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A Review - on Waste Heat Recover From Convetional and Non-Convetional Cycle

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Abstract

The power generation based upon fossil fuel needs to conserved as these fuels are depleting in nature and its furnishing takes years to replenish. Conventional power plants are using them for electricity production and causing harmful emissions and waste thermal energy. Therefore, conservation of such fuel, harvesting the waste heat is the important task for the energy society. To extract heat/power from these waste energies and reduce the hazardous emissions from environment, and methods are to be identified. Usually, massive amount of thermal energy goes wasted from various systems such as the power plants, industries, and vehicles exhaust, and many more. This work is focusing on waste heat recovery from power producing systems and finding a gap to convert the waste energy as useful energy. Further different options for utilizing the waste heat are enumerated and discussed in details.

Keywords: Power Cycles, Internal Combustion Engine, Waste Heat Recovery, Organic Rankine Cycle, Kalina Cycle.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

1. Introduction

In the modern era and the rising need for electricity, the energy generated by the fossil requires to optimize consumption and conversion of these resources. The enormous amounts of heat energy are released, and waste heat is thrown by the power plant and industries that increase the number of harmful gases in the atmosphere. These emissions in the form of heat energy are very harmful to human life as well as causes pollution. The heat energy emitted to the environment has the potential to be utilized as a source for other purposes. The non-conventional sources of energy that such as solar energy, wind energy, geothermal energy, bioenergy, hydro energy, and many more are available in the environment. Conventional sources of energy that is oil and natural gas, are limited and causes pollution. Various experimental/theoretical work are performed to utilized waste heat and several techniques related to the current cycle and non-conventional cycle are examined. By choosing suitable nonconventional and conventional sequences, the waste heat can be converted into an energy form and reuse in a stable system. In recovering waste heat, a traditional combined cycle recovers waste heat from the system that is Brayton- Rankine cycle. Brayton is an open cycle which is consist of compression, combustion chamber, and gas turbine as the main components. In this cycle, after a turbine work, some heat goes wastes through the turbine to the environment. Therefore, a Rankine cycle is used to recover a temperature which is coming through the turbine from the Brayton cycle. A heat exchanger is work as a boiler which is used between Brayton and Rankine period to recover waste heat. The result of this combined cycle is efficiency, exceeding 60% on a lower heating value basis []. The above explanation on the traditional combined cycle is a concept to recover the waste heat from the gas turbine cycle. It is essential to recover waste heat, by reducing the amount of fuel consumption for producing heat or power with the given fuel. Due to higher demand of electricity and the higher fuel price the waste heat recovery process may be the economical option for the present situation.

2. Integrated Internal Combustion Engine and Organic Rankine cycle

The waste heat can utilize as an energy purpose by connecting the recovery heat source. Zhang et al. [8], investigated a system to recover waste heat from a diesel engine with the help of the dual-loop Organic Rankine cycle. Where the first loop is a high-temperature loop and the second loop is a low-temperature loop. These dual loops recover the waste heat from the exhaust, coolant, and intake air. Whereas an exhaust heat recovered by the high-temperature circuit. Whereas residual heat recovered by the low-temperature loop. Benefits to attach a dual loop ORC is a net power output of low temperature, and high-temperature loops are 11.91KW and 6.98KW respectively. The compelling power output is most economical (for the combined system), i.e., 14-16% and highest in the small-load and high-speed region, i.e., 38% to 43%.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

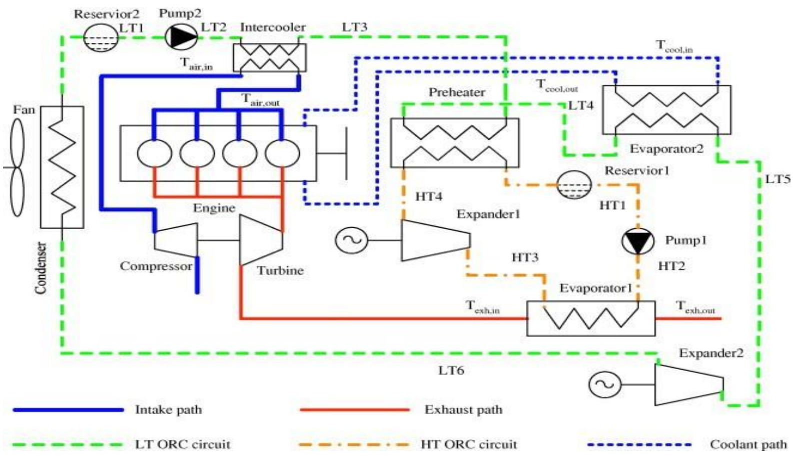

Figure1: Layout of a light-duty diesel engine with a dual loop ORC system

Similarly, A Maogang He et al. [9], also performed work on an internal combustion engine, where heat is recovered by dual cycle, which is Kalina cycle and Organic Rankine Cycle (ORC).

