# Energy Audit Calculations for Heat Exchanger of Captive Power Plant and Recommendation for Energy Conservation

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***Abstract***— **The energy audit is an inspection, survey and analysis of energy flows for energy conservation in a process or system to reduce the amount of energy input into the system without negatively affecting the outputs. When the object of study is reducing energy consumption while maintaining or improving human comfort, health and safety are of primary concern. Beyond simply identifying the sources of energy use, an energy audit seeks to prioritize the energy uses according to the greatest to least cost effective opportunities for energy savings. Energy audit is a technique used to establish pattern of energy use; identify how and where loses are occurring; and suggest appropriate economically viable engineering solutions to enhance energy efficiency in the system studied. [1]**

***Index Terms***— **Captive Power Plant, Energy Audit, Heat exchanger calculation, Recommendation**

## I. INTRODUCTION

In systems involving heat transfer, a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant. Condensers are typically heat exchangers which have various designs and come in many sizes ranging from rather small (hand-held) to very large industrial-scale units used in plant processes. [2]

Heat exchangers are equipment that transfers heat from one medium to another. Shell and tube heat exchanger are used extensively throughout the process and power industry and as such a basic understanding of their design, construction and

performance is important to the practicing engineer. The proper design, operation and maintenance of heat exchangers will make the process energy efficient and minimize energy losses.

## II. PURPOSE OF THE PERFORMANCE TEST

Heat exchanger performance can deteriorate with the time, design operation and other interferences such as fouling, scaling, corrosion etc. it is necessary to assess periodically the heat exchanger performance in order to maintain them at a high efficiency level. This section comprises certain proven techniques of monitoring the performance of heat exchangers, coolers and condensers from observed operating data of equipments.

The objective of performance assessment is to determine the heat exchanger duty, overall heat transfer coefficient, heat exchanger effectiveness, process/utility side pressure drop. Any deviation from the design will indicate occurrence fouling. [3]

**Heat Exchanger Effectiveness**

The heat recovery capability of a heat exchanger is characterized by means of an index referred as the "Heat Exchanger Effectiveness", is a measure of thermal performance.

Calculating the heat exchanger effectiveness helps, engineers.

(1) To predict how a given heat exchanger will perform a new job.

(2) To predict the stream outlet temperatures without a trial-and-error solution that would otherwise be necessary.

Definition:

The heat exchanger effectiveness is defined for a given heat exchanger of any flow arrangement as the ration of the actual amount of heat transferred to the maximum possible amount of heat that could be transferred between the two streams with an infinite area.

The latter is the rate of heat transfer that would occur in a counter-flow exchanger having infinite heat transfer area. In such an exchange, one of fluid streams will gain or lose heat until its outlet temperature equals the inlet temperature of the other stream. The fluid that experience this maximum temperature change this maximum temperature change is the one having the smaller value of C= mass flow rate X specific heat capacity at constant pressure, as can be seen from the energy balance equations for the two streams. Thus, if the hot fluid has the lower value of C, we will have $T_{ho} = T_{ci}$ and:

$$Q_{\max} = WXC_{ph}X(T_{hi} - T_{ci}) = C_{\min}X(T_{hi} - T_{ci})$$

Where



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$Q_{max}$ is Heat transferred (kCal/hr)
$T_{hi}$ is Hot fluid in (K)
$T_{ci}$ is Cold fluid in (K)

A. *On the other hand, if the cold fluid has the lower value of C, the* $T_{co} = T_{hi}$ *and :*

$$Q_{max} = WXC_{pc} X(T_{hi} - T_{ci}) = C_{min} X(T_{hi} - T_{ci})$$

Thus in either case

$$Q_{max} = C_{min}(T_{hi} - T_{ci}) = C_{min} X\Delta T_{max}$$

Where

$$\Delta T_{max} = (T_{hi} - T_{ci})$$

is the maximum temperature difference from the terminal stream temperatures.

By definition the effectiveness, $\in$, is given by:

$$\in = \frac{Q}{Q_{max}} = \frac{Q}{C_{min} X\Delta T_{max}}$$

Heat capacity ratio(r) = $\frac{C_{min}}{C_{max}} = \frac{WXC_{ph}}{WXC_{pc}}$

It should be emphasized that the term effectiveness may not be confused with efficiency. The use of term efficiency is generally restricted to

(1) The efficiency of conversion of energy from A to energy form B or

(2) A comparison of actual system performance to the ideal system performance, under comparable operating conditions, from energy point of view.

