Waste Heat Recovery in the Oil & Gas Sector

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1.Introduction

Waste heat recovery is a process that involves capturing of heat exhausted by an existing industrial process for other heating applications, including power generation. Technavio forecasted the global waste heat recovery market in oil and gas industry to grow at a CAGR of 7.6% during the period 2014-2019[1]. The sources of waste heat mainly include discharge of hot combustion and process gases into the atmosphere (e.g. melting furnaces, cement kilns, incinerators), cooling water sand conductive, convective, and radiative losses from equipment and from heated products. To design the waste heat reclamation unit, it is necessary to characterize the stream in terms of availability, temperature, pressure and presence of contaminants such as particulate and corrosive gases. There are two main goals of recovering waste heat from industries: thermal energy recovery (both internally and outside from the plant) and electrical power generation. Fath & Hashem compared these two solution for the recovery of waste heat in an oil refinery plant located at Bagdad, Iraq[2]. For the overall energy system efficiency, it is nowadays fundamental to improve the utilization of low-temperature heat streams, primarily for thermal applications like heating, ventilation, cooling, greenhouses, etc. Oda & Hashem investigated in 1990 the selection of different strategies (air conditioning, food industry and agricultural uses) for an industrial area around including a refinery[3].

Nonetheless, also for low temperature sources, some innovations have been proposed in order to produce electricity for standalone plants and/or exploiting the resources that cannot be properly used for direct thermal applications. In the following, all these aspects are faced and some from the most recent and interest development in the R&D are reported.

