

Waste heat recovery system engineering essay



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Waste heat recovery system is the process of utilizing waste heat that is being produced in various heating processes. There is enormous heat that is being wasted by industries which affects the efficiency of the industry to a greater extent than any other factors. So, there is an inevitable need to solve this problem and make sure that the efficiency of the industry is increased.

High temperature heat recovery potential is available in many industries.

High temperature waste heat available can be utilized for generating power, heating water & air, increasing process temperature etc. Considering the acute shortage of power, this ready source can prove a boon to the industry in more than one way.

This project is carried out at Nava Bharat Ventures Limited (NBVL), Paloncha, and Khammam District in utilization of waste heat available from Submerged Electric Arc Furnace (SEAF) fuel gases by installing a Double pass heat exchanger (LPHX - Low Pressure Heat Exchanger and HPHX - High Pressure Heat Exchanger) in fuel gas path. Generally Main Condensate & Feed Water in Power Plant is heated in LP & HP heaters of Turbine regeneration cycle by drawing steam from Steam Turbine extractions.

In this project, Main Condensate & Feed Water will be heated in installed heat exchanger by partially/completely bypassing LP & HP heaters.

Therefore, the steam draw from Turbine extractions will come down/zero. As a result, the specific steam consumption of turbine will also come down and consequently the overall efficiency of the whole system is improved.

Chapter 1: INTRODUCTION

Waste heat is heat which is generated in a process by fuel combustion or chemical reaction, and then “ dumped” into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its “ value”. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved.

Large quantity of hot fuel gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat can be recovered, a considerable amount of primary fuel can be saved. The energy lost in waste gases cannot be recovered completely. However, much of the heat could be recovered and loss minimized.

Heat Losses -Quality

Depending upon the type of process, waste heat can be recovered at virtually any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or kiln. Usually the higher the temperature, the higher the quality and the more cost effective is the heat recovery. In any study of waste heat recovery, it is absolutely necessary that there should be some use for the recovered heat. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be practiced to ensure that the maximum amount of heat is recovered at the highest potential. An example of this technique of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for process feed water heating or steam raising.

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Heat Losses – Quantity

In any heat recovery situation it is essential to know the amount of heat recoverable and also how it can be used.

The amount of heat recoverable can be calculated as, $Q = V \times \rho \times C_p \times \Delta T$

Where,

Q is the heat content in kCal

V is the flow rate of the substance in m³/hr

ρ is density of the fuel gas in kg/m³

C_p is the specific heat of the substance in kCal/kg °C

ΔT is the temperature difference in °C

Development of a WHRS

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 an 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 utilize the same. (Reay, 1979)

The basic technique of the waste heat recovery is to capture the waste heat steams and, utilizing a heat exchanger, transfer that heat to another medium to put back into the process. The advantages of waste heat recovery are it can reduce facility's annual fuel bills, reduce plant emissions and improve productivity. In process heating, using waste heat will displace a portion of the fuel or electricity that would otherwise be purchased. Waste heat recovery is always a good idea when:

The temperature of the waste heat is hotter than the input requirements of the process.

The fuel savings achieved are greater than the capital and operational costs of the waste heat recovery equipment.

The value of the waste heat steam is determined primarily by its temperature. It is widely held that any waste heat stream (air or liquid) of at least 500oF (260oC) is a viable source for recovery. Obviously, the higher the temperature, the higher the quality or value of the waste steam. According to a recent Department of Energy (DOE) report, with stack temperatures of 1, 000oF (538oC), the heat carried away is likely to be the single biggest loss in the process. Above 1, 800oF (982oC), stack losses will consume at least 50 percent of the total fuel input to the process.

Equipment used for waste heat recovery:

The variety of equipment available for waste heat recovery includes recuperators, regenerators and waste heat and exhaust gas boilers/steam generators. The heat recovery process can be gas to gas or gas to liquid. The product of waste heat recovery can be preheated combustion air, hot water and steam. The hot water and steam can be used for plant services or as part of the original process heating. The steam can also be used to run steam turbines for mechanical work or to produce electricity.

A recuperator is a gas-to-gas heat exchanger placed on the stack of the oven or exhaust of a prime mover. Recuperator's transfer heat from the outgoing gas to incoming combustion air without allowing steams to mix. There are many designs for recuperators, but all rely on tubes or plates to transfer heat. They are the most widely used waste heat recovery devices.

