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Methods of Quantifying Energy Losses During Energy Auditing in Chemical Process Industries

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ABSTRACT

Energy audit is the key to a systematic approach for decision-making in the area of energy management. Energy audit will help to understand more about the ways energy and fuel are used and help in identifying the areas where waste can occur and where scope for improvement exists and to retrofit for energy conservation equipment etc. Energy audit can be classified into two types namely preliminary audit and detailed audit. This study deals with mythologies to quantify the energy losses both electrical and thermal energy and provide the help in comprehensive energy auditing to establish the conclusion to arrive the retrofit equipments and also to arrive the optimum conditions particularly the boiler operations. The equipment considered for retrofit to the rotary equipments such as pumps, fans and compressors in the chemical process industries in which energy saving can be achieved are variable speed drives. Variable speed drives operation can be understood from the affinity laws. The example an energy saving in forced draft fan and induced draft fan in a boiler which produces steam for the process are considered and discussed. A quick method of combustion calculations and the theoretical air requirement by graphical method is given. Primary and secondary air blowers supply air required for the good combustion of coal in a balanced draft maintained in the furnace is discussed.

Key words: Variable speed drives, excess air in boiler combustion

INTRODUCTION

The fundamental goal of energy management is to produce goods and provide services with the least cost and least environmental effect. Energy audit is the key to a systematic approach for decision-making in the area of energy management. It attempts to balance the total energy inputs with its use. It quantifies energy usage according to its functions. Industrial energy audit is an effective tool for energy management. Energy audit is the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption. In any industry, the three top operating expenses are found to be energy (both electrical and thermal), labour and materials (Hunt, 1979). Energy audit will help to understand more about the ways energy and fuel are used and help in identifying the areas where waste can occur and where scope for improvement exists and to retrofit for energy conservation equipment etc. The type of energy audit to be performed depends on function and type of industry. Thus energy audit can be classified into two types namely preliminary audit and detailed audit. Preliminary energy audit is a relatively quick exercise to establish energy consumption in the organization and to estimate the scope for saving. Detailed energy audit methodology is a comprehensive audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems. It considers the interactive effects of all projects, accounts for the energy use of all major equipment and includes detailed energy cost saving calculations and project cost. In a comprehensive audit, one of the key elements is the energy balance. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated use is then compared to utility bill charges.

This study deals with mythologies to quantify the energy losses both electrical and thermal energy and provide the help in comprehensive energy auditing to establish the conclusion to arrive the retrofit equipments and also to arrive the optimum conditions particularly the boiler operations.

THE RETROFIT EQUIPMENTS

The equipment considered for retrofit to the rotary equipments such as pumps, fans and compressors in the chemical process industries in which energy saving can be achieved are variable speed drives. Variable speed drives operation can be understood from the affinity laws. To obtain the horse power requirements for the variable speed methods, we can use the affinity laws:

$$\frac{Q_2}{Q_1} = \frac{N_2}{N_1}; \frac{P_2}{P_1} = \frac{N_2^2}{N_1^2}; \frac{HP_2}{HP_1} = \frac{N_2^3}{N_1^3} \tag{1}$$

Where:

N = Pump or blower speed (rpm)
Q = Flow ($m^3\ sec^{-1}$)
P = Pressure (m of Head)
HP = Horse power

From these laws, we can see that the flow is directly proportional to the speed of the rotating equipments therefore we can directly relate the percent flow to percent speed of the pump and blower. But the horsepower is varying with cube of the speed. There are two general methods widely used to vary flows. One method is throttling which change the system curve by the use of a control or throttling valve. The other method is variable speed control of the pump which modifies the pump curve. In comparison, the variable speed method takes the advantage of the change in pump characteristic that occur when the pump impeller speed is changed. We have to make a note in this method is that the pump head decrease as the speed is decreased hence we can vary the speed with in the permissible operating conditions. There are several types of variable speed drives that could be used with fans and pumps. These include adjustable frequency drives DC drives, eddy current drives, variable pitch drives, Wound rotor motors etc. For example we will consider an energy saving in FD (Forced draft) fan and ID (induced draft fan) in a boiler which produces steam for the process with the following operating conditions:

Boiler steam production rate	=	$65\ t\ h^{-1}$
Fuel fired	=	1:2
Excess air	=	30%
Air required	=	$57319\ m^3\ h^{-1}$

Design flow of FD	=	92988 $m^3\ h^{-1}$
Design shaft power	=	12 kW

According to the affinity law:

$$\frac{HP_2}{HP_1} = \frac{Q_2^3}{Q_1^3}$$
$$\frac{HP_2}{HP_1} = \frac{(57319)^3}{(92988)^3} \tag{2}$$
$$HP_2 = 26.24\ kW$$