Since we deal here with a component heat exchanger and there is no conversion of different forms of energy in a heat exchanger (although the conversion between heat flow and enthalpy change is present), the term effectiveness the efficiency of a heat exchanger. The consequence of the first law of thermodynamics is the energy balance, and hence the definition of the exchanger explicitly uses the first law of thermodynamics.

For air-to-air heat exchangers, when the two streams have the same mass flow (such as the case of make-up air system), the expression for the effectiveness referred to as the efficiency) can be further simplified to:

$$\in = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}}$$

Heat Capacity ratio= $\frac{T_{co} - T_{ci}}{T_{hi} - T_{ho}}$

If the effectiveness of a heat exchanger is 0.5, this does not mean that heat exchanger is only 50% efficient in its transfer of thermal energy. By conversion of energy, any energy that is loss on one side must be gained on the other so in that way we would say them as 100 % efficient. But the effectiveness is actually just a measure of the ability if a heat exchanger to exchange temperatures. [4] [5]

If a perfect counter flow heat exchanger should be able to get the two fluids to swap temperatures (assuming the same fluid and mass flow rate). If a= 50 ºC air and b= 90 ºC air going through a perfect heat exchanger, then we should get a= 90 ºC air and b=50 ºC air out of it. 50% effective would give 70 º C airs out from both streams.

## III. ENERGY AUDIT

Instrumented and diagnostic energy audits (with aims ranging from identifying ways of conserving energy to evolution of a new print for the energy system) provide insight into the modes of better utilization of fossil resources and high-grade energy and exploration of renewable energy options. [6]

The general methodology of instrumented and diagnostic energy audit consists of the following:

Preliminary data analysis
Measurement at site
Data analysis

Recommendations based on economic viability- short term, medium term and long term measures. Instrumented and diagnostic energy audits have resulted in identification of energy saving of 5-10 % in energy intensive power plants establishments. And also provides consultancy for implementation of the energy saving measures by operational optimization, overhauling of equipment and by replacement by new equipment, processes and energy conversion routes. [7]

## IV. RECOMMENDATIONS

Three are five major energy saving areas having maximum potential. [8] [9]

1. Energy capture from process waste heat streams.
2. Minimization of boiler and boiler plant losses - Flue gas temperature reduction, combustion improvement, excess air control, minimizing boiler surface heat losses, avoiding losses through air pre-heater leaks, selecting boiler water treatment program, which minimizes blow-down and thereby its corresponding heat loss and minimizing losses due to plant start ups associated with Unit tripping by adopting integrated steam and load shedding logics and heat and condensate recovery from steam traps.
3. Installing variable frequency units on major power intensive equipment drives.
4. Installing steam drives and switching over from motor drives.
5. Using waste heat for powering refrigeration and air Conditioning units using vapor absorption.

**1. Energy capture from waste heat streams:**

If one looks around for associated processes, one could come across several wastes heat streams either being let down to atmosphere or to cooling water. In many cases hot product streams are being sent to storage/storage tanks. This energy rich product or material streams offer excellent scope for recovering energy by suitable means. As an example, recovering heat from kerosene product going to storage with demineralised water used as dearator make-up can result in significant savings in stripping steam of power plant dearators. [10]

**2. Minimizing boiler heat losses:**

Critically evaluating various types of heat losses of a boiler presents scope for minimizing the same. [11]

A) One of the criteria for determining flue gas exit temperature to be set in a boiler is the sulfur content in fuel



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fired. Whenever there is scope for reducing this sulphur content and whenever the boilers are operated at less than design loads, it is possible to bring down the flue gas exit temp. However, this temperature should not fall less than sulphur dew point temperature at cold end zones, which has the potential for cold-end corrosion. By carefully monitoring these cold end zone temperatures using on-line thermo-couples and replacing conventional primary air preheater tubes with corrosion resistant tubes it is possible to effectively sustain reduction in flue gas temperatures.

B) Dry flue gas losses can also be minimized by an automatic combustion controller, which is useful for a continuously varying load scenario. However, on-line oxygen sensors and transmitters can sometimes malfunction. Regularly calibrating or cross checking the same with relatively inexpensive hand-held or portable type flue gas analyzers can overcome this problem.

C) Another area for improvement in heat transfer efficiencies of boiler heat transfer surfaces is adoption of Magnesium Oxide based fuel additives. This is particularly effective if the fuel contains higher amount of vanadium, which forms low melting ash, which is tenacious and scale like. MgO dosing makes these scales more friable after which they can be easily removed by soot-blowing.