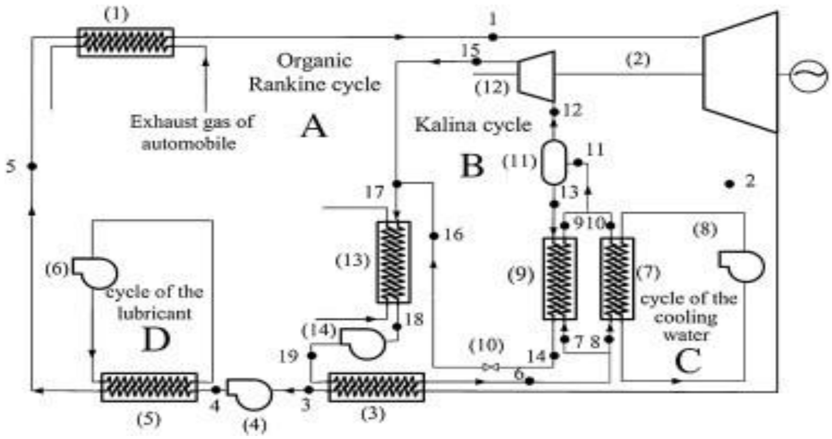

Figure 2: Schematic layout of an internal combustion engine and waste heat recovery system.

The waste heat from lubricant and high-temperature exhaust gases is harvest by an ORC, and waste heat from low-temperature cooling water is harness by Kalina cycle. The above experiment performed according to TOYOTA 8A-FE gasoline engine in a steady-state, only third of the fuel's chemical energy is converted into practical work, and the rest of the waste heat in the form of cooling water, exhaust gas, and lubricant.

Author Chen Yue et al. [3] also research on waste heat recovery from an engine, in this setup waste heat recovered by the trans-critical ORC and a Kalina cycle. Firstly, an experiment performed on Kalina-based ICE and took a working fluid of ammonia-water as a solution in the system. The waste heat recovered from the evaporator during the sensible heating process. Authors also studied on an ORC based ICE, where all methods are relatively equivalent, in an Organic Rankine cycle, using various kinds of Alkanes as a working fluid. Thus, by performing both an experiment, they compare exergy efficiency, thermal efficiency, and all with each other.

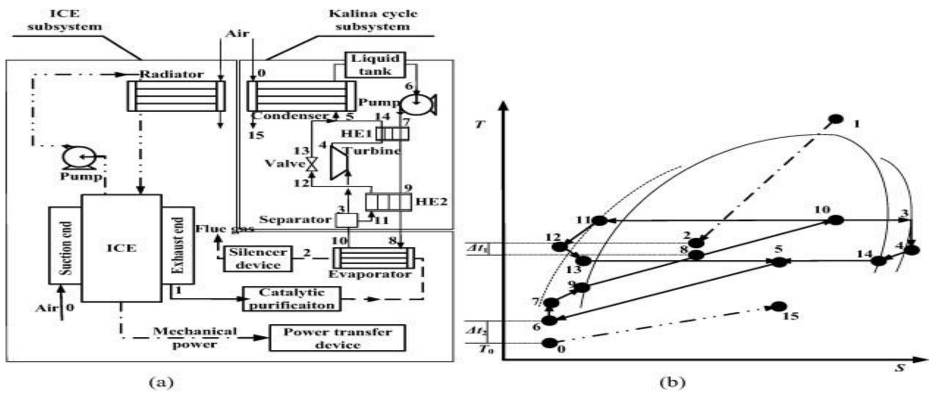

Figure 3: The bottoming Kalina cycle with the topping internal combustion engine

Comparing the results of results ICE with the Kalina cycle, the transcritical ORC is used different types of Alkanes as a working fluid. The costs of PWHR, the efficiency of WHR, and efficiency of exergy increase between the range 106-145 kW, 9.3-12.7 %, and 18.8-25.8 % respectively. The result shows that during the trans-critical process, Alkanes possess a low specific heat capacity during the trans.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

A diesel engine is beneficial in various fields like in a mode of transport, agriculture, small medium-size stationary generator, as well as generate the most significant CO_2 emission and environmental pollution. However, from these above useful areas of diesel engine very less amount of diesel is used as mechanical work, more than 60% of energy from air-fuel mixture combustion is not used to produce the mechanical work and released into the environment as waste heat. Hoang [15], presented an overview of various conventional/non-conventional cycles, the diesel engine based on ORC is one of the beneficial cycles to reuse or recover waste heat.

