A Critical Review of Thermal Waste Heat Recovery Systems

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***Abstract*: A detailed review of waste heat recovery systems used in power generation units and utility of heat from other sources like cement, internal combustion engines, paper, chemical industries were been discussed . Flow diagrams of utilization of waste heat recovery system, conventional and cogeneration power utility systems have been drawn. Supercritical Carbon Dioxide cycle , Gasification and internal combustion engine coupled to an organic rankine cycle from biomass, heat recovery system with organic rankine cycle in cement industry, organic rankine cycle heat recovery in PEM fuel cell, and air conditioning integrated Hot water system have been discussed .**

***Keywords*: steam, power, waste heat and thermal analysis.**

Introduction:
Xianglong Liu et al [1] presented in their technical paper the performance of the waste heat recovery system like offshore oil production, diesel engines, thermal boilers and waste heat boilers. The ideal Bray ton cycle was adopted to evaluate the performance. In comparison with the conventional method , the fans at the engine outlet of the waste heat recovery boiler was removed due to the limited space of the offshore platform. A comparison study was made with fan and without fan to obtained and correlate the thermal motion of energy efficiency and thermo-economic index of the system. Gang Xu et al [2] presented in their technical paper by furthered partition into high-temperature and low-temperature air pre heaters and to evaluate the high quality steam for enhance the better economic energy savings. Energy output of 9.00 MW was to archived but by using new design of waste heat recovery, a yield of available energy was reduced from 34.1 MW in the conventional waste heat recovery system compared to 28.5 MW in the developed waste heat recovery system. Xiaoqu Han et al [3] presented in their technical paper the energy recovery potentials of the FPLPS integrated systems. It was showen that the system improvement of the FPLPS was obtained from 1.14% to 1.47% depending on the moisture content of raw lignite. The water recovery ratio and plant efficiency improvement in the optimal LPE scheme were 39.4% and 0.20%, respectively. In contrast, 83.3% of water recover ratio and 110.6 MW heat supply were achieved in the SPT system. Yuzhong Li et al [4] presented in their technical paper the two models for recovering heat and water was obtained using the flue gas humidity chart form 300 MW coal-fired generator.

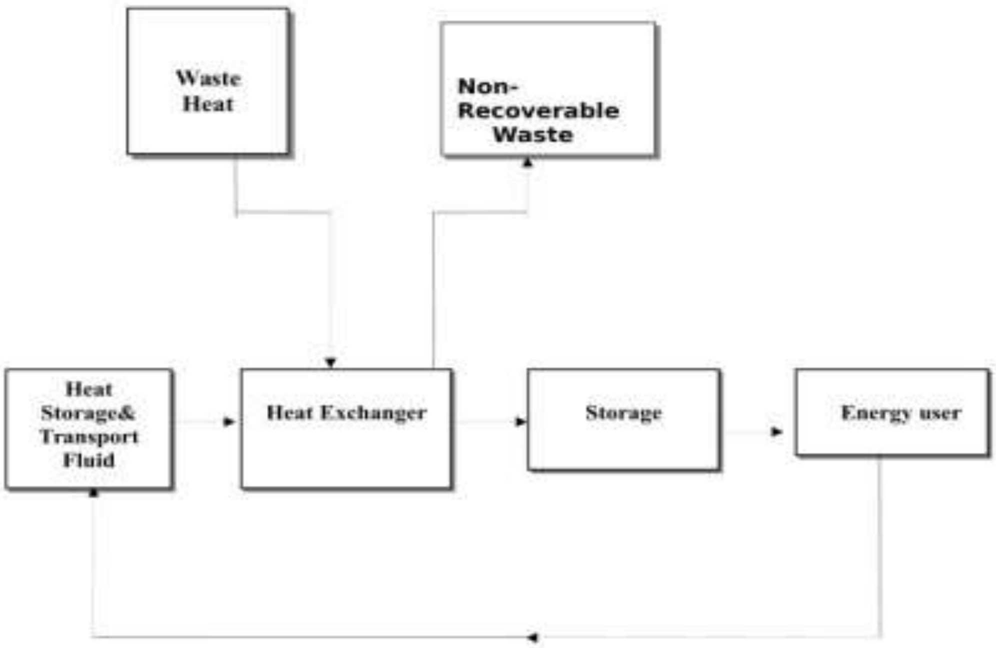

Fig 1 Utilization of waste heat recovery system

Meryem Terhan and Kemal Comakli [5] presented in their technical paper the event of condensing water vapour in flue gas in order to recover the latent heat that was carried by exhaust flue gas in 60 MW natural-gas fired heating system. A mathematical model was developed to evaluate the operational input and output analysis of the unit. With this model the flue gas temperature can be decreased to 40 °C with a flue gas condenser that has 80 m^2 surface area and was made of 316 quality stainless steel horizontal plain tube bundles.

