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Using Waste Heat of Output Gases for Energy Conservation

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Abstract- *The present study is related to the power plant producing electricity for ALUMINIUM COMPANY OF EGYPT.This power generation system is based on a heat recovery system. It was installed onthe waste gas duct of a coke calcination-rotary hearth furnace.A large amount (15 MW / h) of energy is used for the heating process. This energy is in the form of waste heat generated by the by-products of a coke calcination rotaryheater burner. The combustion of coke releases heat, which is used to heat the process, and to generate combustion products that are discharged from the calcification system. All major industries use heating equipment such as furnaces, ovens, heaters, ovens and dryers. Hot gases are discharged from this equipment, after providing the necessary heat process in the atmosphere through the stacks. Therefore, the company can save up approximately 80 GWatt per year due to the production of electricity using their own power plant depending on waste heat recovery boiler and avoiding the loss sustained by releasing this heat into atmosphere.*

Keywords *-Flue gas; waste heat; power; energy and emission reduction.*

INTODUCTION

Waste heat (F) is a process that gives part of the heat that is usually lost. It gives a device or process where it can be used as an efficient, economical and environmentally friendly way to save energy.For the cogeneration system of gas, there are problems to be solved. There is a large heat transfer and temperature difference in heat - exchange progress. It can cause a huge irreversible loss of heat transfer. More serious, the exhaust temperature of flue gas is generally more than 90 ° C.Part of the heat equals 40% of the heating load. Potential benefits of waste heat include: improving energy efficiency in the process, reducing fuel costs, reducing emissions of sulfur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide and non-burning hydrocarbons. Power consumption can usually be reduced by between 5 and 30 per cent in most cases. The heating capacity and energy efficiency of the cogeneration plant is increased by the exhaust heat group recovered from the exhaust gas [1].The best way to save energy and reduce carbon is to produce coal gas, while the optimal scheme is combined to use heat waste coal gas production with scrap heating, which will save approximately 170 kWh / t of energy and a low 57.9 kg / t of carbon emissions [2].Simple geometry is useful for isolating electrochemical properties without the complex microscopic effects of porous electrodes. Many molybdate materials were activated significantly by electrolysis and showed higher performance of the cathode polarization of polarized anode (fuel cell) polarization. While all molybdates showed higher performance for H_2O electrolysis than CO_2 electrolysis. The researchers also found that an excellent electrical catalyst for CO_2 electrolysis and oxidation of CO (more than H_2O / H_2 which is known to be good) [3].Saving ton of steam not only saves the fuel needed to lift it, but also eliminates the associated power output that is produced in additional 80-90% additional factors for energy restoration projects; as heat effect on some equipment, such as burner off. Maintenance schedules for equipment that generate and receive waste heat; reliability and availability of equipment [4]. Increase the temperature of the heat source, and increase the output of the energy with adiabatic side wall conditions. A change in the boundary condition for heat transfer of heat from adiabatic boundary has a significant impact on thermal efficiency [5].The net and net electrical efficiency of the proposed vehicle cycle can be increased by 1.6 and 2.84% respectively from those used in the conventional composite cycle. They also reported that the heat recovery per kilogram of flue gas is approximately 86.27 kJ / s, which could save megawatts of electric power for working sea water pumps [6]. An increase in the ratio of the overall flow rate in the upper channel to the lower channel has a positive effect on the overall efficiency of the system. High flow rate of mass rate results in higher amount of heat transfer and higher power output [7].Hot exhaust gases for combustion processes are the main source of large amount of energy waste through it. They also reported that more than 30%: 40% of fuel capacity in internal combustion engines is wasted from exhaust and only 12%: 25% of fuel energy turns into useful work [8]. By making it possible using a higher heat exhaust temperature, the power generation efficiency can be increased to nearly double that of typical under floor installation [9]. The unique combustion properties of methanol / diesel mixture improve both low temperature heat conduct and combustion temperature, resulting in the destruction of less exergy [10].Standard tubular heat pipe systems represent the largest operating temperature range compared to other systems, thus providing useful potential for improvement and integration of renewable energy systems [11].Outdoor air-heating technology results in higher power than close the supply side. Although, if the requirements of indoor air quality less, it must use a reasonable heat source satisfactory and cost less investment [12]. An increase in Reynolds number,there is no effect on recovery efficiency. Therefore, the heat transfer coefficient and recovery efficiency increased with a decrease in particle diameter and an increase in the velocity of falling particles. Compared with those observed with the aligned arrangement of the boiler tubes, the heat transfer coefficient and recovery efficiency was higher in a nested order [13].Standard tubular heat pipe systems lead to the largest operating temperature range compared to other systems, thus providing sustainable potential for improvement and integration in renewable energy systems [14].The use of heat tubes can reduce heat resistance and pressure losses in the system. They also noted that heat pipes have limitations such as maximum heat transfer rates and temperature limits. When used in conjunction, these technologies have the ability to create a fully solid state and passive waste heat recovery system [15].Economies can be up to 110 watts in cold climates and low airflow rates of about 0.1 kg / s and 0.005 kg / s respectively hot air exhaust and pure cold air. An extrapolation showed that economic energy can exceed 1kW for a chamber of heating load 4 kW if all supply air is exhausted [16].

