Comparison between existing Rankine Cycle refrigeration systems and Hygroscopic Cycle Technology (HCT) †

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Abstract: The objective of this paper is to review the different cooling systems that can be used in a Rankine cycle, especially the new technology called HCT (Hygroscopic Cycle Technology), that is based on the physical and chemical principles of absorption machines to increase the Rankine cycle net electrical efficiency and improve the cooling conditions. This technology allows an efficient and economical condensation of exhaust steam at the outlet of the steam turbine and significant decreases the water consumption. Advantages and high potential of HCT for power plants are analysed, comparing it with the current refrigeration systems. Also performances, investment and operation costs for each of the systems, are studied.

Keywords: Refrigeration, Evaporative, Condenser, Hygroscopic, Absorber, Performance, Water, Dry-cooling, Rankine, Power.

1. Introduction

Development of industries and increasing of population have produced a huge Energy demand. Innovative and feasible solutions are needed to be found [1].

World electricity production is mainly based on Rankine thermodynamic cycles. The objective of this thermodynamic cycle is to convert heat into work, creating what is called a power cycle. Its efficiency is limited by thermodynamic efficiency of a Carnot cycle [2].

Heat sources can come from combustion of fossil fuels (coal, natural gas, oil) or of renewable sources (biomass), or from other kind of source as nuclear energy or thermal solar energy. Even when primary system of an electric power plant is not based on Rankine cycle (as Bryton cycle in natural gas fuelled power plants) they use to have a secondary Rankine cycle based system that is linked to primary system to improve electric power plant performance. Thus, at Earth scale, Rankine cycles efficiency has a huge impact on fuel consumption and on natural resources, on greenhouse effect emissions and on electric power plants profitability [3,4].

Due to this, it is convenient to increase the efficiency of Rankine cycle as much as possible. Refrigeration is an essential part, not only in order to improve efficiency, but also to contribute to water consumption saving. This saving is of great interest in energetic sector, because Rankine cycles are huge consumers of water, being this a fundamental resource for life. Water in this kind of power plants is used for many purposes, as feeding of the cycle itself, for cleaning and for refrigeration system, being this last one the bigger of the above mentioned ones. Consumption depends on selected refrigeration system [5].

2. Existing refrigeration systems

Depending on refrigeration agent, there are several refrigeration systems. Main of them are open circuit systems, refrigeration towers and air condensers and a mix of them that are called evaporative condensers [6].

2.1 Open circuit systems

These are the cheaper ones, but they are not too much used due to, on the one hand, the cost of pumping due to the huge amount of water they require and, on the other hand their environmental impact due to thermic and chemical (biocides) contamination on water discharges [7].

Working system is similar to a heat exchanger: exhaust steam condensation is produced by its cooling by a great cooling water flow, being this taken from rivers or the sea [8].

2.2 Air condensers

This technology began to be implemented in those zones in which availability, accessibility or cost of water had a negative impact on power plant's profitability. Particularly, this technology is increasing its leadership in solar thermal power plants, which are normally located in desert high insolation zones where water sources are very limited or simply do not exist. This situation forces very low quality water wells to be excavated needing this water an intensive treatment[9], or long distance water transporting lines to be made. In air condensers, exhaust turbine steam passes through finned pipes that are in contact with impelled by big fans air current.

Environmental impact of this technology is very lower to the above commented ones. Main disadvantages are lower electrical efficiency (reduction of net electrical efficiency of more than 1%) and increasing of plant investment price

2.3 Evaporative refrigeration systems

In this kind of systems, refrigeration water takes out heat from steam by means of a heat exchanger. Water is sent to a cooling tower in which it is putted in contact whit air that absorbs water flow's heat and cools it down [10].

This is the working principle in which some equipment, such as cooling towers or evaporative condensers, is based. Traditionally used technology is cooling towers, which can be natural draught, forced draught or induced draught, all of them working under the same principle: hot water gets in contact with air that takes the heat of the flow and frees it into ambient air [11], [12].