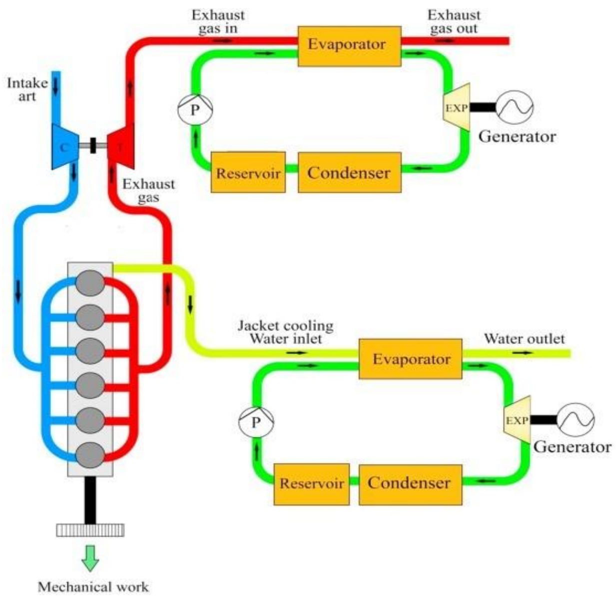

Figure 4: waste heat recovery system of diesel engine based on ORC principle

According to the work, around 25% of thermal efficiency is using a conventional standalone engine- Organic Rankine Cycle system. However, from the study, about 90% of overall thermal energy from the combined recovery system of waste heat sources. The research-based result is Organic Rankine Cycle system is more suitable to use as a waste heat recovery according to economic and environmental aspects.

Hossain et al. [5] presented a system through which waste heat from the exhaust of a diesel generator utilized by a Rankine Cycle to recover the waste heat. As a considerable amount of heat exhaust by the diesel engine, by using a separate Rankine cycle, these exhaust heat can be utilized as an additional heat source to generate power. The work, [5] utilised two-heat exchanger to measure an available exhaust heat from a 40-kW diesel generator. In this experimental work uses water as a working fluid, and the effectiveness of two heat exchangers is 0.44, which is lower than the standard value.

The proposed system with designed data is shown in Figure 5 [];

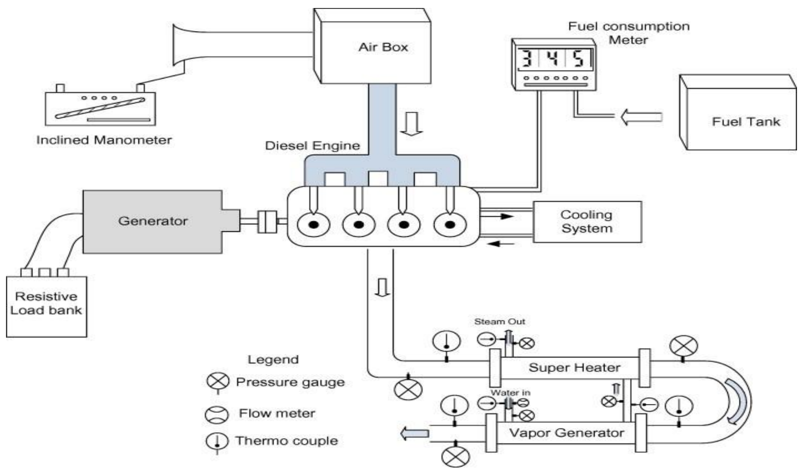

Figure 5: Schematic layout of the experimental setup

Two heat exchangers which are set up in a series and other in parallel (these two heat exchangers used for superheating). The purposed to used two heat exchangers (in series and parallel) to produce additional power. The results discussed that the additional heat exchanger provides 11% power because of using water as a working fluid at 15 bar pressure in a rated engine load. Due to this extra power which is produced by heat exchangers, 12% of improvement has come in brake-specific fuel consumption. The additional potential increases15 bar pressure, it is limited to constraint by exhaust gas temperatures and high pressure.

3. Solar (energy) collector with Kalina cycle

The solar radiations are an excellent source of energy; the solar collector can obtain a considerable amount of energy from the sun. Water used as a working fluid inside a collector, and the receiver receives this energy.

Author Mehdi Mehrpooyaa et al. [5] utilize the advantage of solar energy, integrated a Kalina cycle with solar collector and phase change material (PCM) system.

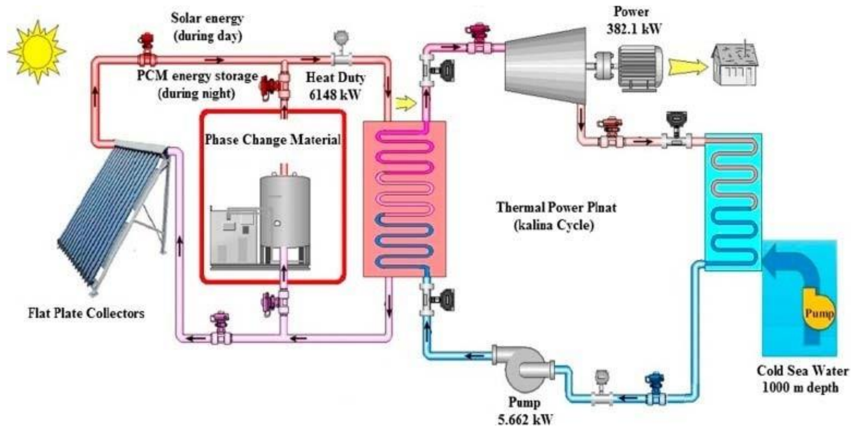

Figure 6: Schematic diagram of the integrated Kalina cycle with a solar collector and a PCM system