Samer Maalouf et al [6] presented in their technical paper two waste heat recovery processes using Organic Rankine Cycle. While the indirect contact condensation was the most favorable heat recovery scheme concerning the net output power, the direct contact heat exchanger has received attention because there are no heat-transfer surfaces exposed to corrosion. In a direct contact water–vapor condensation, the inlet flue-gas wet-bulb temperature determines the operating temperature levels throughout the system and limits the circulating water temperature. The maximal net turbine power for the direct contact system was reached for a final water temperature nearby the entering wet bulb temperature of the flue gases. The temperature pinch was as low as 0.5 K, which was possible with a direct contact heat exchanger.

P.R. Mashaei et al [7] presented in their technical paper the effects of Al_2O_3 nanofluids on the hydrothermal performance of a heat pipe connected to evaporator heat exchanger. The effects of heat loads of 14, 28, 56 and 112 W and nanoparticle volume fraction φ = 0, 2.5, 5 and 0.075% were used on the temperature and velocity fields and further pressure drop and thermal performance of heat pipe was studied . The influence of nanoparticles on both thermal and hydraulic performances of heat pipe become more pronounced as porosity of wick structure and particle size, respectively, increases and decreases. Accurate data was obtained to achieve the efficiency of the system at φ = 5% and Q = 112 W respectively .