A regenerator is basically a rechargeable storage device for heat. They can work with gas-to-gas, gas-to-liquid or liquid-to-liquid waste heat sources and can be installed on ovens, prime movers, chemical reactors and with steam condensate. A regenerator is an insulated container filled with material capable of absorbing and storing large amounts of thermal energy. During the first part of the cycle, the waste stream flows through the regenerator, heating the storage medium. The second part of the cycle has the un-heated stream flow through the regenerator, absorbing heat from the medium before it enters the process. The cycle then repeats itself. In continuous processes, two regenerators are required. As with recuperators, there are many designs for regenerators such as heat wheels, passive, fin-tube and shell-and-tube.

Waste heat and exhaust gas boilers/steam generators are similar to conventional boilers except they are heated by the waste heat steam from the process or prime mover rather than from their own burner. Waste heat boilers are of most value to process industries that require large amounts of steam in their process. The steam generated from a waste heat steam will not generally replace existing boilers but will supplement the steam that they produce, thereby reducing the energy cost to operate the direct-fired boilers. As the steam from a waste heat steam is available only when the process is running, waste heat boilers are generally designed to operate with existing boilers or with steam generators in a combination system. (Kessler, 2004)

Chapter 2: Literature Review

Waste heat may or may not be recovered from all the industries. This basically depends upon the amount of waste heat available in that particular industry and the economics involved in its extraction. The heat recovery that is done in some of the industries in India is discussed below.

Cement industry:

India, being the second largest cement producer in the world after China with a total capacity of 151. 2 Million Tons (MT), has got a huge cement industry.

In cement plants nearly 40 percent of the total heat input is rejected as waste heat from exit gases of preheated and grate cooler. This waste heat can be effectively utilized for electric power generation. Cogeneration of

power besides mitigating the problem of power shortage also helps in energy conservation as well as reducing green house gas emissions.

Cogeneration systems have been successfully operating in cement plants in India, China and South-east Asian countries. In existing plants cogeneration technologies based on bottoming cycles have potential to generate up to 25-30 percent of the power requirement of a plant. However, the Indian cement industry is yet to make strong efforts in this direction due to existence of various technical and financial constraints. (Gulf Coast Clean Energy Application center, 2008)

Sulphuric acid Plant:

Sulphuric acid required for a sulphonation reaction is produced in-house using elemental sulphur as the starting raw material. The process technology used for the purpose is Double Contact Double Absorption (DCDA) process. DCDA is considered to be the most efficient process technology (leading to practically almost zero atmospheric emission of sulphur bearing gases) for producing sulphuric acid. In the process of production of sulphuric acid using elemental sulphur as the starting material hot gas and hot acid streams get generated during various stages of the process. As a part of the process, traditionally the heat contained in the hot gas streams is recovered in the form of steam in waste heat boiler. The waste heat in the hot acid streams is low grade heat (temperatures being low) and is not recovered in all the traditional sulphuric acid plants. The extent of recovery of waste heat from the hot fluid streams, and the quantum of steam generated depends on the technical features of the process plant, the capital cost involved in the

process of heat recovery and the opportunity to use the recovered heat.

(Prakash, 2008)

Waste heat is being bigger than solar energy:

The typical industrial power plant in the U. S. is only about half as energy efficient as those used in 1910, according to Sean Casten, CEO of Recycled Energy Development (RED)

In fact, the ones Thomas Edison designed were more efficient. Edison's plants weren't actually very efficient as making electric power, Casten noted, but he sold the heat generated during operations, which boosted the overall. A full two-thirds of the fuel burned to generate power in today's power plants – which for the most part were built in the mid-1960s with 1850s technology – gets lost he asserts.

Although it can be tricky and expensive to harness, waste heat is getting increased focus as a source of power in both the U. S. and China, mostly because of the quantities of heat out there. A study conducted by Lawrence Berkeley National Labs estimated in 2005 that the U. S. alone has 100 gigawatts of untapped electrical capacity in the form of waste heat that annually could produce 742 terawatt hours of power. That's bigger than the solar fleet, which gets measured in megawatts. UC Berkeley's Arun Majumdar estimates that the U. S. consumes 100 quads (100 quadrillion BTUs) of energy a year and 55 to 60 percent of it gets dissipated as waste heat.

Generating that heat, naturally, also means excess greenhouse gases.

Approximately 42 percent of carbon dioxide emissions come from power

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plants, said Casten. If power plants are truly only 33 percent efficient, that means that 28 percent of the carbon dioxide output in the U. S. could be eliminated without crimping the national lifestyle. Cars only account for 19 percent.

