the surface contains approx. 3 kg of methane, which translates into a volume gas/water ratio of 4.5:1, with a high caloric value of gas at 9.5 kWh/m3. Moreover the geothermal water has a temperature on the surface of approx. 100°C.

On August 7, 2013, the Ministry of Economic of Republic of Croatia has issued research concession for geothermal water in the exploration area "Draškovec AATG" to AATG. In this area, the well "Draškovec 1" (Dr-1) was drilled during the 70's. During 2013 and 2014 AATG and a team from the Faculty of mining, geology and petroleum engineering from University of Zagreb and external experts, has conducted exploration works on Dr-1 well. During 2015, AATG established a team of engineers and external experts to carry out exploitation activities in order to determine best trajectory of the new channel of the new exploration well "Draškovec 2" (Dr-2). Although the area is quite well researched with seismic and drilling activities, selected targets by the project are quite scarce particular. Selected targets were sandstone layers Lower Ratka (or Okoil) and Siget (or Iva). During 2016, AATG hired renewed international companies to conduct drilling and testing of Dr-2. Drilling and testing were completed in July 2016. The project will developed in several stages according to the drilling development and the installation of power equipment.

Figure 5: CLEAG first pilot project development in Draškovec, Croatia – May 2016

The project team built close relationships with important decision-makers in the national government, regional authorities and local municipality. Politicians and opinion leaders at all levels are very keen to be part of an initiative that could see Croatia pioneer a brand-new energy technology. CLEAG involved nearby universities and technical colleges to give them an opportunity to learn about our technology and to share their experience with us. Draškovec plant will sell its electricity to the national utility at favorable fixed prices per MWh. The site in Draškovec has been acquired and developed by AATG and all necessary permits to start the construction have been successfully obtained.

The project is awarded with NER300 award from European Commission in field of innovation in renewable energy sector. This pilot project is the first in South East Europe receiving this award.

Furthermore, CLEAG already pipelined additional projects and are constantly scouting for future sites.

5. CONCLUSIONS

CloZEd Loop technology is a promising solution for the exploitation of aquifers where hydrocarbons are mixed with water. ORC power plants promise economical, installation, operational, and environmental benefits:

Economic benefit. Revenues are made at the same time by gas fired CHP engines with total reinjection of CO2 produced, ORC electric production and eventually thermal energy exploited by thermal users. Unlike many other renewable technologies, ORC electricity is not intermittent and is typically available 24/7. The cost of this production was calculated in 40 USD/MWh electric.

Installation benefits. CLEAG power plants are modular, providing the developer with configuration options to best match the application potential.

Operation benefits. Thanks to a power plant that is fully automatic and does not require continuous operator presence; few stops for maintenance are required, primarily to validate operational parameters. CLEAG capacity factor was calculated in 95%.

Environment benefit. At a CLEAG power plant, all emissions generated by gas engines are cleaned through ammine scrubber and the pure CO_2 extracted is reinjected in the aquifer. Average lifecycle CO_2 emission factor of CLEAG technology was calculated in 5 grams of CO_2 per MWh electric 0, while classic geothermal generates 38 grams of CO_2 per MWh electric.

Hybrid solutions benefit. CloZEd Loop technology is a sustainable energy innovation that generates base load electricity via an ORC and CHP. No emissions are released to the atmosphere.

NOMENCLATURE

Acronyms

ACC	Air Cooled Condenser
CL	CloZEd Loop Technology
CHP	Combined Heat and Power
EVA	EVAporator
GHG	Greenhouse gas emissions
HE	Heat Exchanger
ORC	Organic Rankine Cycle
REC	Recuperator
SRC	Steam Rankine Cycle

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