These systems require a very lower air flow than air condensers, so their efficiency do not depend on climatic conditions.

Cooling towers efficiency depends on combined temperature and humidity of inlet from the ambient air, air flow through the tower (depends on fan capacity) and technical election of the tower itself [13].

Evaporative refrigeration systems, in turn, as opposed to water or air condensers, are more difficult to be controlled due to water vaporization into the air current [14].

2.4 Hybrid refrigeration systems

Hybrid refrigeration system combines two previously known heat transfer ways: on the one hand, dry refrigeration and, on the other hand, evaporative refrigeration [15].

Its main working system is based on the transporting of heated by the exhausted turbine steam water to some fan-coil refrigerators. In a counter flow process cold air moved by the fan and hot water are putted into contact. The refrigeration system in this case is dry mode.

If climatic conditions are cold, this process is enough. But when ambient temperature rises up, power losses can appear. In these cases, in order higher efficiency to be reached, a water pulverization circuit that uniformly cools down the refrigerator is included in the system [16], [17].

These systems can reduce to 50% water consumption in comparison with wet refrigeration, with low incidence on plant efficiency. Main problems are significant increase of investment and higher operation and maintenance costs [18].

3. HCT: Hygroscopic Cycle Technology

Before Hygroscopic Cycle Technology or HCT to be explained, it has to be said that an hygroscopic compound is the one that attracts water, liquid our vapour state, from its environment. A clear example is the boiling point elevation that is produced when common salt and water are mixed. These compounds are normally salts (LiBr, NaCl, etc.), normally nontoxic, volatile nor flammable, but stable, abundant and cheap. Depending on their nature, all of them have in common that their solutions with water allow condensation temperatures to be raised [19].

3.1 Working principles

This technology is applicable to combined cycles, solar thermal power plants, nuclear power plants, etc. Cycle configuration is the following: It is formed by the same elements than a Rankine cycle except the condenser that is replaced by an absorber.

As it can be viewed in figure 1 diagram, the steam produced in the boiler feeds the turbine; the exhaust turbine steam is taken to the absorber in which it is put in contact whit a current that takes the hygroscopic compounds. This current acts as a cooling reflow and has an electrical conductivity that is always higher than the one of the steam. After this contact, the whole condensation of all the exhaust steam is reached. Condensation temperature is higher than the corresponding to pure steam one for the same pressure.

Condensed steam is pumped into two circuits: one part goes to fan-coil refrigerator and the other part of the flow goes to deaerator to be recirculated into the boiler [20].

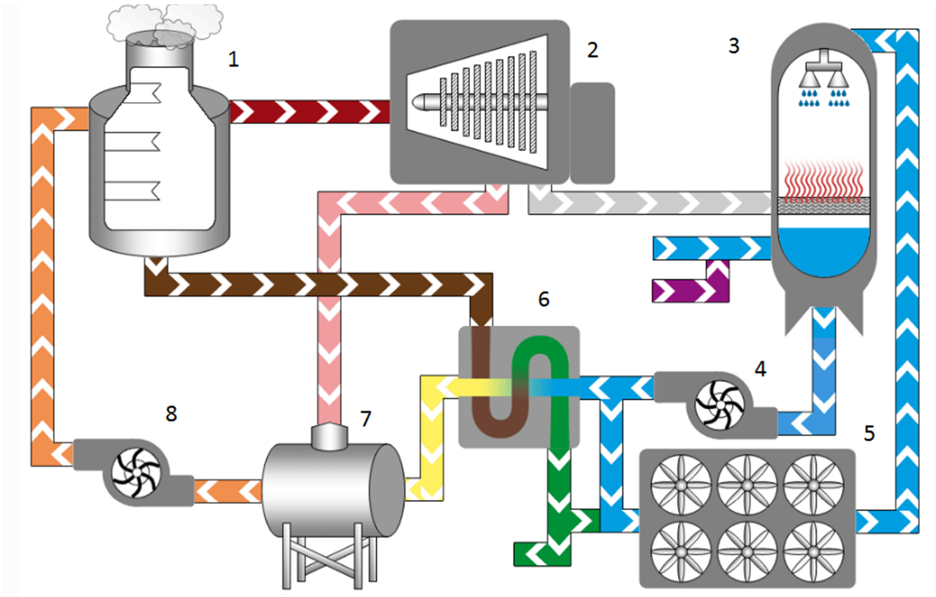

Figure 1: Hygroscopic Cycle (www.hygroscopiccycle.com)