Some companies, such as Cypress Semiconductor and GMZ Energy, are trying to develop thermoelectric materials. These are semiconductors that, wrapped around a steam pipe, could convert ambient heat to electricity.

Companies like Israel's Ormat and Westmont Ill.-based RED - which raised a \$1.5 billion fund with Denham Capital Management to take on waste heat projects - are largely focusing on the more traditional techniques. Namely, exploit excess steam pressure and heat to turn a turbine, power heating systems or boil more water. It all depends on the circumstances on the ground. Waste fuels can also be harvested.

While the bulk of waste heat is generated in large plants, there are also smaller pockets. Natural gas pipelines are equipped with booster stations which maintain the pressure inside the pipeline as the gas travels from one point to another. Each one on average requires 10 megawatts of power but gives off about 3 megawatts worth of waste heat.

"There are opportunities all over the place - silicon manufacturers, cement, steel," he said. "They have high volumes of fairly high quality waste heat."

One of the company's more dramatic projects will go online in 2010. West Virginia Alloys, a silicon manufacturer, will install a waste heat recovery system that will generate 45 megawatts of electrical power. The company

only uses 120 megawatts right now. (Put another way, the company only really needs 75 megawatts for its operations and is currently burning off 45 megawatts.)

To date, the big challenge has been cost. Most industrial-scale waste heat projects cost between \$5 and \$50 million. That's too high for most to pay out of capital budgets and too low for a public financing project.

"There's a huge Goldilocks problem," he said. To get around this, RED pays for any waste heat recovery system it installs and then gets paid for energy savings under long-term contracts. Goldilocks problem is nothing but finding the appropriate solution for the problem. (Kanellos, 2009)

Hence having looked at lot of examples and the past and the present of waste heat recovery, we can access that waste heat is not recovered in all the industries. It depends on the various factors as the amount of heat, the economics involved and the feasibility of the waste heat to convert into useful heat in that particular plant. The plant that I have looked at has that opportunity to convert waste heat into useful heat in all the perspectives.

Chapter 3: Methodology

Nava Bharat Ventures Limited has Electrical arc furnaces for production of Ferro alloys (Manganese, Silicon and Chromium alloys), which are essential inputs for manufacture of steel. Manganese and Silicon alloys impart strength and hardness and act as powerful deoxidizing agents, Chromium alloys make steel corrosion resistant and heat resistant.

The fume from the furnace is diluted with ambient air and cleaned by the gas cleaning plant before exhausted to atmosphere. One of the furnaces is equipped with radiant gas cooler. It is intended to save the heat, which is dissipated from the radiant cooler. It is proposed to install a double pass heat exchanger (LPHX-low pressure heat exchanger and HPHX-high pressure heat exchanger), that transfer the waste heat to Main condensate and feed water before the main condensate and feed water are preheated in the LP & HP heaters of 32MW Captive Power Plant.

Chapter 4: Findings

Ferro Alloy Plant arrangement:

The plant consists of the Submerged Electric Arc Furnace (SEAF), Bag filter, Radiant Gas Cooler, ID fan and Stack.

The submerged arc furnace is a semi open furnace with a capacity of 27.6 MVA, in which the ores are melted. The off gas is emitted from the furnace. The quantity of the gas varies depending on the raw material. The dilution air is drawn from the openings around the furnace by the effort from ID fan, which is located at the downstream of the radiant gas cooler.

There are two chimneys directly connected to water-cooled furnace hood. These two chimneys are provided with butter fly dampers, which are normally kept under closed condition. Each chimney is provided with the branch connection to radiant gas cooler below the butter fly dampers. Under normal circumstances the gas goes through the radiant gas cooler.

Radiant gas cooler is an arrangement of gas carrying pipes. The heat from the gas is cooled by the natural radiation and convection to ambient air.

The gas after cooling is drawn by the ID fan and sent to the bag house to remove the dust in the gas stream. The bag house is provided with reverse air fan to clean the dusty bags. The bag house is with eight compartments out of which one compartment will be under cleaning at any time. The bag material is fiberglass.

Manufacturing Process:

The above alloys, known as bulk Ferro alloys, are manufactured by charging pre-determined quantities of raw materials consisting of ores, reductants and fluxes into submerged electric arc furnaces. The mix of raw materials depends on the specification of Ferro alloy to be produced.

High currents at low voltage are passed through the three electrodes of the furnace and the charge of raw materials. The resistance offered by the raw materials to the flow of electricity creates immense heat, resulting in smelting of the raw materials charged into the furnace and the consequent metallurgical reactions takes place.

