A Review: Utilization of Waste Energy to Improve the Efficiency of the Systems

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Abstract

Objectives: This review explores the rationale of using waste heat energy from hot exhaust gases, hot water & hot steam to improve efficiency of systems. Methods: Since the amount of non-renewable sources is limited, there is unmet need to develop systems which utilize nonrenewable sources or waste energy (reusable) sources. Energy recovery systems (i.e. heat pumps & exchangers) of waste-to-energy units represent a substantial part which utilizes waste energy to increase thermal as well as electric power of whole system. Findings: Waste water can be considered as a reusable key energy source. Because of the higher thermal efficiency, combined cycle power plants are striking options based on this technology for generation of power as compared to individual gas or steam turbine cycles. Along these lines, the ideal outline of such cycles is of incredible noteworthiness inferable from expanding fuel costs and diminishing fossil fuel assets. Improvements: As a consequence, cost of product can be optimized and environment can also be protected.

Keywords: Energy Recovery Systems, Energy Conservation, Heat Exchanger, Non-Renewable Sources, Waste Energy Utilization

1. Introduction

Difficulties associated with the shortage of energy and also, natural contamination brought on by unnecessary vitality consumption requires an efficient and efficient use of existing energy resources. There is a dynamic need of building up the option energy sources or enhance vitality use systems. In up and coming time manageable energy framework will require an expanded offer of reusable vitality or energy sources. In this worry, examines on unmistakable, consolidated or incorporated utilization of reusable energy advancements have significantly increased in the course of the most recent years1. Urbanization brings about the critical environmental issues such as pollution, greenhouse effect and contamination. Presently, 80% of electricity is approximately produced from fossil in the world2. There are several sources to get waste energy which is reusable as in the form of liquid, solid or gaseous but out of these, waste heat recovery from waste water acting a key part in the field of energy conservation and environmental protection3. The loss of heat from the waste water of power plant shows a large potential. Waste water is considered as a reusable heat source for heat exchangers. Owing to high heat capacity and density waste water offers an intense source of heat4. So, energy from waste water is an important source, which can be recycled for pre-heating of natural gases with heat exchangers, cooling and heating buildings using heat pumps etc5.

Heat can be transmitted from one medium to another medium effectively by heat exchange. The medium is either in separated by solid partitions or direct contact to each other. Heat exchangers are usually used as one of a part of aerating and cooling, compound plants, space warming, force plants, refrigeration, petrochemical plants, sewage treatment, normal gas preparing, and

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petroleum refineries. The exemplary representation of HE has ignition motor at inside. The liquid which is flowing inside known as motor coolant and it’s also make the cool different parts like radiator, heat air. Because energy is playing key role in heat recovery system, it is need to be found out. To analyses the energy preservation of mass and energy with second law of thermodynamics for structure design and analysis. Furthermore, it is also observed that the energy method examination is potential tool. This method is promoting goal of using energy resources more efficiently it’s also explore the use of wastes. Finally this will give the efficiency and losses of the system.

Table 1 indicates the waste heat sources with different temperatures and its recovery applications. Ample of resources are available to get the waste energy as described in Table 1. Annual waste water discharge (million cubic meters) in different types of industries is shown in Table 2 that shows 87.87% of consumption of water in power plants.

So the cost of water per year in India compared to another country is higher shown in Table 3. Therefore, it is very essential to save water and utilize the maximum water by using the recovery systems.