Actual present power consumption	=	99 kW
Power saving expected	=	(99-26.24) = 43.7 kW
Energy saving for 200 days of operation with Rs.5.0 per kW (Approx.)	=	Rs 1,048,800
Cost AC variable speed drives	=	Rs 15, 00000
Payback period	=	1500000/1048800 = 1.43 years

Similarly the energy saving in ID by providing variable speed drives:

Flue gas quaintly generated	=	105547 $m^3\ h^{-1}$
Design capacity of ID	=	168336 $m^3\ h^{-1}$
Design shaft power	=	211.33 kW

According to Affinity law from Eq. 2:

$$\frac{211.33}{HP_2} = \frac{(168336)^3}{(105547)^3}$$
$$HP_2 = 53\ kW$$

Present power consumption	=	97.5 kW
Power saving expected	=	(97.5-53) = 44.5 kW

Power saving for 200 days with power cost of Rs 5.0 (Approx.):

Energy saving in a year	=	44.5*24*200*5.0 = Rs 1068000
Cost of variable speed drives	=	Rs 1800000 (Approx.)
Payback period	=	1.68 years

Consider another example of trimming of OD of pump impeller. It is recommended to reduce the power consumption of a pump by machining the OD of the impeller. Our aim is to achieve 15 kW instead of 22 kW power. The existing OD of the impeller for pump model 65×80 sizes has been assumed as 218 mm:

$$\frac{P_a}{P_b} = \frac{D_a^5}{D_b^5}$$

$$\frac{22}{15} = \frac{(218)^5}{D_b^5} \tag{3}$$

D_b = OD of trimmed impeller from 218-202 mm

Estimated power saving = 33600 kW
Investment needed = Nil

Quick Methodology to determine the excess air in coal fired boiler: Raw water, electricity, process steam and cooling water are main utilities in a chemical process plant. The economy and profit of a chemical process industry is mainly depending up on the efficient generation and effective utilization of these utilities. Steam is generated from a boiler by combustion of fuel. A boiler (steam generator) is a container into which water can be fed and by applying heat, evaporated continuously into steam. Large area of heating is surface to ensure the utmost possible transfer of heat from the hot gases in the furnace to the water in the boiler. Ample combustion space so that gases will be completely burned before passing to the chimney.

Consider a radiant type water tube crushed coal fired using spreader stroker over a traveling grate and ash discharges in to submergible ash conveyer system:

Maximum continuous rating	=	25 t h^{-1}
Steam pressure at super heater outlet	=	32 kg cm^{-2} g
Steam temperature at super heater outlet	=	285°C

The heat losses are:

- Heat loss in dry flue gas
- Heat loss in the moisture in fuel
- Heat loss in moisture produced
- Heat loss due to combustible in refuse
- Heat loss due to radiation

$$\text{Boiler thermal efficiency} = 100\text{-(Total heat losses as calculated above)} \tag{4}$$

Proximate analysis of coal:

Moisture	:	5.2%
Ash	:	42.58%
Volatile mater	:	21.37%
Fixed carbon	:	30.05%
Gross calorific value	:	3714.49 kcal kg^{-1}

Ultimate analysis of coal:

Carbon	=	38.6%
Hydrogen	=	2.48%

Oxygen	=	6.04%
Moisture	=	5.20%
Ash	=	42.58%
Nitrogen	=	5.10%

Theoretical flue gas analysis on dry basis:

CO_2	=	18.78%
N_2	=	81.22%

Boiler performance:

Ambient temperature	=	30.11°C
Flue gas outlet temperature	=	188.09°C
CO_2 in flue gas	=	11.17%
O_2 in flue gas	=	8.46%
Steam flow	=	28.17 t h^{-1}
Ash: Fly ash	=	85:15
GCV of coal	=	3714.49 kcal kg^{-1}
GCV of ash	=	688.83 kcal kg^{-1}
GCV of fly ash	=	582.41 kcal kg^{-1}

Enthalpy of steam in flue gas at 51.7 mm Hg and 188°C = 682.2 kcal kg^{-1}
Enthalpy of water at 30.11°C = 36.02 kcal kg^{-1}:

$$\begin{aligned}\text{Heat loss in ash pit} &= \text{(GCV of ash \% in coal)(\% ash discharged in to ash pit)}\\ &= \{(688.83)(0.4258)(0.85)\}\\ &= 249.30 \text{ kcal kg}^{-1} \text{ of coal fired}\end{aligned} \tag{5}$$

$$\begin{aligned}\text{Heat loss in fly ash} &= \text{(GCV of fly ash \% in coal)(\% ash discharged in to fly ash pit)}\\ &= \{(582.41)(0.4258)(0.15)\}\\ &= 37.19 \text{ kcal kg}^{-1} \text{ of coal fired}\end{aligned} \tag{6}$$