Carbon in the reductant reacts with the oxides in the ores. The metallic content of the ore forms a Ferro alloy while the other gangue materials become slag. Both the Ferro alloy and the slag are in liquid form because of the high temperature in the furnace bath. Due to difference in densities the alloy and slag are separated. The density of slag is lower than the liquid metal, slag floats to the top.

At periodic intervals, the molten metal and slag are tapped out from the furnace bath through a tap hole. The liquid slag is granulated by impingement against a jet of water in case of Ferro chrome and Silico Manganese. The Ferro Manganese slag is reused for the production of Silico Manganese due to its high Manganese and low Phosphorous content.

The granulated slag is used for manufacture of fly ash bricks and concrete rings.

The liquid metal (i. e., the Ferro alloy produced) is collected in a ladle and cast into moulds in a continuous casting machine or powder beds as a cake. These cakes, after cooling, are broken down to the size specified by the customer, depending on the metallurgical practices followed by the customer. The sized material is packed in bags of 50 kilograms for domestic markets and one tone or loose for export markets in general and dispatched to the customers.

Thermal Power Plant arrangement:

Thermal Power Plant mainly consists of Boiler, ESP (electrostatic precipitator), Steam Turbine, Generator, Condenser, LP heater, HP heater, Boiler Feed Pump, Condensate Extraction Pump, Deaerator, Cooling Tower, CW (clockwise) & ACW (anticlockwise) pumps, Water treatment plant, Coal and ash handling plant.

Process of Power Generation:

The Thermal Power Plant employs steam turbine based power generation, which is the most widely used method for production of electricity from coal.

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In this system, water is used as a working fluid and is heated in a Boiler by burning coal, to produce steam, which, on further heating, becomes superheated steam having a high temperature of 530°C and a high pressure of 93 kg/cm². This superheated steam runs the turbine, which converts heat energy into mechanical energy and drives an electrical generator coupled to it. The generator converts the mechanical energy into electric power.

The auxiliary system includes circulating water system, ash collection and ash handling system, coal handling system, electrical switchgear, transformers, etc.

The required coal is crushed and screened in the Coal Handling Plant with the help of crushers & screens. This crushed coal is transported to boiler bunkers through conveyors. From the bunkers, the coal is fed into the boiler furnace.

Necessary air for combustion is pumped into the furnace by Primary and secondary air fans. Primary and Secondary air are heated in Air Pre-Heater by utilizing waste heat in fuel gases before fed to furnace for improving the Boiler efficiency and the fuel gases are exhausted to atmosphere through ESP & Chimney.

Ash collected after combustion of coal in two different locations. One is under bed and the other is at ESP. Ash collected under bed is called as bottom ash or bed ash, which is conveyed to ash pond through slurry system and Fly ash at ESP is conveyed pneumatically to ash storage silo.

Required feed water in Boiler for steam generation is pumped from water treatment plant with the help of Boiler Feed Pump.

The steam turbine is a totally condensing type. After passing through the turbine, the steam is condensed to water in the condenser and pumped back to the boiler. This cycle is repeated. There are no discharges from this system except a very minor quantity of steam blown out of the steam circuit to maintain the technical quality of boiler feed water.

The steam Turbine has three extractions, one is for HP heater to heat the feed water, second is for Deaerator to deaeration process and third is for LP heater to heat the main condensate.

The cooling water system for condensing the steam is of circulating type. From the cooling tower sump, cool water is pumped to the turbine condenser where it picks up heat while condensing the steam and is pumped back to the cooling tower for cooling.

Waste Heat Recovery System

The company (NBV) has installed a heat exchanger to utilize the heat available in the furnace fuel gases, for heating the boiler feed water and main condensate of 32 MW Captive Power Plant located in the same premises. The heat exchanger is of cross flow type with two passes. The first pass is called as HPHX and the second pass is called as LPHX. The fuel gases are passed vertically downwards over bundles of horizontal water tubes in HPHX and upwards in LPHX. Feed water and main condensate are heated in HPHX and LPHX respectively. The flue gas coming from the furnace passes

over HPHX first, later over LPHX and finally enters Gas Cleaning Plant (GCP) through an ID fan.

WHRS is meant for utilizing the waste heat available in Submerged Electric Arc Furnace (SEAF) fuel gases. It is installed in the down stream of furnace. This system consists of Low Pressure Heat Exchanger (LPHX) and High Pressure Heat Exchanger (HPHX) to heat the main

Condensate and feed water.