### Table 1. Waste Heat Sources from Industries and Commercial Area

| Type of Facility | Waste Heat Source                                      | Temperature (°C) | Recovery Applications                                    |
|------------------|--------------------------------------------------------|------------------|----------------------------------------------------------|
| Industrial       | Electrical Refractory Furnace Exhaust                  | High Grade       | Process steam, preheat combustion air, space heating.    |
|                  | Nickel Refining Furnace Exhaust                         | 1600 – 2700      |                                                          |
|                  | Fume Incinerator Exhaust                               | 1375 – 1550      |                                                          |
|                  | Solid Waste Incinerator Exhaust                        | 650 – 1550       |                                                          |
|                  | Reheat Furnace Exhaust                                 | 650 – 1000       |                                                          |
| Industrial       | Gas Turbine Exhaust                                    | Medium Grade     | Preheat combustion air, direct drying, space heating, heating process water, preheating boiler water. |
|                  | Diesel Generator Exhaust                               | 375 – 550        |                                                          |
|                  | Steam Boiler Exhaust                                   | 375 – 500        |                                                          |
|                  |                                                       | 230 – 250        |                                                          |
| Commercial       | Drying and Baking Over Exhaust                          |                 | Preheat combustion air, heating process water, preheating boiler water. |
|                  | Dryer Exhaust                                           | 230 – 600        |                                                          |
|                  | Furnace Flue Gas                                       | 150 – 230        |                                                          |
|                  |                                                       | 175 – 230        |                                                          |
| Industrial       | Steam Boiler Exhaust                                   | Low Grade        | Space heating, preheat combustion air, process heating.  |
|                  | Dryer Exhaust                                           | 150 – 230        |                                                          |
|                  | Process Steam Condensates                              | 85 – 150         |                                                          |
|                  | Condensate Tank Flash Steam                            | 55 – 95          |                                                          |
| Commercial       | Steam Boiler Exhaust                                   |                 | Space heating, preheat combustion air, process heating, temper ventilation air. |
|                  | Dryer Exhaust                                           | 85 – 150         |                                                          |
|                  | Furnace Flue Gas                                       | 150 – 230        |                                                          |
| Institutional    | Steam Boiler Exhaust                                   |                 | Space heating, preheat combustion air, temper ventilation air, domestic water heating. |
|                  | Furnace Flue Gas                                       | 150 – 230        |                                                          |

1.1 Waste Heat Recovery Technology

Waste heat can be defined as the heat contained in a substance excluded from a process at a temperature greater than the ambient levels of the plant. Waste heat source can be gaseous, liquid or solid and mainly there are some technologies to recover this waste heat like direct use, heat exchangers, recompression of vapor and heat pumps. Amongst those, heat exchangers and heat pumps have the widespread range of applicability, irrespective of the type of an industry. Table 4 gives a general guide to select heat transfer equipment for waste heat recovery applications.

There are many applications where any suitable heat transfer equipment can be used to generate the electricity or any other energy. Amongst those described in the Table 4, tube type of heat exchanger and shell and direct contact heat exchanger are broadly exploited because their conditions match with the widespread applications. Electricity which is produced from the reusable or waste energy plays important role in industries and for the public domain.

The method of generating electrical power and capturing the waste heat energy is shown in the diagram Figure 1.
In brief, hot gases are passing through exchanger and hot gases are transported heat from gases to liquid. Then in the Organic Rankine Cycle (ORC) system, hot liquid is impelled to the heat recapture evaporator. The refrigerant, in ORC evaporator is also boiled and provided to an expander turbine. It is also controls the electrical generator. Electrical power, generated by turbine generator, is supplied to the plant distribution network. Using plant water as a heat sink, the exhaust refrigerant is pumped and condensed come back to the evaporator for repetition.

| Industrial | Cooling Water from Air Compressors | Cooling water from Power Plants | Warm Air from Ceiling Level | Process Wastewater Streams | Warm Product |
|------------|-----------------------------------|--------------------------------|---------------------------|---------------------------|--------------|
| Commercial | Air Conditioning and Refrigeration | Condenser Exhaust             | Process Wastewater (laundry, etc.) | 30 – 45                   |              |
| Institutional | Air Conditioning and Refrigeration | Condenser Exhaust             | Kitchen Exhaust                   | 30 – 45                   |              |
|             | Ventilation Exhaust               |                                |                            |                            |              |
|             | Vacuum Jet Ejector Exhaust        |                                |                            |                            |              |

**Table 2. Water Intensive Industrial in India**

| Type of industry | Annual waste water discharge (million cubic meters) | Annual consumption (million cubic meters) | Proportion of water consumed in the industry |
|------------------|-----------------------------------------------------|------------------------------------------|---------------------------------------------|
| Thermal power plant | 27000.9                                             | 35157.4                                   | 87.87                                       |
| Engineering      | 1551.3                                              | 2019.9                                    | 5.05                                        |
| Pulp and paper   | 695.3                                               | 905.8                                    | 2.26                                        |
| Textiles         | 637.3                                               | 829.8                                    | 2.07                                        |
| Steel            | 396.8                                               | 516.6                                    | 1.29                                        |
| Sugar            | 149.7                                               | 194.9                                    | .49                                         |
| Fertilizer       | 56.4                                                | 73.5                                     | .18                                         |
| Other            | 241.3                                               | 314.2                                    | .78                                         |
| Total            | 30729.2                                             | 40012.0                                   | 100.0                                       |