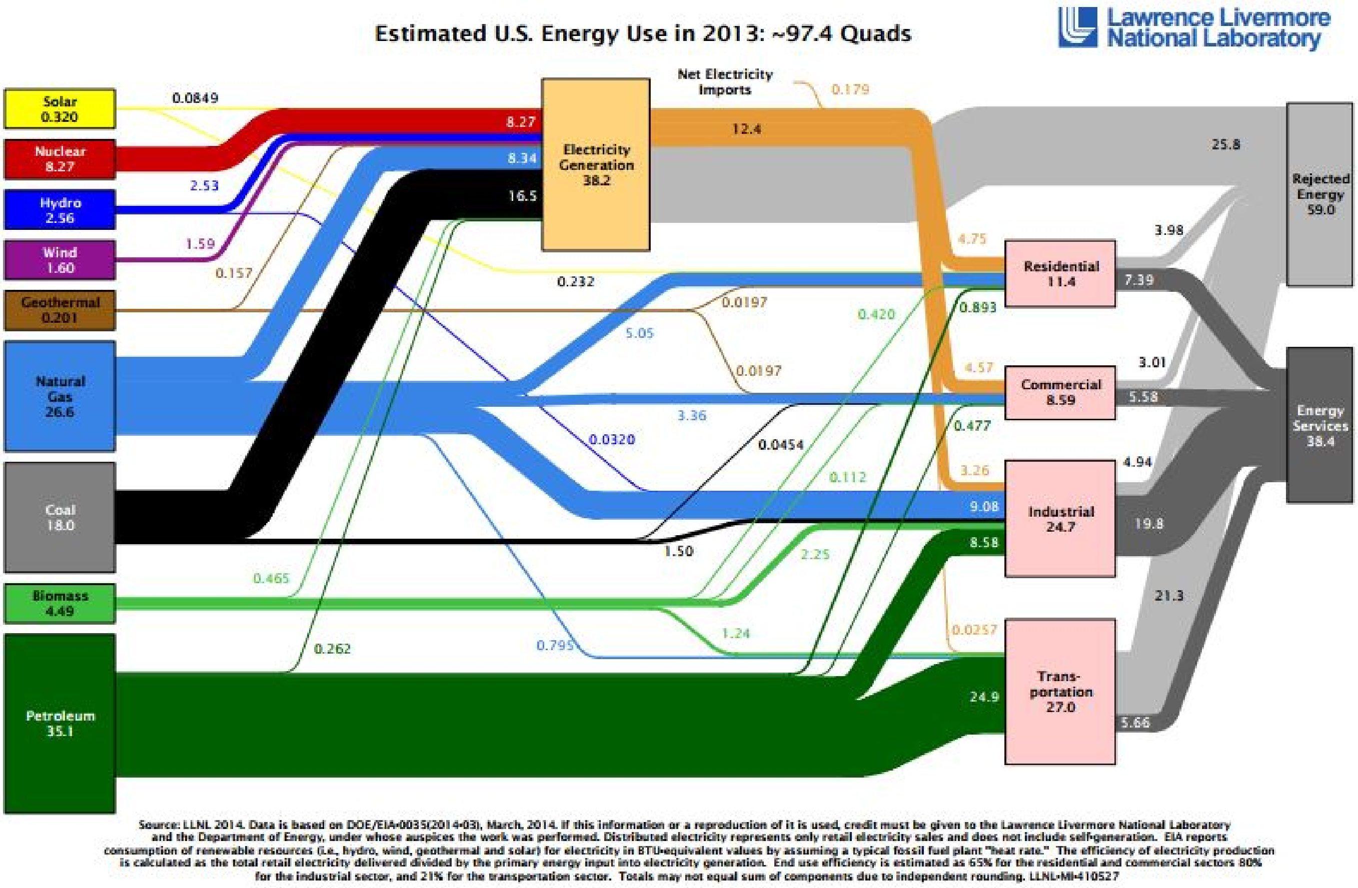

Fig.1 – Estimated U.S. Energy use in 2012.

2. Thermal energy

Electrical Energy Traditionally, waste heat of low temperature range (0-120 °C) cannot profitably implemented for electricity generation because of the low Carnot efficiency (typically ending up with 5-7% net electricity). In the field of thermal energy direct utilization, two main options are available:

waste heat recycling within the process (Fig. 2) or recovering within the plant or industrial complex.

Fig 2 – Rotary regenerator on a Melting Furnace

The main utilizations in the industrial systems are the preheating of combustion air and load or the steam generation. Transfer to liquid or gaseous process streams is also common in petroleum refineries where the operation (distillation, thermal cracking…) requires large amounts of energy that can be recovered from exothermic reactions or hot process streams in integrated systems.

Doheim et al.[4]described the integration of rotating regenerative heat exchangers in 4 refining processes (two crude distillation units, a vacuum distillation unit, and a platforming unit) in order to reduce the current losses (25 to 62% of total heat input) to the values of 9.9 to 37.3%. At the low temperature (<200° C), the best uses are the regenerative (recuperative) heating of feed-stocks (process internal reuse), district heating and LP steam generation. District heating (or tele-heating) is a system for distributing heat generated in a centralized location for residential and commercial requirements via a network of insulated pipes (mainly or pressurized hot water and steam). In alternative, low temperature waste heat can be used for the production of bio-fuel, space heating, greenhouses and eco-industrial parks. In the industrial complexes, requiring large amount of freshwater and located near the sea, a viable alternative is that of desalinate seawater via thermal processes as Multiple Effect Distillation and Multi Stage Flash Desalination in order to obtain demineralized, potable or process water.

The generation of electricity from thermal energy should be taken into account if there are not viable options of in house utilization of additional process heat or neighbouring plants' demand. The most commonly system involves the steam generation in a waste heat boiler linked to a steam turbine in a **Rankine Cycle (RC)**. Industrial examples can be easily found in the literature. Steam Energy WHP from Petroleum Coke Plant, located at Port Arthur (Texas), recovers energy from three petroleum-coke calcining kilnsat temperature higher thant 500°C for producing LP steam (to use at an adjacent refinery) and 5 MW of power(saving an estimated amount of 159,000 tons per year of CO_2 emission).

Since the thermal efficiency of the conventional steam power generation becomes considerably low and uneconomical when steam temperature drops below 370 °C, the **Organic Rankine Cycle** (**ORC**) utilize a suitable organic fluid, characterized by higher molecular mass, a lower heat of vaporization and lower critical temperature than water[5] (silicon oil, propane, haloalkanes, isopentane, isobutane, pxylene, toluene, etc.).

