An Efficient Approach for Heat Recovery and Cogeneration

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Abstract: Cogeneration[1] and regeneration[2] have become a great concern in today’s world. It is the process of converting the exhaust heat from various steam power plants[3], boilers and sentence them into usable renovative form of energy[4]. In recent strategic form, it is found that for every power plant, the overall efficiency is much lesser than the percentage heat loss wasted into the atmosphere which may damage the surroundings. The practical form of heat recovery can be done by coupling the heat power plant or boiler to a gas turbine-generator and the waste steam from outlet of gas turbine can be directed to a steam turbine through a heat exchanger for secondary power generation. Hence this process can provide more power with low losses at operating condition. Regeneration is proposed in cars where the heat developed due to exhaust-engine set can be directed through a heat exchanger to absorption chill that produces cooled air for air-conditioning. Several other applications of regeneration such as power plants, engine systems have also been discussed in this paper. The merits and demerits of all the applications have also been studied in this paper.

Keywords: Absorption chill, Cogeneration, gas-turbine generator, power plant, regeneration.

I. INTRODUCTION

A. What is cogeneration?

Cogeneration (also combined heat and power, CHP) is the use of a heat engine or a power station to simultaneously generate both electricity and useful heat. All thermal power plants emit a certain amount of heat during electricity generation. This can be released into the natural environment through cooling towers, flue gas, or by other means. By contrast, CHP captures some or all of the by-product heat for heating purposes, either very close to the plant, as hot water for district heating with temperatures ranging from approximately 80 to 130°C. This is also called Combined Heat and Power District Heating or CHPDH[5].

Cogeneration was practiced in some of the earliest installations of electrical generation. Before central stations distributed power, industries generating their own power used exhaust steam for process heating. Large office and apartment buildings, hotels and stores commonly generated their own power and used waste steam[6] for building heat. Because of the economies and high cost of early purchased power, these combined heat and power operations continued for many years after utility electricity became available. Cogeneration is still common in pulp and paper mills, refineries and chemical plants.

II. SOURCES OF WASTE HEAT

Some of the sources of waste heat[7] are:
- Biomass Boilers
- Turbines
- HRSGs
- Combustion exhaust
- Excess steam
- Gas >300°F, Fluid >200°F, Steam >200°F
III. NEED FOR DEVELOPMENT OF WASTE HEAT RECOVERY SYSTEM

A. Understanding the process

Understanding the process is essential for development of Waste Heat Recovery system. This can be accomplished by reviewing the process flow sheets, layout diagrams, piping isometrics, electrical and instrumentation cable ducting etc. Detail review of these documents will help in identifying:

a) Sources and uses of waste heat
b) Upset conditions occurring in the plant due to heat recovery
c) Availability of space
d) Any other constraint, such as dew point occurring in equipments etc.

After identifying source of waste heat and the possible use of it, the next step is to select suitable heat recovery system and equipments to recover and utilise the same.

B. Economic Evaluation of Waste Heat Recovery System

It is necessary to evaluate the selected waste heat recovery system on the basis of financial analysis such as investment, depreciation, payback period, rate of return etc. In addition the advice of experienced consultants and suppliers must be obtained for rational decision. Next section gives a brief description of common heat recovery devices available commercially and its typical industrial applications.

IV. COMMERCIAL WASTE HEAT RECOVERY DEVICES

A. Recuperators

In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be pre-heated, the other side contains the waste heat stream. A recuperator for recovering waste heat from flue gases is shown in Figure 2

The simplest configuration for a recuperator is the metallic radiation recuperator, which consists of two concentric lengths of metal tubing. The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which now carries additional energy into the combustion chamber. This is energy which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading. The saving in fuel also means a decrease in combustion air and therefore stack losses are decreased not only by lowering the stack gas temperatures but also by discharging smaller quantities of exhaust gas.

B. Radiation/Convective Hybrid Recuperator

For maximum effectiveness of heat transfer, combinations of radiation and convective designs are used, with the high temperature radiation recuperator being first followed by convection type. These are more expensive than simple metallic radiation recuperators,
but are less bulky. A Convective/radiative Hybrid recuperator is shown in figure.4.

Fig.4 Convective Hybrid Recuperator

V. EXISTING SYSTEM

A. Voith SteamTrac

Modern combustion engines have a mechanical efficiency of approximately 40%. This means that 60% of the energy remain unused and are dissipated in the form of waste heat via exhaust gases and cooling water. With the waste heat recovery system developed by Voith[8], some of this energy can be recuperated.

1) Function

The operating medium is pressurized by a feed pump and delivered to the operating cycle. In a heat exchanger that is integrated in the exhaust gas system, the operating medium is heated, evaporated and superheated by the heat from the exhaust gas. The superheated steam is expanded in a piston expansion machine. This generates mechanical power, which can be transferred directly in the combustion engine or fed into the electric network via a generator. The expanded operating medium is condensed in the condensation heat exchanger and redirected to the operating medium tank in a closed cycle. The condensation heat exchanger is integrated in the cooling circuit of the cogeneration plant. This residual heat can be utilized further via a combined heat and power cycle, since the condensation takes place at the temperature level of the flow line of the cogeneration system. The entire process and the integration into the cogeneration plant is controlled and monitored by the Voith systems-control[9].

B. Voith SteamDrive

The SteamDrive has been developed specifically for retrofitting existing biogas plants or for plants where a direct link-up to the combustion engine is not possible. In order to save space, all components are arranged in the compact module, which consists of steam engine with generator, feed pump and feed water tank, condensation heat exchanger, as well as switch cabinet with control electronics and power electronics. The exhaust gas heat exchanger is directly integrated in the exhaust gas system.