II. General Equipment Description:

The petroleum coke calciner consists of the following major items of equipment:

II.1 Feed Bin

A storage bin designed to hold 62 M^3 approx. of green petroleum coke. Coke flows from this bin to calciner by gravity via a circular chute which terminates in an adjustable section.

II.2 Calciner

This is a rotary hearth furnace with a working diameter of 16.8 meters. It includes a process air system, a dilution air system, an afterburner air system, a combustion system, an exhaust system, a hearth drive mechanism, rabbles to move coke across the hearth, and a recirculating water system to cool select components.

II.2.1 Combustion System

This system includes ten Natural Gas burners rated at 630,000 Kcal/hr. each and necessary piping and controls to deliver natural gas to the burners. Air for combustion is obtained from the process air system. The burner firing rate is controlled manually.

II.2.2 Air Process System

This system includes a fan (001) with inlet guide vein actuator (TY 101) and the necessary piping and controls to push the air through the recuperated and distribute this air throughout the furnace. The quantity of process air delivered is controlled by a thermocouple TE 100A in the furnace. Upon a drop in furnace temperature below setpoint, the inlet guide veins will open to allow more process air to enter the furnace. Upon a temperature increase above setpoint, the inlet guide veins will close to reduce the flow of process air into the furnace. Additionally, a minimum pressure is maintained in the combustion air header to prevent volatiles from entering the combustion air duct.

II.2.3 Exhaust Gas System

The exhaust gas system includes refractory ductwork connecting the calciner to a recuperator to preheat process air from ambient temperature to approximately 500°C, a bypass, and a furnace pressure control damper and a natural draft stack.

II.2.4 Rotating Hearthand Soaking Pit

(Hearth Turntable) and (Soaking Pit). The hearth as it is rotated pushes the coke against the rabbles, which forces the coke down the sloped hearth toward the soaking pit. The coke is dropped into the soaking pit, where it is deposited into the discharge table.

II.2.5 Hearth Drive Mechanism

II.2.6 Rabbles

Twelve water cooled rabbles are suspended from the roof of the calciner to move the coke from the furnace periphery to the soaking pit. Rabbles also produce a mixing action, exposing new surfaces to radiant heat.

II.2.7 Calciner Recirculating Water System

II.2.8 After-Burner Air System

The after-burner air system consists of a fan, ductworks, air valve and controls to introduce air into the flue in order to burn off excess volatiles. The after burners air flowrate is controlled by the Carbon Monoxide and Oxygen sensors in the flue.