and discussed a method, schematic diagram shown in Figure 6 to be used the heat through a Kalina cycle with mounted energy resource solar collector & auxiliary heater. The mixture of ammonia and water are used as a working fluid in an above cycle. This mixture is passing through the solar collector (generally the temperature of flat plate collector or solar collector are 20-200 ^{O}C in industry and domestic user). A flat plate collector gives the energy to the system; subsequently, an auxiliary heater also gives the rest of the required energy to the system. The system required 53.85 GWh energy per year, from the solar collector system, get 45.13 GWh energy supply per year. Therefore, the auxiliary heater is used to full fill the required power and provide the rest of the energy (i.e., 8.72 GWh per year) to the system. The phase change material is used to provide energy at night; the rest of the process is to follow the Kalina Power Cycle working principle.

The result explained that the proposed model offered 6.12% of thermal efficiency gained by Kalina cycle. The model has used MATLAB and Aspen-HYSYS software to estimate the performance.

Author Mehdi Mehrpooya et al. [12] also proposed the experiment on biogas upgrading, where Mehdi et al. a Developing and exegetic performance assessment of biogas upgrading.

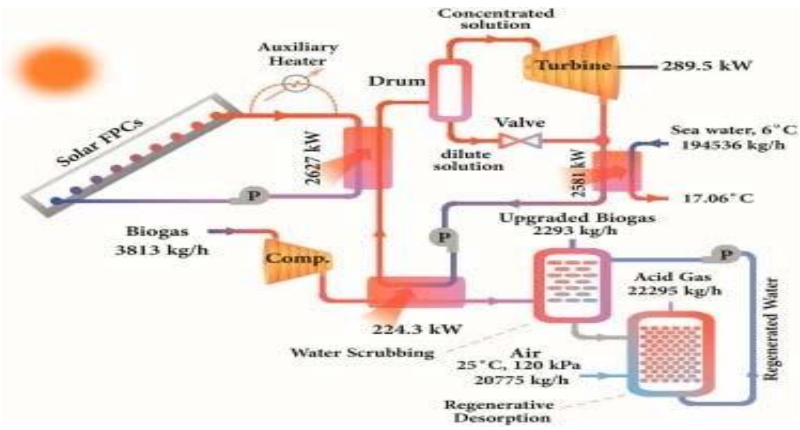

Figure 8: Schematic diagram of biogas upgrading process using Kalina power cycle and FPCs in Bushehr City.

The work evolved and introduced an innovative integrated system composed of water scrubbing biogas upgrading process with water regeneration, flat plate solar collectors (FPC) and Kalina power cycle. Solar thermal energy was exploited through FPCs and delivered to the

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Vol-22-Issue-17-September-2019

Kalina cycle aiming at producing the electrical power required by the biogas upgrading process. The excess heat in the biogas upgrading cycle was recovered and fed to the Kalina cycle. The proposed system used an Aspen Hysys software based on the real solar data in Bushehr city. Overall, the FPCs provided 2627 kW thermal power to the Kalina cycle, where 289.5 kW electrical power was produced and delivered to the biogas upgrading process. The water scrubbing process was capable of removing the CO_2 and H_2S content and provide upgraded biogas. A mass flow rate is 2293 kg/h. A, comprehensive second law based thermodynamic analysis was accomplished to assess the effectiveness of the proposed cycle. The exegetic performance of the components was examined and discussed thoroughly. The exergy efficiency of the proposed integrated system did perceive by 92.36%. The highest exergy destruction was occurred in the FPCs being responsible for 73% of the total exergy destruction. The desorption column and steam turbine had the second and third highest exergy destruction, respectively. The effects of the collector's number and minimum approach temperature on the exergy efficiency, upgraded biogas production, Kalina cycle efficiency, and exergy destruction were studied and discussed as well. Processdriven by flat plate solar collectors coupled with Kalina power cycle.

4. Kalina cycle with low-grade heat source and cogeneration:

The Kalina cycle is a power cycle used to converts waste energy into useful energy. The working fluid for the cycle is a mixture of ammonia and water, having different boiling points for energy recovery.

Liyan Cao et al. [6] have taken advantage of the Kalina cycle and combined (Kalina cycle) with cooling power cycle (vapor absorption

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

cycle). A heat is recovering by the heat recovery steam generator (HRSG).

After being heated by HRSG, a solution of ammonia-water is separate into ammonia stable solution and ammonia weak solution by a separator. A durable ammonia solution passes to the expander, and a weak ammonia solution, which has a relatively high temperature enters into an absorption refrigeration cycle as a heat source.