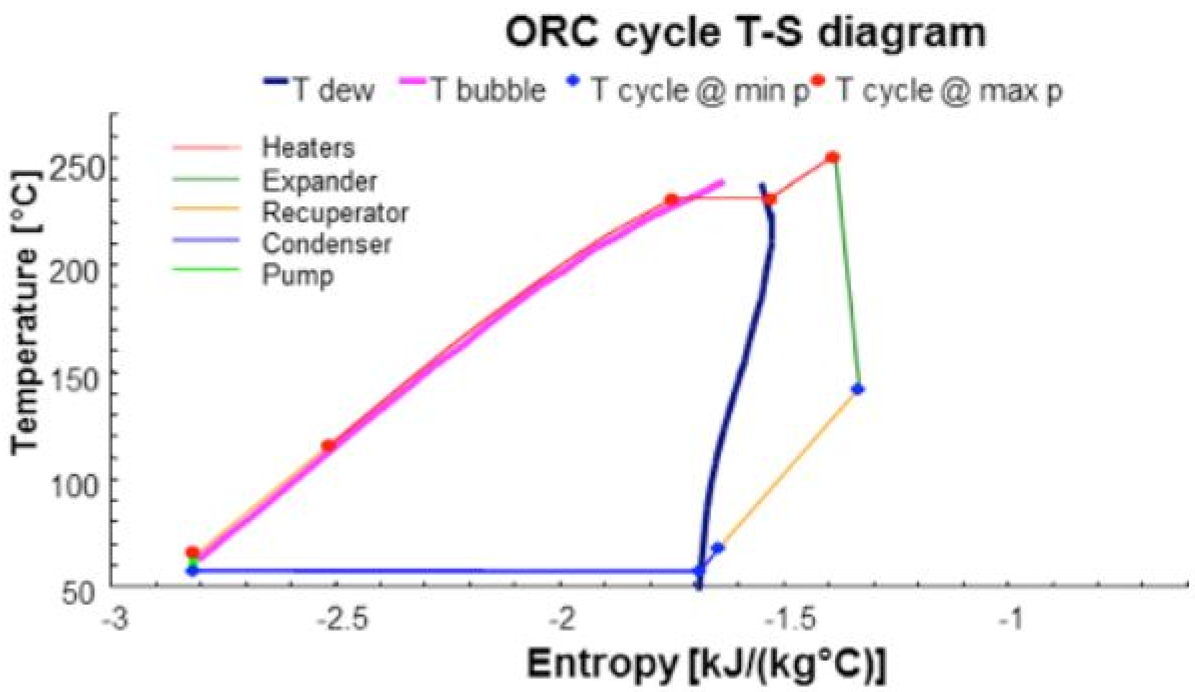

Fig. 3.- T-s diagram of a ciclo- pentane ORC cycle

These enable the utilization of lower temperatures (if compared to the RC) and a “better”coupling (lower entropy generation) with the heat source fluid to be cooled[6]. The higher molecular mass enables compact designs, higher mass flow and higher turbine efficiencies (as high as 8085%). However, since the cycle works at lower temperatures, the overall efficiency is only around 1020%. As abovementioned, it is important to remember that low temperature cycles are inherently less efficient than hightemperature cycles. Jung et al., 2014, reported a techno-economical evaluation of an ORC cycle (with pure refrigerant and mixtures of R123, R134a, R245fa, isobutane, butane, pentane) to recover the heat from a liquid kerosene to be cooled down to control the vacuum distillation temperature[7]. An example of a recent successful ORC installation is at a cement plant in Bavaria (Germany) to recover waste heat from its clinker cooler (exhaust gas @ 500°C) providing the 12% of the plant’s electricity requirements and reducing the CO_2 emissions by approximately 7000 tons/year. Several R&D projects[8]and commercial plants[9]are reported in the references (footnotes).An example of T-s diagram of an ORC with Cyclo-Pentane (MW 70, boiling point 49,5°C) developed by GE[10]is showed in Figure 3.Also, ElectraTherm applies proprietary ORC to generate power from low temperature heat by utilizing, as fuel in industrial boilers, the natural gas that would otherwise be flared[11].

The **Kalina cycle**(**KC**)utilizes a mixture of ammonia and water as the working fluid (with a variable temperature during evaporation). It was invented in the 1980s and the first power plant (6.5 MW, 115 bara, 515 ºC)was constructed in California (1992) and followed by many plants in Japan, Pakistan and Dubai.[12]The KC allows a better thermal matching with the waste heat source and with the cooling medium in the condenser achieving higher energy efficiency.Although the Kalina systems have the highest theoretical efficiencies, their complexity still makes them generally suitable for large power systems of several megawatts or greater.