II.2.9 Dilution Air System

The dilution air system consists of a fan, ductwork, air valve and controls to dilute the waste gas temperature in the exhaust gas system from 1482°C to 982°C prior to entering the recuperation. The dilution air flow rate is controlled automatically via a thermocouple located in the exhaust flue before the recuperator.

II.2.10 Discharge Table

The innermost rabble directs coke into the soaking pit which rotates with the hearth. Coke flows by gravity from the soaking pit to the center of a rotating discharge table. Here the coke is moved from center to outside by only one water cooled plow. Coke leaves the discharge table via a chute which feeds into the coke cooler.

II.2.11 Discharge Table Drive

The Discharge Table is rotated by one 7.5 HP (5.5 KW) A.C. motor, reducer, and driven pinion which drives a gear mounted on the discharge to the table bearing which rotates the discharge table. The speed of the discharge table is adjustable between 18 and 216 revolutions per hour by a variable voltage, variable frequency drives.

II.2.12 Coke Cooler System

Coke flows from the discharge table into an indirect coke cooler. This cooler consists of a rotor (hollow tube) which receives hot coke and a water bath in which the rotor turns. The rotor is designed with many pockets to maximize heat exchange area. Heat is exchanged from coke to rotor shell to water. A recirculating water system is supplied, which includes a water sump, coke cooler water bath, pumps (P-1A,P-1B,P-2A & P-2B), wet surface heat exchanger to cool the water.

III. Furnace

The shape of the furnace heating chamber is cylindrical with a diameter of 16.8 meters. The cylinder is in a vertical position. The top is closed by the roof, a flat suspended arch and the bottom by the hearth, which slopes (at 10% off the horizontal) towards the center of the furnace. The chamber height at the periphery is 1.825 meters. The flow of gases is from the periphery towards the vertical flue in the roof at the center of the furnace. The furnace roof, including rabbles and the upper portion of the sidewall, are stationary. The hearth, the lower portion of the sidewall and a large discharge chute at the center of the furnace called the soaking pit, rotate to move coke from the periphery to the soaking pit.

Furnace temperatures are monitored by eleven type **S** thermocouples (TE-100A, TE-100B, TE-100C, TE-100D, TE-100E, TE-100F, TE-100G, TE-100H, TE-100J, TE- 100K, TE100L) located in the roof. The furnace temperature is controlled by only one of these thermocouples, TE-100A. This thermocouple measure the temperature very close to the inlet to the waste gas uptake, which will be approximately 1468°C.

The soaking pit is located at the center of the rotating hearth. The soaking pit is a cone shaped with a 3.6 meter diameter at the hearth and slopes to a 0.965 meter diameter at the discharge table.

The depth of the coke in the soaking pit is measured with a rod lowered automatically through the calciner roof at the rabble pit. Once the rod contacts the material the cable holding the rod goes slack.

IV. Combustion System

IV. 1 Combustion Air

The combustion system consists of ten natural gas burners. Each burner is rated at 630,000 KCal/Hr. at 225 mm H_2O of combustion air pressure and 0.067 bar of natural gas pressure. Combustion air is supplied by the process air system.

Control of total process air (process and combustion air) is obtained by positioning the inlet vanes of the process air fan (001). The inlet vanes are positioned by an electric actuator (TY-101), which receives a control signal from the primary Calcinerthermocouple (100A) and the Furnace Pressure Indicating Transmitter (PIT 101). Balancing the quantity of air to each is done by manually.

IV. 2 Combustion Gas

Natural gas to the burner is owner provided at 2.5 kg/cm^2 at a maximum flow rate of approximately 650 Nm^3/hr. The pressure is reduced to 0.35 kg/cm^2 by a regulator. The flow of natural gas to the burners is controlled by pneumatic spring return actuator through a North American adjustable port valve. The pneumatic actuator is positioned by electro-pneumatic positioner with 4-20mA dc control input signal and two limit switches.

The flow of natural gas to the burners is measured by a transmitter across an orifice plate. The differential pressure on the orifice plate is 0.014 kg/cm^2 at a gas flow rate of 844 Nm^3/hr.