**Table 3. Economic value of water**

| Country          | Industrial water use (billion cubic meters) | Industrial productivity(million US $) | Industrial water productivity (US $ /cubic meter) |
|------------------|---------------------------------------------|--------------------------------------|-----------------------------------------------|
| Argentina        | 2.6                                         | 77171.0                              | 30.0                                          |
| Brazil           | 9.9                                         | 231440.0                             | 23.4                                          |
| India            | 15.0                                        | 113041.0                             | 7.5                                           |
| Korea, rep.      | 2.6                                         | 249268.0                             | 95.6                                          |
| Norway           | 1.4                                         | 47599.0                              | 35.0                                          |
| Sweden           | 0.8                                         | 74703.0                              | 92.2                                          |
of cycle. System variables like pressure, electrical power, flow and flexible speed of pumps are affecting on optimum thermal performance\textsuperscript{10}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{waste_heat_energy.png}
\caption{Waste heat energy and generating electrical power.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{return_on_investment.png}
\caption{Return on investment steel reheat furnace\textsuperscript{12}.}
\end{figure}

Waste heat recovery system varies in different power range and it is started from 250 335.253 horsepower. As per the author\textsuperscript{12}, 2250KW energy can be recovered from the waste of steel reheat furnace. The energy savings, up to Rs.12 lacs per year and at Rs.6 per kWh electric expense. So finally energy conservation data collection is the important for safe future\textsuperscript{12}.

\section{2. Review of Waste Energy Utilization Sources}

Heat Exchangers (HE) are key part of waste heat to energy plants to recover energy. More emphasis on the selection on types of heat exchanger because of proper efficient design and working. It is crucial to complete the design of HE with highest degree of compactness and also by considering process parameters like proximity to fouling, composition of fluids used, temperature and possible operational problems\textsuperscript{12,14}. Heat exchanger from waste or biomass to energy technologies have been used for energy recovery. In that, heat contained in flue gas or off-gas from combustion chambers or incinerators have been consumed. The heat recovery system, as a part of incinerator, adds value to incinerator itself. This will in turn work as a technical component for the thermal treatment of

\begin{table}[h]
\centering
\caption{General Aspects of Selection of Heat Transfer Equipment}
\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|}
\hline
Commercial Heat Transfer Units & Specifications For Waste Heat Recovery Unit \hline
 & Low temperature below 0\degree C to 120\degree C & Intermediate temperature 120\degree C-650\degree C & High temperature above 650\degree C & Large temperature differentials & Packaged unit available & Can be retrofit & No cross communication & Gas to gas heat exchanger & Gas to liquid heat exchanger & Liquid to liquid exchanger & Corrosive gases permitted with special construction \hline
Shell and tube type Heat exchange(HE) & yes & yes & - & yes & yes & yes & yes & yes & yes & - & yes & - \hline
Finned tube HE & yes & yes & - & yes & yes & yes & yes & - & yes & - & - \hline
Waste heat boiler & yes & yes & - & - & yes & yes & - & - & yes & - & - \hline
Spiral heat Exchanger & yes & yes & - & - & yes & yes & yes & yes & yes & yes & yes \hline
oncentric tube heat exchanger recuperator & - & yes & yes & - & yes & yes & - & - & - & yes \hline
Plate heat exchanger & yes & yes & - & yes & yes & yes & yes & - & yes & yes & yes \hline
Run around system & yes & yes & - & yes & yes & yes & yes & - & yes & yes & - \hline
Heat pipe & yes & yes & - & - & yes & yes & yes & yes & yes & - & - \hline
\hline
\end{tabular}
\end{table}
waste and for waste to energy system. Thermodynamics of heat exchanger units and its effect in a power plant for optimum design condition based on cost have also been discussed. Compact welded plate heat exchanger can be proficiently used for heating of water to require temperature of whole district. The principle behind this is condensing of steam extracted from certain turbines section. Furthermore, an inventive waste warmth region heating system utilizing joint heat and force based ejector HEs and retention heat pumps are used. For existing CHP framework waste heat energy can be used from steam turbine. This will lead to improve heat transmission and increase the temperature. Likewise, heat transmission capacity improved by 66% and system temperature drop approximate 30 °C. A novel kind of absorption heat exchanger for reduction of returning water's temperature of the existing primary heating network (PHN) have also been studied. Results are shows that the temperature of PHN is reduces from 25 °C to less 20 °C. Initially, mixing of cool water from evaporators and water from primary heating network is mixed in heating stations, as well as it is flowing through water pump of PHN. This water can be heated by getting exhausted steam from the turbine. The step by step process of recovering the waste heat for circulating water using primary heating network is presented in Figure 3. it is shows that the percentage of waste heat utilized by the different equipment. It is observed that compare to pumps recovering of non-used (waste) heat can be maximum utilized by heat exchanger and water temperature can be also mange by heat exchanger at higher degree. so heat exchangers are more preferable as heat recovery system.