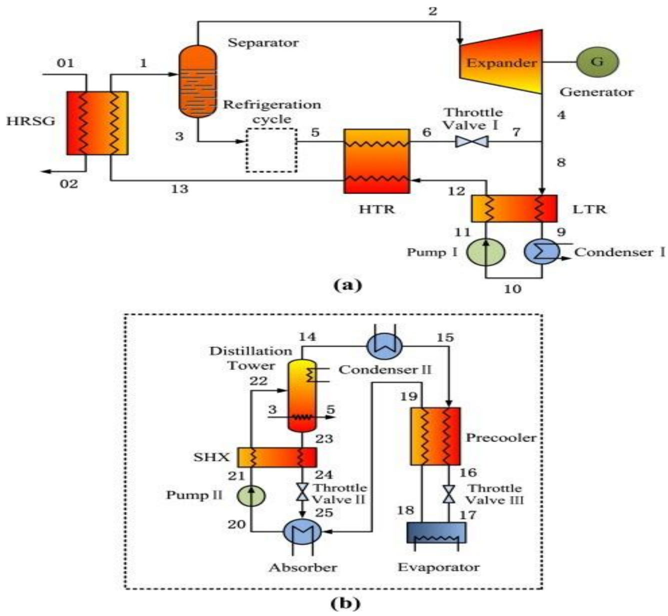


Figure 8: (A) Schematic view of Kalina based CCPP cycle (B) Detailed view of the refrigeration cycle

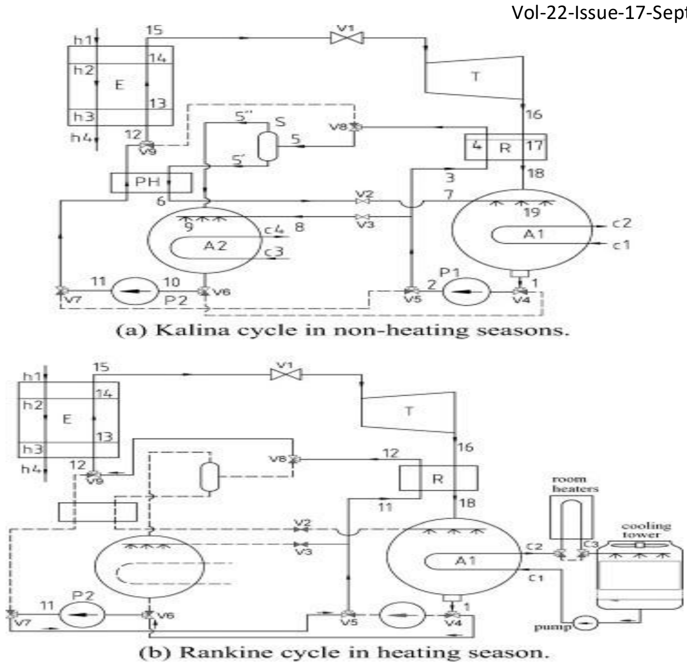
de Bor [13], presented a system to recover the low-grade waste by using the heat pump and power cycles. Thermal energy is the most significant part of global energy and around 43 % of thermal energy used in an industrial application. A considerable amount of energy is waste by exhaust gases, liquid streams, and cooling water. The Heat pump, upgrading waste heat to convert the process of heat and cooling and power cycles into electricity. The potential of several alternative technologies, either for the upgrading of low-temperature waste heat such as compression-resorption, vapor compression, and trans-critical heat pump, or for that conversion of the waste heat by using organic Rankine cycle, Kalina cycle, and trilateral cycle engines, which investigated for energetic and economic performance. This researchbased on temperature levels of 45-60 ^{o}C, at this temperature range vast amounts of heat, are wasted to the environment but also investigates the temperature levels for which power cycles become competitive. At the low-temperature range heat pump deliver 2.5-11 times more energy than power cycles at equal waste heat input and at 100 ^{o}C and above the temperature of waste heat become competitive for heat engines with heat pumps.

Liyan [6] also performed another experiment, with Kalina based- vapor compression cycle and compared both results (experimental and analytical) with each other. As per the analysed result, Kalina-based vapor absorption cycle is more efficient than Kalina-based vapor compression cycle. The net power output, along with exergy efficiency of Kalina-based absorption cycle and compression cycle is 85.59KW and 71.81KW and 25.76% and 23.44% respectively.

Zhi Zhang et al. [2] also used a Kalina cycle in their experiment and combined with a Rankine cycle.

Figure 9-(a) and 9-(b), it is a modified cycle of the Rankine cycle that is called Kalina cycle. In figure 9, authors set two different systems for this experiment, first system is Kalina cycle and second system is Rankine cycle, both systems used according to the season (like summer and winter).

ISSN: 0971-1260
Vol-22-Issue-17-September-2019



(a) Kalina cycle in non-heating seasons.