Gas Composition (percent volume): Working Fluid

H_2O : 22.1
N_2 : 68.2
CO_2 : 5.7
Ar : 0.8
O_2 : 3.1
SO_2 : 0.1

Gas flow (Nm^3/h): 58,000.
Gas inlet temperature (°C): 1,350.
Minimum gas outlet temperature (°C): 180.
Steam at outlet stop valve, pressure (bar): 75.
Steam at outlet stop valve, temperature (°C): 450.
Steam flow at outlet stop valve (ton/h): 40.36

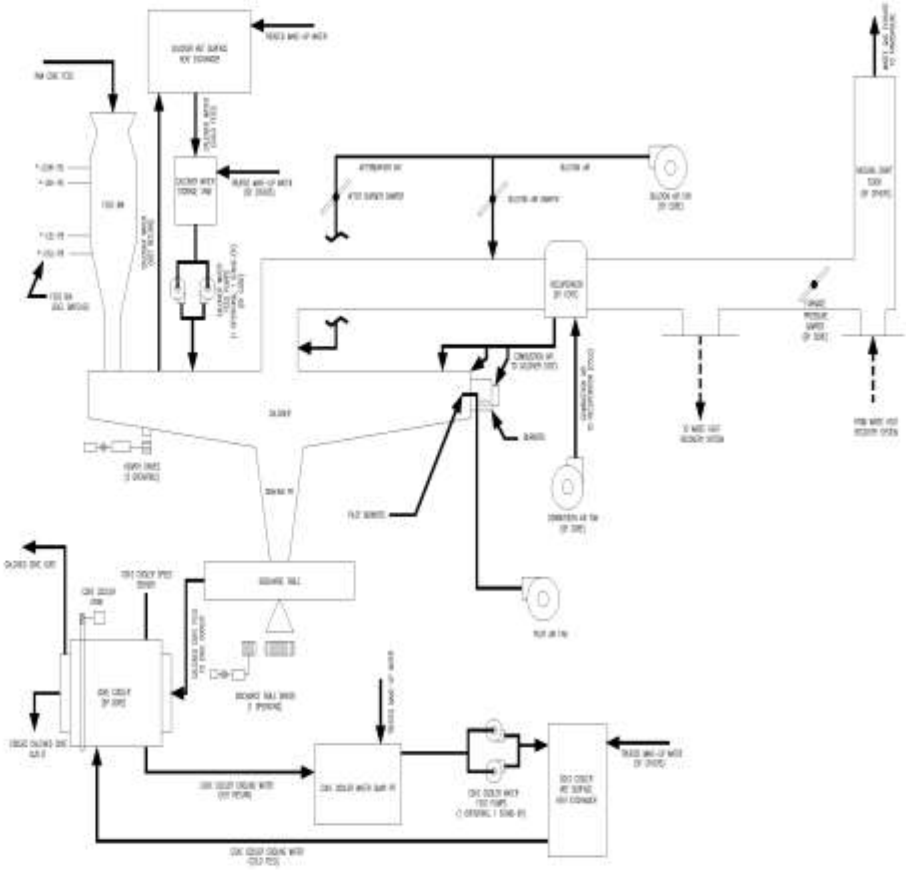

Fig.1: General Schematic Diagram of the CalcinerPlant in EgyptalumCompany

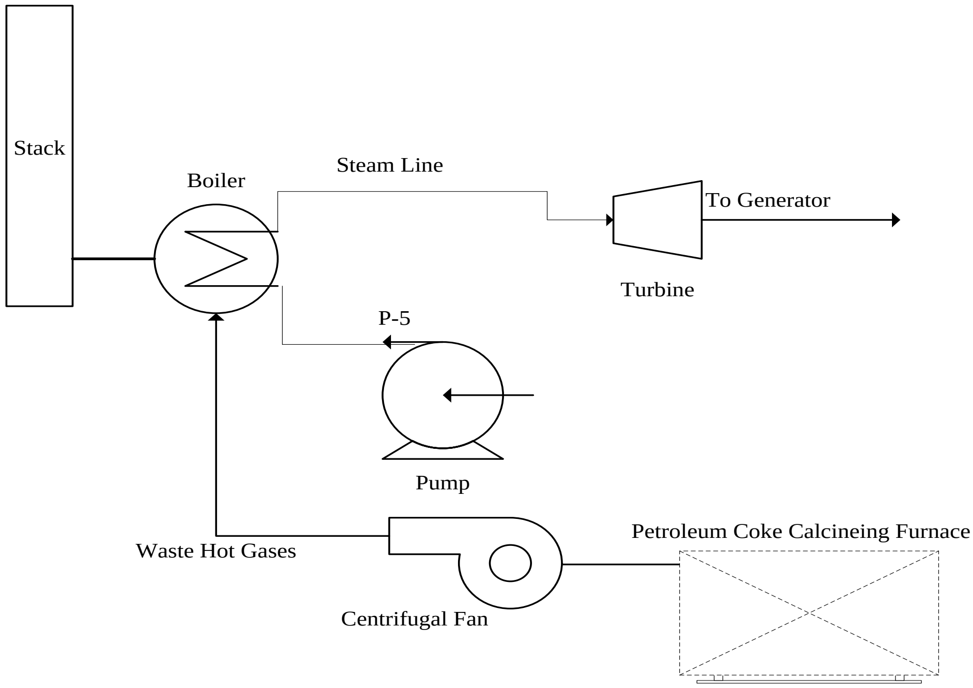

Fig.2: General Schematic Diagram of the Suggested Heat Recovery Plant

$\dot{Q}_{avialable} = \dot{Q}_g + \dot{Q}_{air}$(1)
$\dot{Q}_{\mathrm{g}} = m_g * \dot{m}_{\mathrm{coke}}[C_{p1}T_1 - C_{p2}T_2]$ (2)
Therefore, at a flow rate of 2.69 kg/kg of coke the heat is $Qg^{\cdot} = 14{,}462.17$kW.
Heat available from cooler vent hot air can be calculated from Eq. 3 as: The flow of hot air through the cooler vent is 1.938 kg/kg of coke or 1.5 Nm^3/kg ofcoke (164,106 Nm^3/hr), the available heat will be:

$$\dot{Q}_{hotair} = m_{air} * \dot{m}_{\mathrm{coke}}\,[h_{air1} - h_{air2}] \quad (3)$$

Where $h_{air1@T=285.85oC}$= 293.02 kJ/kg and $h_{air2@T=80^oC}$= 79.53 kJ/kg. Hence, at aflow of 1.938kg/kg coke the heat becomes $Q_{air}{}^{\cdot}$ = 12,573.67 kW. Therefore, the totalheat available from the calcination processing plant is $\dot{Q}_{avialable}$= 27,035.84 kW.When it is assumed that the overall efficiency of the system is to be 90% of thetotal available heat will be $\dot{\mathrm{Q}}$ available = 24,332.25 kW. However, how much of thisavailable energy can be recovered will be a result of technological advancement of the system or other physical, technical and operational factors. The main thing here is thatthe heat recovery system should be a type which tolerates a moderate to high dust level,so that the existing electrostatic precipitator and bag filter on the plant can be used afterthe gas and air got out of the boiler of the waste heat recovery system.