Figure 3. Waste Heat Recovery and Heating Phases of the Circulating Liquid in Primary Heating Network.

Hot water is the primary requirement of the universe. Its consumption is day by day increasing sue to this reason energy conservation sources are utilizing to meet the energy requirement. Hence, the appropriate selection of an energy conservation system is required. Few parameters are also to be consideration like cost, lifecycle, efficiency etc. for domestic hot water application. It is also observed that the heat exhaust from the diesel engine is a source to get energy. This can be possible by applying the distinct Rankine cycle. Test results are also shows the good platform of energy source. Diesel generator with 40 kW can be operated 40% by the energy which is generated by exhaust gases of generator. So finally environment can be protected residual gases. They have shown that by using this system to improved brake-specific fuel consumption, produce extra power, reduced exhaust emissions finally waste energy can be recovered. Basically there are so many thermal cycles to utilized for saving energy and power generation. But out of this Brayton and Rankine cycle have been develop for recovering low level waste heat. In contrast to the conventional cycle, the two novel cycles, Brayton and Rankine cycle, bring exergy performance of 60.94% and 60% and thermal efficiency of 53.08% and 52.31%, respectively. In recent development changes or reconciliations of material lead to free heating and cooling of the building. Both trial and reenactment mechanism have been developed for air heat exchanger. In which PCM material is used for making free cooling of the building structure. Selection of the PCM can be based on its thermal properties like melting temperature etc. Thermodynamic studies have been performed of two pre-drying methods (steam drying and boiler flue gas drying). Results indicated that the plant thermal efficiency improves up to 3 % to 5 % by pre-drying methods. A system has also been proposed that combines a trans critical CO_2 refrigeration cycle. A Brayton cycle with ejector-expansion device, which used solar energy as the heat source to alleviate environmental problems and reduce fossil fuel consumption. In Table 5 Summary of waste water heat pump studies inspected. Table 5 is also indicating the heating cooling capacities are depended on the capacity of evaporate and condenser, few of them are solar assisted and remaining systems are simple. Similarly, Ahmadi et al. have studied combined cycle power plant (CCPP). In this power plant additional firing system thermodynamically is added. The consequence deviations in the demanded fuel cost and power by energy and exergy were examined by taking three different output powers into consideration to improve the effectiveness of power plant. (160, 180 and 200 MW). Some researchers have
Table 5. Summary of waste water heat pump studies inspected