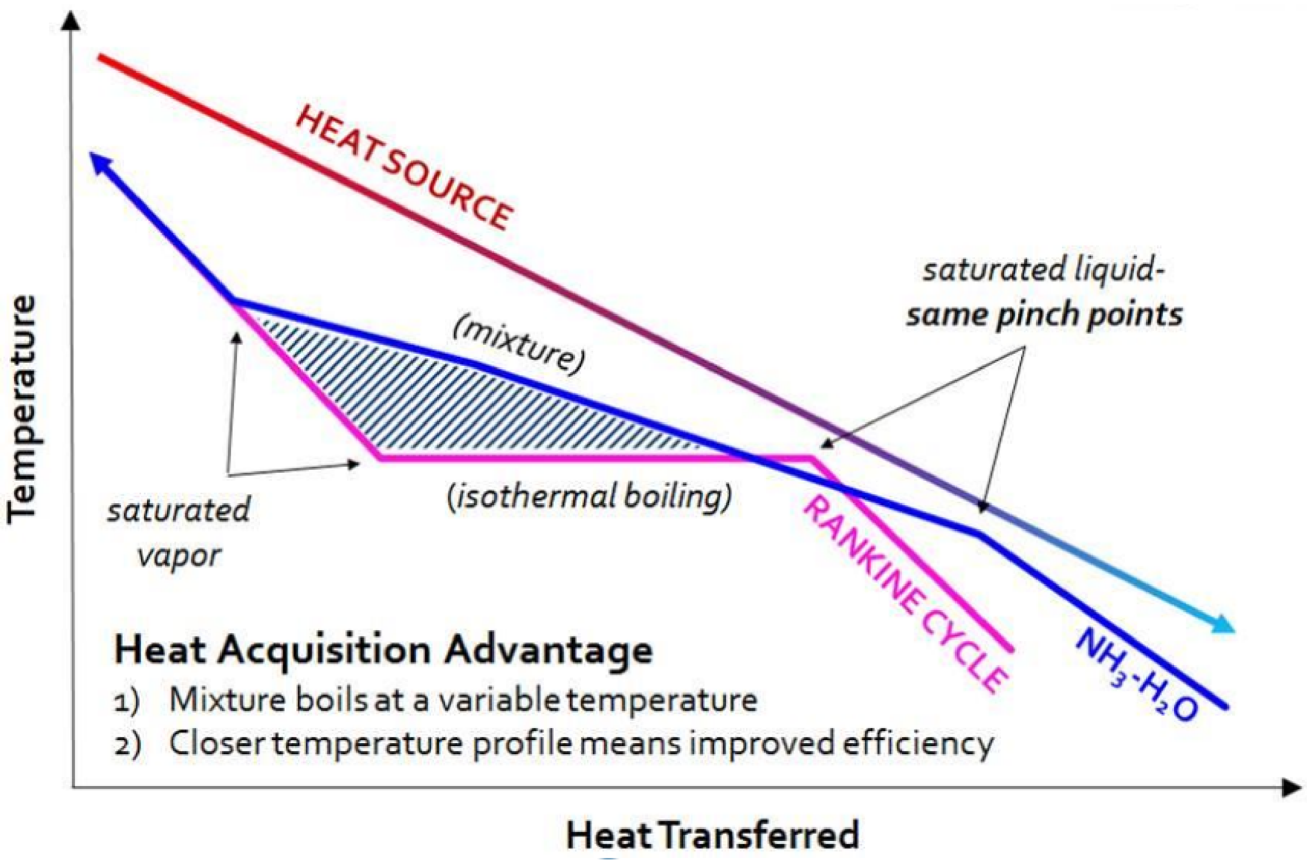

Fig. 4. – H-T energy recovery in the Kalina Cycle[11]

In addition to these cycles, some advanced technologies in the research and development stage can generate electricity directly from heat. These technologies include the Stirling engine[13], thermoelectric, piezoelectric, thermionic, and thermo-photovoltaic (thermo-PV) devices. Although they could in the future provide additional options for carbon-free power generation, nowadays show very low efficiencies. Keeping in mind that a Carnot engine operating with a heat source at 150ºCand rejecting it at 25ºC is only about 30% efficient, all these system shows global efficiencies in the range 1-10%.As an example, in the piezoelectric power generation(PEPG), a thin-film membrane is used to create electricity from mechanical vibrations from a gas expansion/compression cycle fed by waste heat (150-200°C). The temperature change (across a semiconductor),inducing a voltage (through a phenomenon known as the Seebeck effect), is implemented in the Thermoelectric generation(TEG)[14].Öström and Karthäuser recently claimed a method for the conversion of low temperature heat to electricity and cooling,comprising CO_2 absorption and an expansion machine[15].