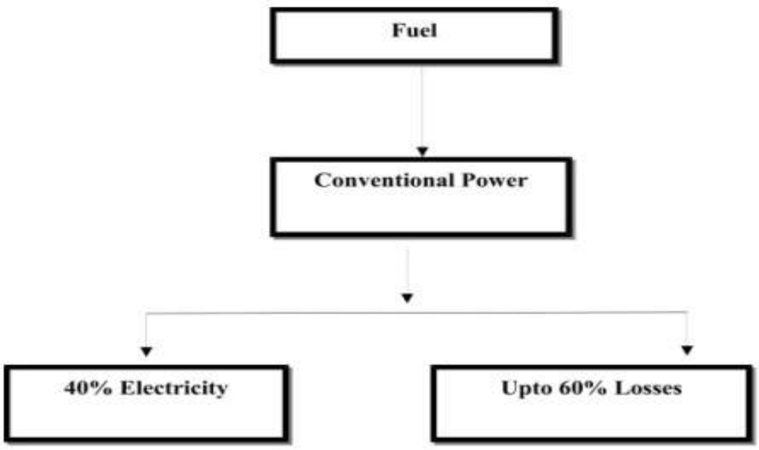

Fig.2 Conventional Power Generation

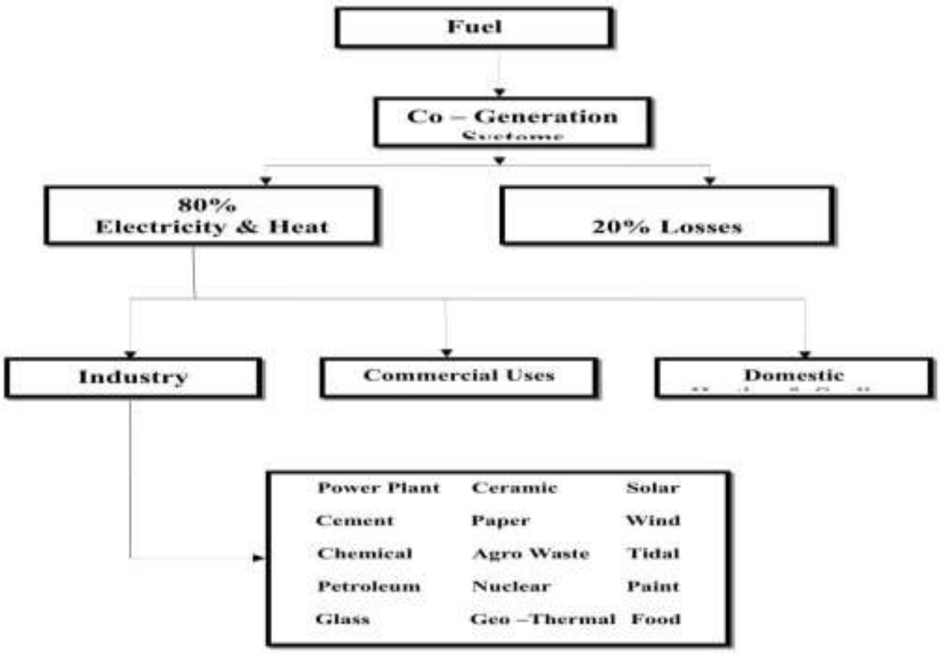

Fig.3 Co-generation Power Utility

Adéla Macháčková et al [8] presented in their technical paper on heat transfer rates and fluid flow equations of the second heat exchanger, which was connected as a secondary line circuit and it was evaluated the overall highlighted on the performance flue gas waste heat and water condensation from the flue gas . Water temperature in both heat exchangers was obtained 370 K , which was increased by 33% of the temperature rise from the secondary heat exchanger. The mean logarithmic temperature difference of the secondary heat exchanger was found to be 166 K. A decrease of flue gas temperature by 100 K led only to formation of a more continuous layer of the condensed water on the entire length of the wall of the tube.

H.S. Zhang et al [9] presented in their technical paper the mathematical models of the CHP system with absorption heat pump recovering waste heat system. Comparison was made with conventional heating mode, it was found to be coal degradation was reduced with the increase of the load when the heating load was maintained constant . When the thermoelectric ratio was maintained constant , the power output was increases about 3.81 MW and coal consumption rate decreases 11.69 g/kW h full load, where as the total thermal efficiency was increased 1.89% and 2.27%, respectively.

Ahmad Kamal Ismail et al [10] presented in their technical paper the effect of combination of silcon nickel chromium dip coating method was used to improve the performance of pre-sintered porous . Al_2O_3 substrate burner. Thermoelectric cells were used in the cogeneration system to generate electricity from the porous medium burner. The highest recorded surface flame temperature at flow rate of 0.25 L/min was 750 °C for SiC-coated, 741 °C for Cr-coated, 739 °C for Ni-coated and plain substrate was obtained a temperature of 634 °C. An 18% increase in flame temperature was noticed for SiC-coated substrate when compared to the plain substrate.

Hongsheng Zhang et al [11] presented in their technical paper and compared with the conventional heating system, the output power increases by about 3.58 MW, gross coal consumption rate and total exergy loss respectively reduces by 11.50 g/kW h and 4.649 MW, while the total thermal and exergy efficiency increases by 1.26% and 1.45% in the EHCS when the heating load was 99,918 kJ at 75% THA condition.

Hayato Hagi et al [12]. presented in their technical paper a analytical method to evaluate the performance parameters working on steam power plants with waste heat recovery system taken into consideration. This approach was found to be useful for finding out the relation to establish for available energy to improve the parameters with this method.

P. Gao et al [13] presented in their technical paper a small pumpless ORC (organic rankine cycle) system with different scroll expanders modified from compressors of the automobile air-conditioner was established, and the refrigerant R245fa was chosen as the working fluid. Different hot water temperatures of 80, 85, 90 and 95 °C are employed to drive the pumpless ORC system. Experimental results show that a maximum shaft power of 361.0 W was obtained under the hot water temperature of 95 °C, whereas the average shaft power was 155.8 W. The maximum energy efficiency of 2.3% and the maximum exergy efficiency of 12.8% are obtained at the hot water temperature of 90 °C. The torque caused by the internal mechanical friction of the expander was about 0.4 N m. Additionally, another scroll expander with a displacement of 86 ml/r was also employed to investigate how scroll expander displacement influences the performance of the pumpless ORC system.

E. Galloni et al [14] presented in their technical paper the plant design, the experimental methodology and the thermodynamic analysis of the work cycle . The aim of the work was
to assess the feasibility of small-scale ORC plants. The basic idea was to analyze the performance of a small ORC plant able to exploit low-temperature heat sources.

Thus, a simple organic Rankine cycle has been analyzed and R245fa as working fluid has been selected. Due to the small working fluid flow rates, a volumetric machine, in particular a scroll expander, has been chosen for mechanical power generation. The hot source temperature has been varied in the range 75–95 °C and the cold sink temperature ranged between 20 °C and 33 °C. The R245fa vapor maximum pressure varied from 6 up to 10 bar. In this operating range, the best obtained results were: electric power equal to 1.2 kW, specific work about 20 kJ/kg and cycle efficiency slightly greater than 9 percent.

Nattaporn Chaiyat Tanongkiat Kiatsiriroat [15] presented in their technical paper a 25 kW_e R245fa ORGANIC RANKINE CYCLE HYBRID WITH with a 20 kW Lithum Bromide water absorption refrigeration system. With this arrangement the performance was increased by 7%, with 15 °C of cooled water temperature supplied from the absorption system. In term of the environmental impact, a released carbon dioxide intensity of the new unit was lower than the normal unit at around 0.203 and 0.216 kg CO_2 eq/kWh, respectively.