VI. PROPOSED SYSTEM

A. In heavy duty machines

The main idea of the proposed system is to provide extra power in the vehicle using moderate temperature and pressure steam generated from two phase cooling and super-heated by an exhaust gas heat exchanger. The proposed system adopts nucleate two phase cooling concept for engine cooling and steam generation.

While the engine is running liquid phase during the cold start and warming up phase, the coolant liquid becomes the boiling phase and saturated steam is generated at medium and high load conditions. The separator separates the mixture of liquid and vapor generated in the boiling phase and only the liquid cooling water returns to the engine via an electric coolant pump. The saturated vapor separated in the separator is sent to a heat exchanger and superheated by the heat transferred from exhaust gases. The superheated vapor is expanded in the mini-turbine and generates the electric power for the vehicle. The saturated fluid at the exit of the turbine turns into liquids at the condenser. The combinatory control of electric water pump and
thermostat may achieve precise control of the liquid coolant flow rate to optimize the cooling load and maximize steam generation. The advantage of the proposed system is to gain extra power from both engine cooling loss and exhaust enthalpy with high efficiency and low cost.

B. Advantages of Nucleate boiling engine cooling systems over traditional cooling systems

Nucleate boiling[10] engine cooling systems have promising characteristics compared to traditional cooling systems. In Fig.6, once boiling starts at points A, the boiling can be categorized into three different regions. Nucleate boiling exists between A and C. In nucleate boiling region, isolate bubbles or jets form and separate from the surface. Heat transfer rates and convection coefficients become very high due to increased fluid mixing and evaporation. Two phase boiling passing C region undergoes transition to film boiling. Unstable region between C and D is termed transition boiling and oscillates between film and nucleate boiling. Film boiling exists after point D. At film boiling region, the surface is completely covered by a water vapor film and as the temperature increases, the surface condition rapidly changes into burnout conditions.

Fig. 6 Graph of nucleate boiling engine cooling systems

VII. APPLICATIONS OF THE PROPOSED SYSTEM

The recover use of heat loss through exhaust gases and waste can be efficiently improved by the following applications proposed for day to day life. Major applications are seen in power plants and boilers, and proposal to apply in car air conditioning system.

A. In power plants

Improved version of power plant heat recovery can minimize much heat loss due to exhaust gases by following method of secondary power generation:

- The proposed system consists of directing exhaust gases from gas turbine to a secondary steam turbine through a heat exchanger rather than emitting as a waste heat to atmosphere.
- This plan sufficiently consists of two turbines and two alternators rather than using one. The primary working of electric generation is self explanatory. The outlet of the first gas turbine is then sent to heat recover boiler which in turn accepts exhaust heat as fuel and convert those gases into super heated steam. This super heated steam trisected with ideal pressure to lateral uses, secondary power generation and innovative a/c system.
- The trisected super heated steam is directed to produce secondary power using any steam turbine usually with pressure condensing.

1) Advantages

- Though usage of more economic devices increases the cost, the overall heat efficiency is raised to 50-60% thus minimizing heat loss.
- More amount of power can be generated.

Fig. 7 Power plant heat recovery

B. In Automobiles

In automobiles, we propose the idea of recovering the exhaust heat to future use, rather converting them to power. The same power plant model with same circuit but it is implanted in a car system or automobile system. The trisected super heated steam from the boiler power plant is then directed to an absorption chill conditioner[11]. It’s a device that expands the pressure to vapor phase and then condenses into a chilled wet steam which is then coupled to an air-conditioner to get a chill air with less work.
1) Advantages

- The secondary advantage in the system is that giving a cooled air to a/c system may reduce its work input, henceforth increasing the system efficiency.

Fig. 8 Air-conditioning unit

- The proposed system of waste heat recovery to air conditioning system is shown. It can be implemented by fitting into the engine part and coupling with the a/c system device.

Fig. 9 Air-conditioning recover unit in car

C. In engine system

- In modern era, the usage of engine system and motor has evolved abruptly. Hence the minimal transformation of heat to recover in practical engines has the innovation here. The figure seems to be complex for viewing but the general idea of generation of power has again been discussed here.

Deviation:

- The major deviation of our system from other applications is that the exhaust renewal[12] is done separately and summed up at the end of the survey.
- It consists of exhaust turbine(for low work generation) and steam turbine (for boiler power). The low work turbine is connected to steam turbine by an over-speed shaft to relate equal work.
- It is based upon the fact that in a practical main engine, the overall exhaust gases are uniquely received and then sum up to enter the boiler configuration. This not only decreases the heat liberation but also produces enormous power.
- The FEEDBACK system of WORK at the output increases the engine work more and more, which again increases the overall power generation.

1) Merits

- Overall gain and efficiency is greater.
- Work output can be altered for the convenience of the power generators.

2) Demerits

- Efficiency may get reduced due to usage of more tubo-gen set.
- Engine life is very less.

Fig. 10 Engine system recovery

VIII. CONCLUSION

“Nothing is waste unless it is not operated”

A two phase cooling system for a waste heat recovery system has been tested and evaluated via engine experiments using a Perkins diesel engine[13]. As the saturated vapor pressure increases during two phase cooling, the cylinder head and coolant temperatures are also increased. Inspite of the partial
vapor pressure, the amount of heat liberated at the same pressure also matters the surroundings and exhaust the breathe air. Hence by the heat recovery, the power output may be increased and a surplus amount of work can be produced. The power output using waste heat recovery under the same engine operating conditions ranges from 0.47 KW ~ 1.05 KW. It is seen that the overall efficiency due to waste recovery is increased to upto 60%.

IX. REFERENCES


[8] Voith, “Utilizing exhaust heat through a steam cycle, Steam Trac and Steam Drive”.