Constructional Features:

WHRS mainly consists of ducting from SEA furnace to heat exchanger, double pass Heat exchanger, Ducting from Heat exchanger to GCP ID fan, Feed water & Main condensate lines from Power Plant.

Ducting from furnace to Heat exchanger: Submerged Electric Arc Furnace (SEAF) is having two chimneys of diameter 2000mm each with 65Mtrs height. A tap off (size 2000mm) diameter from each chimney is taken horizontally at (+) 26. 50Mtr elevation and made a common duct. After tapings, pneumatic operated isolation dampers are provided in two chimneys. The other end of common duct is connected to inlet of Heat exchanger. The diameter of common duct is 3000mm. One dilution damper of size 800mm is arranged in common duct to dilute the flue gas with fresh air.

Double pass Heat exchanger: It is a two - pass cross flow type heat exchanger. First pass is called High Pressure Heat Exchanger (HPHX) and the second pass is called Low Pressure Heat Exchanger (LPHX). HPHX & LPHX

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consists of 3 modules each and having water tube coils inside the casing. Fuel gases are passing over the water tube coils during operation. A by-pass duct (1000mm diameter) with regulating isolation damper is provided in between HPHX & LPHX. Insulation material of 175 & 125mm thick is provided on HPHX & LPHX respectively.

Ducting from Heat exchanger to GCP ID Fan: It is 2200mm diameter. LPHX bypass duct is connected to the outlet duct. Outlet duct is provided with one temperature transmitter & one draft transmitter. The ID fan inlet is having a multi lower damper for controlling the flow rate.

Feed Water line: A tap - off is taken from Power Plant feed water line after HP heater with a motor operated isolation valve (with bypass valve) and connected to HPHX. The outlet from HPHX is connected before the control valve in Power Plant feed water line with a motor operated isolation valve. One HPHX by-pass motor operated valve is provided near control valve. Insulation material of 75mm thick is provided over the complete piping.

Main Condensate line: A tap - off is taken from Main Condensate line of Power Plant after LP heater with a motor operated isolation valve (with bypass valve) and connected to LPHX. The outlet from LPHX is connected before the control valve in Power Plant Main Condensate line with a motor operated isolation valve. One LPHX bypass motor operated valve is provided near control valve. Insulation material of 50mm thick is provided over the complete piping.

Process:

Feed water coming from the Boiler Feed Pump with a temperature of 155OC is heated in HPHX with 380OC of fuel gas coming out from SEA furnace, then the feed water temperature increases to 225OC and the fuel gas temperature comes down to 226OC. This feed water line is connected to the Boiler for steam generation.

Main Condensate coming from Condensate Extraction Pump through Steam Jet Ejector & Gland Steam Condenser with a temperature of 89OC is heated in LPHX with a 226OC of fuel gas, then the Main Condensate temperature will rise up to 123OC and the flue gas temperature will come down to 160OC. This outlet of Main Condensate is connected to Deaerator inlet piping.

The flue gases are discharged to atmosphere, after utilizing the waste heat available in flue gases through chimney with the help of ID fan.

The extraction steam for HP & LP heaters will be cut off from Turbine i. e. HP & LP heaters are bypassed, while Waste Heat Recovery System is in service.

Chapter 5: CONCLUSIONS

The objective of this project was to design a Waste Heat Recovery System (WHRS) for Nava Bharat Ventures Limited. The existing system was examined and found 1. 25 x 10⁷ kCal/hr of waste energy is reject to the environment from Sub - merged Electric Arc Furnace (SEAF).

Different methods of heat recovery were examined to determine which are most feasible with the NBVL. 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.

When calculating energy savings and payback periods for heat recovery units, it is important to compare heat recovery with the current source of energy for generating thermal energy, which may be a low-price fossil fuel such as natural gas.

The aim of installing a new energy recovery system at Nava Bharat Ventures Ltd was to be able to reduce fuel cost and increase Steam Turbine heat rate caused by heat being lost to the environment. Simultaneously, the GDP ID fan power consumption will reduce, life of GCP bags is increased by reducing the gas temperature at GCP inlet and thermal pollution also will reduce.

A Double pass Heat exchanger was selected and designed to recover heat from exit fuel gases of SEAF system and heat the Feed Water and Main Condensate by utilizing the waste energy available in fuel gas.

The main focus of this project was to reduce the cost of energy bills by reducing the amount of fuel used to heat the facility.