Bernardo Peris et al [16] presented in their technical paper an experimental application of an organic Rankine cycle in a ceramic industry for low grade waste heat recovery and achieving a maximum gross electrical efficiency of 12.32%.

Usman Muhammad et al [17] presented in their technical paper a 1 kW organic Rankine cycle system for net electrical power output ability, using waste heat from steam. The system was developed for waste heat steam at pressure of 1–3 bar. A scroll expansion device coupled with generator to achieve maximum power output of 1.016 kW. The thermal efficiency of the system was found to be 5.64%, net efficiency was found to be 4.66% and expander efficiency was 58.3% at maximum power output operation condition . Maximum thermal and expander efficiency was found to be 5.75% and 77.74% respectively. Effect of superheating of working fluid at expander inlet has been noticed with increase in the degree of superheating by 1 °C and further reducing thermal efficiency of system by 0.021% for current system. It was shown from the rated power output and enthalpy output was differed by 40%.

M. Kolahi et al [18] presented in their technical paper with comparison between thermodynamic and economic analysis of two kinds of organic Rankine cycles with pure and zeotropic mixtures for recovering waste heat from the exhaust gases of heavy duty diesel engines used in the offshore platforms. The organic rankine cycle with mixture of R236ea has the best performance as its available energy output found to be 14.57% and 37.84%, respectively. These values are increased to 16.81% and 40.75%, respectively by adding IHE to system. Shaleen Khurana et al [19] presented in their technical paper data from a working 1 Mt per annum plant in India was used to obtain an energy balance for the system and a Sankey diagram was drawn. It was found that about 35% of the input energy was being lost with the waste heat streams. With the introduced of waste heat recovery system about 4.4 MW of power output can be achieved. The target improvement was achieved about 30% and 10% of the power output of the plant respectively .

Ehsan Khorasaninejad et al [20] presented in their technical paper a hybrid multi criteria decision-making method based on the fuzzy analytic network process , fuzzy decision-making trail and evaluation laboratory and fuzzy preference ranking organization method for enrichment evaluations was formulated and best fit method was given importance in a thermal power plant coupled with Organic Rankine Cycle for waste heat recovery system.

Daniele Forni et al [21] presented in their technical paper to convert the waste heat into electricity, usually self-consumed. This electricity, generated without additional emission and fuel consumption, substitutes electricity withdrawn from the grid. One of the solutions to generate electricity recovering heat, otherwise dispersed into the environment, was the Organic Rankine Cycle .Those characteristics are relevant differences in comparison to traditional steam cycles.

Kevin R et al [22] presented in their technical paper a novel energy recovery device based on a SCO2 regenerative Rankine cycle for 1kW to 5kW waste heat recovery. This work has shown a thermodynamic SCO2 cycle analysis for waste heat recovery from temperature 200°C - 500°C with mass flow rates of 20 – 60 grams/sec. Modeling gives an idea for adopting SCO2 systems for low temperature waste heat recovery systems. N. B. Chaudhari and P. N. Chaudhar [23] presented in their technical paper demonstrated through experimental setup for understanding the basic heat transfer processes by utilizing the waste heat from a condenser of a refrigerator to heat water for basic use. Heat recovery from condenser of a refrigerator by thermo-siphon system was attractive because it eliminates the need of a pump.

T.T. Ayu et al [27] presented in their technical paper the heat recovery system modeling for a cement factory in Ethiopia as a case study. The system was a dry type rotary kiln equipped with a sixth stage cyclone type preheater, pre-calciner and grate cooler. The kiln has a capacity of 3,000 tons/day. It was shown that 25.23% of the total heat input was released to the environment through the preheater and another 15.58% through the cooler exhausts. The waste heat recovery system can produce a gross power of 5.26 MW as long as the kiln was in operation.. M. Joseph Stalin et al [28] presented in their technical paper the theoretical analysis of production of hot water and reduction of LPG gas using air conditioner waste heat. An attempt has been taken to recover waste heat rejected by the 1 TR air conditioning systems. For this water cooled condenser was exerted and the water was circulated by the feed pump at constant temperature ShunsenWang et al [29] presented in their technical paper the waste heat recovery for internal combustion engine coupling with the transcritical carbon dioxide refrigeration cycle with the supercritical CO2 power cycle have been developed. With the exhaust parameters of engine, the maximum work output of two stage turbine was found to be higher at 40%–50% than that of the single stage turbine. Except for the power consumption of air conditioning, the net power output of this thermodynamic system can reach up to 13%–35% of the engine power when it was used to recover the exhaust heat of internal combustion engines.

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