IIV. Heat Recovery Using Integrated System

The working principle of the integrated system is that both steams from the two heatsources will be mixed and entered into one turbine. This means that with the availabletemperature, the system can be designed by having a separate boiler for both fluids andthe water would first pass through the economizer section of the cooler hot air boiler forpreheating, then the water splits with a part going to the evaporator section of the PHboiler and the rest to evaporator section of cooler boiler and finally the steam rejoins inthe super-heater section of the PH boiler and enters the turbine. Figure 5 shows the typicalschematics of the system. Thermodynamically, the entering water to the condenser willhave a temperature of 36oC, both evaporators will have the same saturated steamtemperature of 120oC and finally the maximum super-heated steam temperature in the PHsuper-heater will be 280°C. Considering the hot gas and air from the heat sources, the PHexhaust gas with a temperature of 323.44oC gets in to the PH boiler through the super heater,and then leaves to the evaporator with a temperature of 200°C. On the other side,the cooler hot air gets in to the evaporator with a temperature of 285.85°C and leaves theeconomizer with a temperature of 80°C.

Using a steam table with the given parameters and assuming a 90% overall systemefficiency, the amount of steam produced from the cooler vent will be $\dot{m}_{s1}$=3.93 kg/sec. Similarly, assuming that all the available heat from the PH exhaust gas istransferred to the steam as a heat input with a 90% overall efficiency to the system , theamount of steam

produced will be $\dot{m}_{s2}$ = 4.52 kg/sec. The total steam produced istherefore:
$\dot{m}_s = \dot{m}_{s1} + \dot{m}_{s2}$= 8.45kg/sec.

The net work done by the system is calculated to be:
$W_{net} = W_T - W_P = \dot{m}\,(h_1 - h_2)$ = 5,258.1 kW
This shows that the actual gross power that can be harnessed from the system is about
5.26 MW. Therefore, the efficiency of the system is calculated to be:

$$\eta\text{Rankine} = \frac{\text{W net}}{\text{Qhot air} + \text{Q eg}} = 21.6\ \% \qquad (4)$$

This potential power generation and the calculated efficiency are in line to theranges given by Kemp I.C [4] andRonilRabari [5]. Let this system be an air cooledone, so the air flow which should be circulating in the sink will be calculated based onthe heat output from the condenser from Eq. 4. That is:

$$Q\text{c}_{ondenser} = (h_2 - h_3) = m_a C_{Pa}(T_1 - T_2)$$

where, ma – mass of circulating cooling air of the sink, Cp_w – Specific heat of water (0.24kcal/kg ^{o}C = 1.005 kJ/kg ^{o}C), T_1 - Temperature of air leaving the condenser(36.2^{o}C) and T_2 - Temperature of cooling air from the cooling tower at inlet of thecondenser (20^{o}C)

$$\text{ma} = \frac{\text{ms(h2} - \text{h3)}}{\text{Cpw (T1} - \text{T2)}} = 1{,}171.76\,\frac{\text{Kg}}{\text{Sec}}$$

IIIV CONCLUSIONS

1. The net power produced from the system is 4,839.20 kW, which is equal to 159.24 kJ/kg of coke (4.37%). This will increase the thermal efficiency of the kiln system from 46.22% to 50.59% and also covers 10.75% of the total electrical power consumption of the plant in to consideration.

2. The standard specific coal consumption for the technology ranges from 730-780 kcal/kg of coke. However, the current consumption of the plant as per the data gathered from the CCR during the study period is about 884 kcal/kg coke or 3.7 GJ/ton of coke on average. This shows that there is an excess of about 100 kcal/kg of coke or 418.6 kJ/kg of coke of coal consumption on the system.

3. Producing electricity with own power using waste heat from the process will reduce electrical consumption from national grid supply, which, on the other hand, decreases the cost of coke production and helps the company to be more competitive in today's unstable market.

4.Using integrated waste heat recovery system, the exit temperature at the preheater side will be reduced from 323oC to 200oC and at the cooler stalk from 286oC to 80oC. A water treatment plant with a capacity of purifying 40.3 m3/hr should be incorporated with the waste heat recovery system and the condenser should be an air cooled one. Considering the estimated initial investment for the water purification plant, the payback period is calculated to be less than 10 years, indicating its economic feasibility.