Finally, recent R&D efforts in the use of saline solutions at different concentrations enabled the heat conversion into electricity in the lowest temperature range of application. This is possible by making use of heat engine based on **Salinity Gradient Energy**(**SGE**) (or Salinity Gradient Power, SGP) technologies.

Salinity Gradient energy is a novel non-conventional renewable energy related to the mixing of solutions with different salinity levels, as occurs in nature when a river discharges into the sea. Clearly,when this mixing process spontaneously occurs, the associated energy is completely dissipated during the process. Conversely,this energy can be harvested by adopting a suitable device devoted to perform a ”controlled mixing” of the two streams at different salinity (e.g. river water and seawater).Depending on the device type, different technologies have been proposed so far: the Chemical Engineering Research group of the University of Palermo, involved in this field of R&D activities[16], recently edited a book[17] where Pressure Retarded Osmosis (PRO), Reverse Electrodialysis (RED) and Accumulator mixing (AccMix) are indicated as the most promising technologies.

When employed within a closed loop,each SGP technology can be used to convert waste heat into electricity. This concept is named **Salinity Gradient Power Heat Engine** (SGPHE) (Figure 5) and consists of two main units:

i. the SGP unit devoted to mixing two solutions at different salt concentration in order to convert the Gibbs free energy of the relevant salinity gradient into valuable power;
ii. a regeneration unit which employs unworthy waste heat at very low energy levels (i.e. 50-100°C) to separate again the two streams thus restoring the initial salinity gradient and closing the cycle.

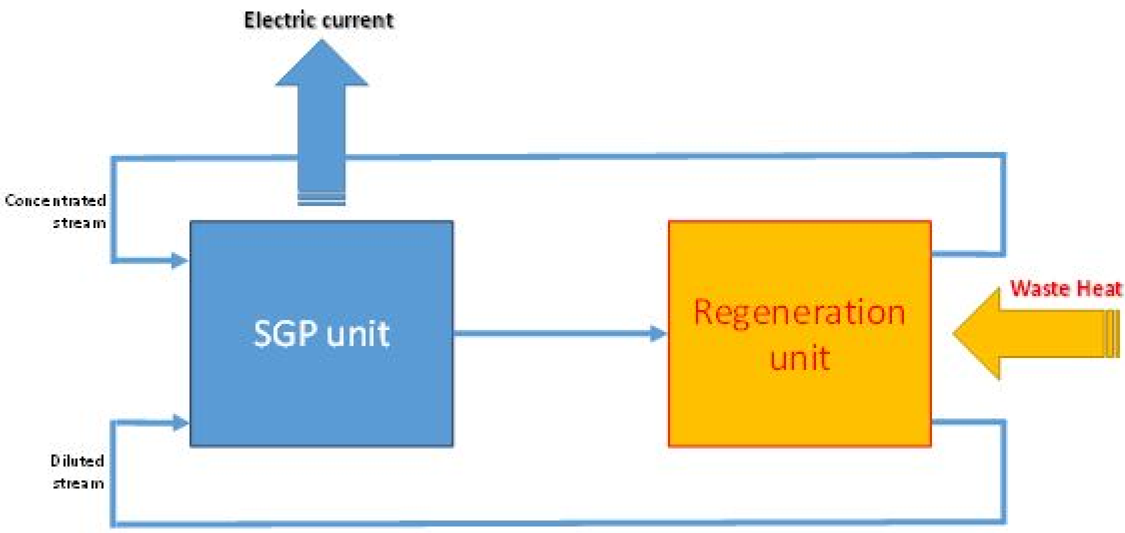

Fig. 5 – Scheme of a SGP Heat Engine

The adoption of the closed loop opens room to a large variety of advantages and possibilities with respect to open-loop SGP technologies. Just as an example, the closed loop does not require the need of natural/artificial basins of solutions at different salt concentration in the same area. More important, no pre-treatments are necessary and any kind of solute or solvent can be employed with the aim of maximizing the power production and the cycle efficiency. In this regard, according to recent estimates, it appears that SGPHE (i) can be operated at very low temperatures where no alternative technologies exist and (ii) can potentially achieve exergetic efficiencies higher than any other technology[18].

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