(b) Rankine cycle in heating season.

Figure: 9 Circulation loops of the AWKRC in a different season

In the above diagram of the Kalina cycle, a reliable solution enters into an absorber A_2, and a weak solution preheats in a pre-heater (P.H.) and goes back to the absorber A_1. There is the various process has done behind this step where weak and robust solution enters into absorber A2 and absorber A1 respectively. By these kinds of process author Zhang et al. recover the heat and recirculated in this system. After the experiment done on the Kalina cycle, they experiment with Rankine cycle by removing the dilute and active solution loop from the system. Kalina cycle not only generating the electricity with improved efficiency in the winter season, likewise heat water with Rankine cycle in cogeneration during the summer season.

The thermal efficiency, as well as power recovery efficiency of the Rankine cycle, is decreased by 18% and 24.7% respectively, as it is obtained that by comparing it with the Kalina cycle. However, getting extra heating water with 70^{o} F for the Rankine cycle, around 55.3% of

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

the input heat load absorbed in the evaporator and the overall efficiency is higher in comparison to Kalina cycle, i.e., 23.7%.

Shaobo Zhang et al. [6] used a parallel power, and refrigeration cogeneration Kalina cycle (PPR-KC). Its driven waste heat recovery source of flue gas. The working fluid passed through the outlet of midp-absorber (A2) and distributed into two-stream. First, pumped to the high-pressure state by a pump (P2), and second, preheated (PH1) by a dilute solution which is coming from the separator (S) and enters into the boiler. In which the endothermic process made of three liquid portions heating, evaporation, and vapor-superheating.

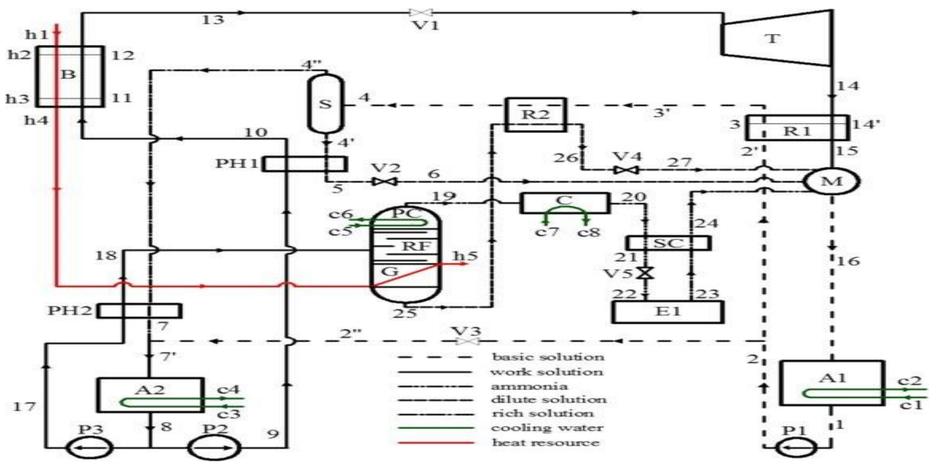


Figure 10: Schematic diagram of parallel power and refrigeration cogeneration Kalina cycle

The work solution absorbs heat from the waste flue gas and transfers the superheated vapor with high temperature and vapor flow into the turbine (T) for expansion and power generation.

Turbine (T) released heat into the first solution in the recuperator R1, and the work solution mixed with another stream (that is dilute solution and ammonia), and the mixture goes to the low-p-absorber (A1) in an

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

absorber (A1). Cooling water spraying to the mixture to release the heat.

The primary solution also distributed into two forms that are a minority solution (2") is fed up to the absorber (A2), and majority solution goes to the recuperator R1 and R2 series to be heated. After the process of recuperator (R2), the solution separated by a separator (S), where dilute solution enters into the pre-heater (PH1) to preheat the high-pressure work solution. The mixture (m) and rest of the solution directly goes to the pre-heater (PH2), where ammonia vapor release heat in PH2. A preheater, the second-high-pressure work solution mix with minority basic solution and inlet into the absorber (A2). The outlet of the second high pressure (distilled pressure) goes to the pre-heater (PH2), which is being preheated and enters into a generator. The ammonia vapor from the distillation column passes through the condenser, sub-cooler, throttle valve (V5) and generator, and goes to the mixture (m) via sub-cooler (S.C.).

The result of the above experiment is 27.2% of comprehensive power recovery efficiency of

the PPR-KC reaches, which is 9.85% and 20.24% respectively higher than those of the cogeneration cycle proposed by Liu et al. and the Kalina cycle.