3.2 Components

1- Steam generator, boiler
2- Steam turbine
3- Absorber: Main equipment of the system in which exhaust turbine steam and concentrated and absorbing current rich in hygroscopic compounds are in contact for steam condensation to be made.
4- Boiler feed water pump and main circulation pump. They guarantee the correct cycle pressures.
5- Fan coil refrigerator: It evacuates cooling reflow condensation heat by a current of fresh ambient air. Refrigerated flow is introduced into the absorber as cooling reflow.
6- Heat recovery exchanger: It allows boiler purges heat to be recovered in order for the cycle not to lose efficiency.
7- Deaerator: It eliminates all the bubbles and non-condensable gases from boiler inlet [21].
8- Boiler feed water pump and main circulation pump. They guarantee the correct cycle pressures.

3.3 Hygroscopic compounds features

Al these compounds must fulfill with the following features in order them to be used into the cycle:

- They must be highly hygroscopic compounds
- They must not be toxic or flammable
- They must be chemically stable under cycle's working pressures and temperatures
- Their vapour pressure must be lower than water's one and they must be able to be easily separated from water in order the reaction to be reversible.

3.4 Advantages

Hygroscopic compounds have exhaustively being studied and very interesting results have being obtained. Products based on them and knowledge of their properties are continuously expanding.

Advantages of using Hygroscopic cycle compared with Rankine cycle are:

- Cycle deficiency increases (it depends on the concentration of the selected hygroscopic compound) because lower condensation pressures can be reached due to the condensation temperature raise. Temperature of the cold reservoir due to ambient conditions becomes very less limitative regarding efficiency. This means an improvement of efficiency between 1 and 5% under the same working conditions and being the self-consumption the same or even lower than in a conventional Rankine cycle.

- Second advantage is that this technology allows the power plant to work in a dry cooling configuration, what it means a saving of 100% of refrigeration water. Emissions of CO2 by kWh are also decreased, since fuel consumption is lower for the same power output.

- Third advantage is a reduction of operation and maintenance costs. Most of Rankine cycles us surface condensers with cooling water towers or wet refrigeration. Cleaning, change of fillers, waste treatments, chemical additives, and other cooling towers related activities become unnecessary when you use HCT, since steam absorber and dry coolers needs low maintenance.

- Finally, fourth advantage is investment reduction in comparison with a conventional Rankine cycle with air condenser.

All these improvements depend on the hygroscopic compound and its concentration. An increasing on the concentration increases the cost, but this is compensated with the increasing of efficiency [22]. In this moment HCT with the lower concentration technologically needed by the technology is replacing Rankine cycle in existing and new power plants.

4. RESULTS

4.1 Technical aspects that make efficiency to be increased thanks to HCT

Condensation temperature increasing is sustained by Raoult's law, in which it is stated that:

"The partial vapour pressure of each component of an ideal mixture of liquids is equal to the vapour pressure of the pure component multiplied by its mole fraction in the mixture"

Since vapour pressure of the mixture is lower than pure water's, vapour is being condensed as micro-drops until bigger drops are made that stimulate condensation.

Thanks refrigeration temperature to be increased for a given condensation pressure, condensation heat can be free in dry mode, this means by a dry cooler, without water consumption until ambient temperatures very higher that which could be admitted by an air condenser and permitting a really significant save, since middle price of water in Europe is around 4€/m3 and in Spain around 2 €/m3.

5. REFERENCES

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