| Item no | Authors | Year | Refrigerant for Heat Pump cycle | Type for Heat Pump cycle | Application capacity and location | Heat exchanger |
|---------|---------|------|---------------------------------|--------------------------|----------------------------------|----------------|
| 1.      | Qian et al. | 2006 | - | - | Heating (kw): 1000 | COP (Heating): 4.2 | COP (Cooling): 2.8 | China | shell and tube type heat exchanger | - | Y |
| 2.      | Qian et al. | 2009 | - | Vapor compression (VC) | Heating (kw): 1000 | COP (Heating): 4.2 | COP (Cooling): 2.8 | China | Freezing latent heat exchanger | - | Y |
| 3.      | Zhao et al | 2010 | VC | - | Heating (kw): 1300 | COP (Heating): 4.3 | COP (Cooling): 3.5 | China | Shell and Tube | - | Y |
| 4.      | Qian | 2011 | VC | - | Heating (kw): 1300 | COP (Heating): 4.3 | COP (Cooling): 3.5 | China | Freezing latent heat exchanger | - | Y | Y |
| 5.      | Gu and Deng | 2012 | VC | - | Heating (kw): 27378 | COP (Heating): 9.3 | COP (Cooling): 8.2 | China | Shell and Tube | - | Y |
| 6.      | Wang | 2013 | R-22 | - | Heating (kw): 1300 | COP (Heating): 4.3 | COP (Cooling): 3.5 | China | Shell and Tube | - | Y | Y |
| 7.      | Liu et al | 2013 | VC | - | Heating (kw): 1520 | COP (Heating): 4.3 | COP (Cooling): 3.5 | China | Direct expansion | - | Y |
| 8.      | Yaxiu and Fang | 2013 | VC | - | Heating (kw): 1520 | COP (Heating): 4.3 | COP (Cooling): 3.5 | China | Cross flow horizontal falling film heat exchanger | - | Y | Y |
| 9.      | Liu et al | 2014 | R-134A | - | Heating (kw): 1520 | COP (Heating): 4.3 | COP (Cooling): 3.5 | China | Shell and tube heat exchanger | 880KW | Y | Y |
| 10.     | Liu et al | 2014 | VC | - | Heating (kw): 5.15-6.69 | COP (Heating): 3.8 | COP (Cooling): 4.8 | USA | Direct heat exchanger | - | Y |
performed the exergy analysis, exergo environmental and exergo economic analysis of a CCPP\textsuperscript{23}. The outcomes revealed that the destruction in exergy and cost of exergy. its demonstrates that combustion chamber has highest exergy destruction and maximum cost of exergy destruction compared with other parts of the cycle. In the same context, it has been showed that to optimize the process structure and variables of CCPP evolutionary algorithms are use\textsuperscript{22}. Additionally, researchers have optimized CCPP cost using irreversible Carnot-like heat engines number of stages was increased\textsuperscript{31,32}. Similarly geometrical parameters are also affecting the heat exchanger but without changing in the parameters optimization of multi-stream plate fin heat exchanger is possible by changing in variables like entropy Generation\textsuperscript{31}.

Rosen and Dincer together carried out an exergo economical study of coal fired electricity generating station and power plants. They exposed that the ratio of thermodynamic loss rate is a significant parameter for evaluating performance of the plant. it lead to a successful design of the plant\textsuperscript{33}. Likewise, in for high temperature sometimes ceramic monolith heat exchangers are used. These heat exchangers are unique and new development. It’s found that the heat transferred rate can be increased by 3% and overall heat transferred rate increased by 4.5 - 5\%\textsuperscript{33,34}. On the other side binary cycle has been suggested. In Binary cycle, geothermal sources provide thermal energy. This thermal energy transferred to other working fluid. Thus, selection of second working fluid is very critical and plays key role on the performance of the cycle. in this review geothermal binary power cycle was studies in which different refrigerants were selected as a working fluid. For all twelve refrigerants, exergy and energy efficiencies of binary cycle were calculated. Study shows that refrigerants like R600a, R227ea, R236ea, and R600 showed higher energy and exergy efficiencies, respectively and they were from dry type. On the other hand, wet fluids such as R143a, R415A, R290, and R 413A were indicated to have lower energy and exergy efficiencies, respectively\textsuperscript{35}. The cost is also very important factor when the design the energy conservation system. Heat exchanger is a unit in which modifications can be done and low cost system to be developed and also minimize the inventory cost\textsuperscript{31}.

3. Conclusion

Waste water is a vital energy source, which can be effectively used to improve the performances of different system by different type of sources like heat exchangers, heat pumps etc. The amounts of water used in India compare to other countries are more. To utilize the waste water energy shell and tube types of heat exchangers are more preferable. By using these types of technologies we can maintain the non-renewable sources and protect the environments. The cost behind this type of development can be reimbursed by utilizing the waste energy resources. Heat and electricity generation from waste provide a more environment friendly alternative source of energy.

This review is also exploring that not only the waste energy has utilized but other sources of energy like solar, wind, geothermal can be used for domestic applications like supply of hot water, heating and cooling of building etc. In future to meet for energy requirement renewable sources operated system will be developed for energy conservation.

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