Author Soheil Rana et al. [10], experimented with generating electricity from a thermoelectric model.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

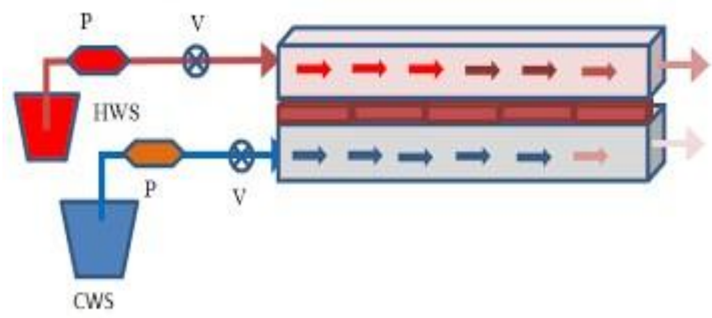


Figure 11: Generate Electricity from thermoelectric model

The main focus of the work is to generate electricity from low heat generation. Efficiency does not matter whether it is high or low; the central issue in this technology is to recover waste heat. Performance or efficiency of System of TEG technology depends on system configurations and module properties. This work, focuses upon the optimization of waste heat, concentrating on all the theoretical parts to find all the possible way to recover waste heat from thermoelectric generation.

The tremendous amount of heat goes waste by the transportations and mobile sectors. Several kinds of technologies are used to utilize lowgrade waste heat by using the Rankine cycle, Organic Rankine cycle (ORC), Kalina cycle, and many more.

A methodology is used to optimize the model, maximize the waste heat recovery and electrical power conversion performed by using TEG. Two rectangular ducts are uses in setup; which thermally insulated from three sides. The tube is set up on an upper side, which considered a hot water source, and the lower pipe considered as a cold-water source. A pump used in both water source to pumping the fluid and a valve is used to control the flow rate in both water source. A thermoelectric

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

module is put between two rectangular ducts to attain the temperature gradient among the TEG surfaces to produce electricity.

The gap size is quite important to increase the heat transfer coefficient and enhanced with the decreases of gap size, and net power out is also proportional to gap size. Net energy shows the positive trends up to 0.01m gap size. If gap size decreases, further parasitic power loss increased significantly if the gap size is less than 0.01m, then net power shows negative trends.

Bertrand Delpech et al. [11] worked upon a case study of ceramic industry, energy efficiency enhancement and waste heat recovery in the industrial processes utilizing the heat pipe technology discussed. The application of heat pipe-based heat exchanger is used to improve energy efficiency in the industrial process. It determined in the ceramic industry to the reduction in fuel consumption and potential heat recovery. According to the requirement on the ceramic industry, authors constructed a theoretical model where they used the heat pipe technologies and the performance of the ceramic process computed by numerical simulation. The experiment also performed by the combined approach and the theoretical model of heat pipe-based heat exchanger. The potential heat recovers to evaluate and reduction of fuel consumption. The theoretical and numerical approach into the application of heat pipe-based heat exchanger to a cooling stack of the ceramic process to recover more than 863 MWh of thermal energy that can use for heating up hot air stream of the pre-kiln dryer. As a result of this, almost 110,600 Sm^3/year of natural gas can be saved from the burners powering the dyer and the ejection of 164 tonnes/year of carbon dioxide (CO_2) can avoid. Besides, 22,000 Euro/year of the fuel consumption reduction is going to prevent, due to a theoretical model of heat pipe-based heat exchanger, improvement of the system has to influence in energy efficiency and economically impact on an environment.

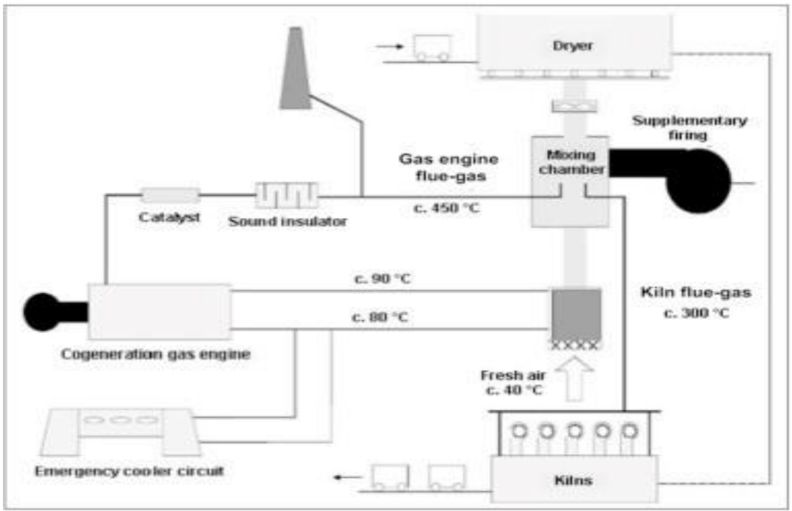


Figure 11: Schematic of a CHP (Combined Heat and Power) Plant

The result has come from a theoretical model of heat pipe-based heat exchanger, the design of the construction of the above model is used to recover the waste heat from exhaust of hot air heat fresh supply air.