5. During the power interruption period, the company can make use of own generated power to keep the calciner mill (3.35 MW) and packer I (1.5 MW) running. The implementation of a waste heat recovery system avoids kiln heating up due to power interruption more than 2 hours and save some money. It also save the company's productive time around the kiln area during power shedding hours. The company can also save some electrical energy usage to the air mixer and cooling fan that would have been used to cool the exhaust gas and hot air from the preheater and cooler stalk before it enters the electrostatic precipitator and bag filter respectively.

6. Because the exhausts are already on the required temperature range after it leaves the WHR system. It is recommended that the Aluminum Company of Egypt encourages this waste heat recovery system implementation through tax exemption and other incentives, especially in aluminum industries because this sector is growing fast and there is a good opportunity from the heat that is easily released to the environment without any use.

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REFERENCES

[1] FengLia, "Research and application of flue gas waste heat recovery in cogeneration based on absorption heat-exchange", 8th International Cold Climate HVAC 2015 Conference, Procedia Engineering 146 (2016), PP. 594 – 603.

[2] Yanget. al., "High Temperature Materials and Processes", Volume 35, Issue 2, id.183, 6pp, Feb. 2016.

[3] Graves, Thesis (Ph.D.)--Columbia University, 2010.; Publication Number: AAT 3448327; ISBN: 9781124543222; Source: Dissertation Abstracts International, Volume: 72-05, Section: B, page: 281.

[4] Kemp I.C. et. al., "Pinch Analysis and Process Integration", 2nd edition, Elsevier December, 2006.

[5] RonilRabari et al. " Effect of Convection Heat Transfer on Performance of Waste Heat Thermoelectric Generator", Journal of Heat Transfer Engineering , Volume 36,Feb. 2015 - Issue 17, Pages 1458-1471.

[6] Xiaojun Shi et.al, "Thermodynamic analysis of an LNG fuelled combined cyclepower plant with waste heat recovery and utilization

system", International Journalof EnergyResearch, Elsevier, Volume 50, Issue 1, February 2013, Pages 364-373.

[7] M.F. Remeliet. al., "Power Generation from Waste Heat Using Heat Pipe and Thermoelectric Generator, Energy Procedia", Volume 75, August 2015, Pages 645-650.

[8] Karagoz, S. et. al., "Exhaust Gas Heat Recovery at an Engine Test Facility," SAE, World Congress and Exhibition, April 2016.

[9] Mori, M.et. al., "Concept for Improving Cost Effectiveness of Thermoelectric Heat Recovery Systems," SAE Int. J. Passeng. Cars - Mech. Vol. 9(1), April 2016, PP. 17-24.

[10] YaoPeng Li, et. al. "Numerical study on the combustion and emission characteristics of a methanol/diesel reactivity controlled compression ignition (RCCI) engine ", Elsevier, Applied Energy, June2013, Vol. 106, PP. 184-197.

[11] Hassam N. C., et. al, "A review of heat pipe systems for heat recovery and renewable energy applications", Renewable and Sustainable Energy Reviews, Volume 16, Issue 4, May 2012, Pages 2249–2259.

[12] MiklosKassai, "A Developed Method for Energy Saving Prediction of Heat-and Energy Recovery Units", Energy Procedia, Volume 85, January 2016, Pages 311-319.

[13] JunxiangLiuet. et. al.,"Thermal energy recovery from high-temperature blast furnace slag particles", International Communications in Heat and Mass Transfer, Volume 69, December 2015, Pages 23–28.

[14] Hassam N. C. et. al.,"A review of heat pipe systems for heat recovery and renewable energy applications",Renewable and Sustainable Energy Reviews, Volume 16, Issue 4, May 2012, Pages 2249–2259.

[15] B. Orra, et. al., "A review of car waste heat recovery systems utilizing thermoelectric generators and heat pipes", Applied Thermal Engineering, Volume 101, 25 May 2016, Pages 490–495.

[16] Khaledet. al., "Heating fresh air by hot exhaust air of HVAC systems", Elsevier Ltd, 2016, Vol. 8, PP. 398-403.