D) It pays to monitor surface temperatures of boiler insulation using a temperature gun. By replacing sections of worn out insulation, radiation losses can be minimized.

E) By monitoring flue gas oxygen before and after air pre-heaters, it is possible to quantify the combustion air bypassing the boiler furnace. This loss in combustion air leads to increased fuel consumption on account of reduction in combustion air temperatures as well as losses in fan power as the fan has to now supply more air for meeting the boiler load. Regularly monitoring flue gas helps to take early corrective actions and savings.

F) Minimizing heat loss through blow down. Very High pressure boilers require ultra-low TDS in their feed water make-up. Demineralised quality make-up water with mixed bed as polisher followed with boiler water treatment that contributes minimum solids, will help in maximizing cycles of concentration without necessitating to give frequent blow down, thereby saving on heat and water make-up.

G) Frequent trip outs/black-outs of power plants are associated with significant costs. Some of them are cost of start-ups, product reprocessing costs, costs on lost productivity and costs associated with deterioration of equipments and life of process catalysts to name a few. It is therefore essential to design and implement a robust load cum steam shedding system to take care of such eventualities, which cuts off non-critical loads for saving Power Plant and Essential Units.

H) Whenever 2 Power Plants are located nearby, it is beneficial to interconnect associated facilities such as feed water, steam headers and associated utilities. By doing this, cost of internal steam can be brought down since the facility is now optimized. In such cases it is possible to stop one boiler feed pump from operating by interconnecting feed water heaters, thereby saving enormous pumping energy.

I) Heat and condensate recovery from steam traps. Condensate steam traps located within the Power Plants, inside process units as well as in interconnecting pipe racks provide opportunities for recovering sensible heat as well as demineralised grade boiler make-up water. Recovery schemes can be engineered in-house, while taking certain precautions such as segregation of condensate streams of different pressure levels and sizing the headers to allow for 2-phase owe. Pumping of flashed steam condensate can be achieved through commercially available steam pressured pumps, which offer energy benefits as compared with motor driven pumps.

J) Good practice dictates that stack temperature be kept as low as possible without causing cold end corrosion.

K) Repair the broken or corroded baffle that could be bypassing the hot gas to the stack.

L) Decrease soot deposits on heating surfaces by improving fuel combustion efficiency.

M) Decrease soot deposits on heating surfaces by improving fuel combustion efficiency.

**3. Installing variable frequency units on major power intensive equipment drives:**

Areas where VFDs can be employed are forced draft fans and boiler feed pumps, which are major power consumers. Where 2 Fans are provided, one of the fans can be an ordinary drive operating at full load, while the other can be on VFD, modulating the speed based on boiler load. Adopting VFD in boiler feed pumps can minimize throttling of boiler feed control valves. Another application is cooling tower fans, where the set point for cooling water supply temperature can be maintained at web-bulb temp minus design approach. [13]

**4. Installing steam drives and stopping motor drives where feasible:**

Applications for steam drives within power plant can be boiler feed pumps, combustion air fans, condensate extraction pumps, cooling water pumps, fuel oil pumps etc. Steam drives offer significantly higher direct energy savings, since power generation is a relatively inefficient process compared with steam generation and at the same time improving cogeneration efficiencies due to enhanced extractions. It is relatively easier to adopt steam drives during conceptual stages/configuration of a power plant.

5. Using waste heat for refrigeration and air condition (A/C) requirements using Vapor Absorption Machine.(VAM):

Conventional A/C Units are motor operated compression chillers systems. With changing dynamics of global energy scenario and focus on energy conservation efforts, VAM stands to gain importance. These machines relate to solutions for ever increasing power cost, unreliable power scenario and CFC emission issues. Common sources of energy for VAM are exhaust from gen-sets, waste/vent steam, hot water, steam condensates or even fuels like Natural Gas, LDO and FO. With VAM, Power consumption can be drastically reduced as compared to operation of compressors of vapor compression systems and limiting the same to auxiliary pumps, which consume only a small fraction of the power. In addition depreciation benefits can also be availed, making these projects attractive by having a faster payback. [14]

## V. Conclusion

On basis of above calculation and recommendation we can say that any part of power plant (like boiler, turbine, heat exchanger) efficiency is not affected by its own parameters only. There are so many parameters are in the cycle which



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are jointly effect on all parts of the plant. So if lost is happened any one of the parameters, we must resolve that issue as soon as possible otherwise control loops will work fine but energy and money loss will increases.

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