Rasool Bahrampoury et al. [7] proposed a thermodynamic optimization of double pressure Kalina cycle driven from Kalina cycle system 11. The work performed thermo-economic analysis on four arrangements .

The author applied a numerical method to set an exact pinch temperature difference, to get the values of temperature. Three different temperature that is 383.15K, 413.15K, and 443.15K is assumed to the product of combustion of the HTF of inlet stream, and their performance variables compared with the base case and the optimum condition. The Levelized cost (L.C.) of power selected as a criterion for the evaluation of the work and thermo-economic analysis performed. A

 ISSN: 0971-1260
Vol-22-Issue-17-September-2019

cycle-based defined by the different decision variable on the cycle's degree freedom. The decision variables are mass flow rate, pressure level, and concentration of ammonia at the base stream. The novel dual pressure-Kalina cycles together with base Kalina cycle are correlated, and the objective function chosen as exergy efficiency.

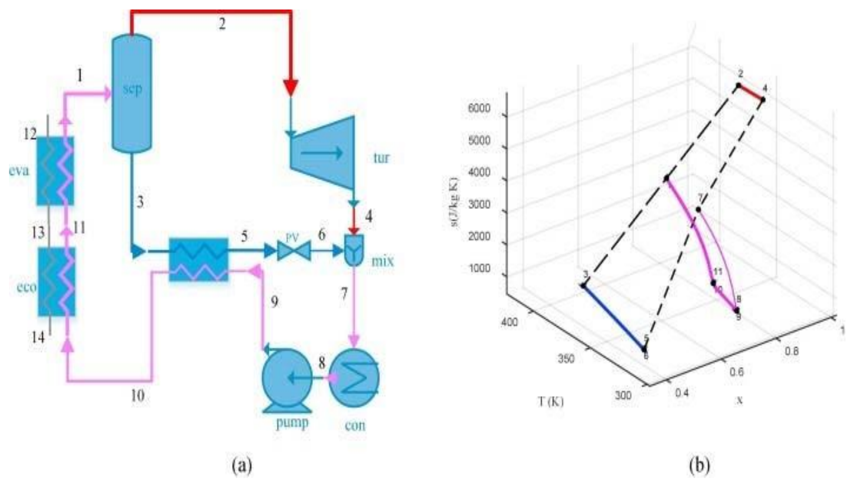


Figure 12a: Schematic diagram of base Kalina Cycle

Author Rasool Bahrampoury et al. [] experimented on a different application of low and moderate Kalina cycle and for the utilization of geothermal energy KCS 11 considered as an efficient cycle.

Basically, authors investigated on four double pressure Kalina cycle they are named as KCS- 111a, KCS-111b, KCS-112a, and KCS-112b these all are driven from KCS 11. A result has come by solving all the values in a MATLAB software.

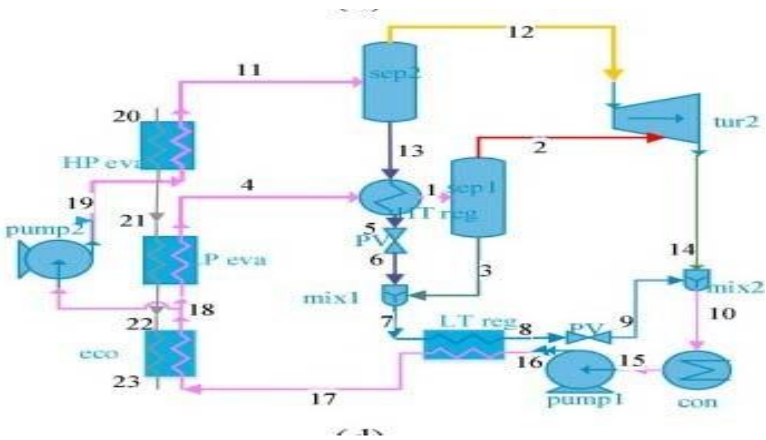


Figure 12b: Schematic diagram of KCS 112B

The result shows that KCS-112b is capable of produced net power. As per the result, KCS-112b is a sufficient cycle according to the sensitivity of efficiencies. However, KCS 11 is most justified cycle when thermoeconomic aspect matters. As can be seen among the introduced sequences, i.e., KCS-111a, KCS-111b, KCS-112a and KCS-112b in which a KCS-112b is sufficient and acceptable and LCOE (Levelized cost of efficiency) value assessed is the nearest to the base case.

Conclusion

After reviewing the various research paper on the subject, the following findings have been made to utilize the waste heat from multiple systems.

By selecting the appropriate combination of the conventional/unconventional cycle, by these cycles, waste heat can be converted into useful heat/power from thermal power systems. Kalina Cycle and Organic Rankine Cycle are integrated with conventional cycles and used to harvest heat / power. Amount of fuel burnt save by harvesting the energy in different forms explained in different cases.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

These are the various techniques used to harvest energy and also be useful to obtain energy/power from low temperature sources.

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