Total heat loss in incombustibles	=	286.49 kcal kg^{-1} of coal fired
Equivalent of unburnt carbon	=	286.49/8080 = 0.0354
Actual carbon burnt = 0.3860-0.0354	=	0.3506 kg kg^{-1} of coal fired
Nitrogen in flue gas	=	100-O_2-CO_2 = 100-8.46-11.17 = 80.37%

$$\begin{aligned}\text{Dry flue gas} &= \frac{(11CO_2+8O_2+7\,N2)\,(C)}{3CO_2}\\ &= \{(11)\,(0.1117)+(8)\,(0.0846)+(7)\,(0.8037)\}\,(0.3506)/3(0.1117)\\ &= 7.88 \text{ kg kg}^{-1} \text{ of coal fired}\end{aligned}$$

Rise in flue gas temperature = 188.09-30.11 = 157.98°C

Calculation of heat losses:

$$\begin{aligned}\text{Heat loss in dry gas} &= (\text{mcp t})\,(100)/\text{GCV}\\ &= (7.88)\,(0.24)(157.98)(100)/3714.8\\ &= 8.042\%\end{aligned} \tag{7}$$

$$\begin{aligned}\text{Heat loss in moisture in fuel} &= (\text{Moisture in fuel})\,(\text{Enthalpy difference})\,(100)/\text{GCV}\\ &= (0.0520)\,(682.2\text{-}36.02)\,(100)/3714.49\\ &= 0.91\%\end{aligned} \tag{8}$$

$$\begin{aligned}\text{Heat loss in moisture produced} &= (\text{Moisture produced})(\text{Enthalpy difference})(100)/\text{GCV}\\ &= (0.2232)(682.3\text{-}36.02)(100)/3714.49\\ &= 3.88\%\end{aligned} \tag{9}$$

$$\begin{aligned}\text{Heat loss due to combustible in refuse} &= (\text{Total heat loss in incombustible})\,(100)/\text{GCV}\\ &= (286.49)\,(100)/3714.49\\ &= 7.71\%\end{aligned} \tag{10}$$

Heat loss due to radiation = 0.6%

Thermal efficiency = 100-losses = {100-(8.042+0.910+7.771+0.600+3.88)} = 78.79%

Determination of excess air from flue gas analysis:

Percentage of CO_2 and O_2 are known from flue gas analysis

Percentage of N_2 in the flue gas = 100-%CO_2-%O_2

O_2 in the flue gases is obtained as:

O_2 for C	=	Number of moles of CO_2 in flue gases
O_2 excess	=	Number of moles of O_2 in the flue gas
O_2 for H_2	=	O_2 in supply air-(O_2 for C+O_2 excess)
O_2 required theoretically	=	O_2 for C+O_2 for H_2
Excess O_2	=	(O_2 in supply air-O_2 required)
%Excess O_2	=	(Excess O_2/Theoretical O_2) 100

The % excess air can be determined using the following:

$$\%\ \text{Excess} = y/21/79\,(100\text{-}x\text{-}y)\text{-}y \tag{11}$$

Where:

x = %of CO_2

y = % of O_2 in flue gases

Heat loss through stock due to excess air:

$$\% \text{ Heat loss} = (C{*}Cp{*}\ T)\frac{11CO_2+8O_2+7N2}{(GCV)/3CO_2}\times 100 \quad (12)$$

Where:

C = Coal utilized for burning

= 0.3506* 0.24(157.898) ($11CO_2+8O_2+7N_2$)/(3714*3CO_2

= 0.3579 (11*10+8*11+7*79)/3*10 = 8.96%

DISCUSSION

Combustion calculations and the theoretical air requirement calculated and tabulated. Primary and secondary air blowers supply air required for the combustion of coal and a balanced draft is maintained in the furnace around minus 1 mm of water column pressure using the induced draft fan. Affinity Curve for Centrifugal Pumps is shown in Fig. 1. Figure 2 gives the %O_2 in the flue gas vs. excess air percentage. As the percentage of O_2 increases from 4% to 11% the excess air increases from 23-110%. Figure 3 gives effect of excess air on % heat loss in the flue gas. As the percentage of O_2 increases which is related to excess air as, given in Fig. 2 from 4-11% the percentage of heat loss through flue increases from 5.42-8.96%.

To get the good combustion of coal over the Travagrate, time of contact of coal with air, temperature of the combustion chamber or furnace and turbulence of air over the surface of the coal is important. If too much of excess air is supplied; heat loss in the flue gas will be increased. If very low excess air is supplied, heat loss in the incombustible to the bottom ash and fly will increase due to in efficient combustion of coal. In order to obtain the optimum combustion efficiency,

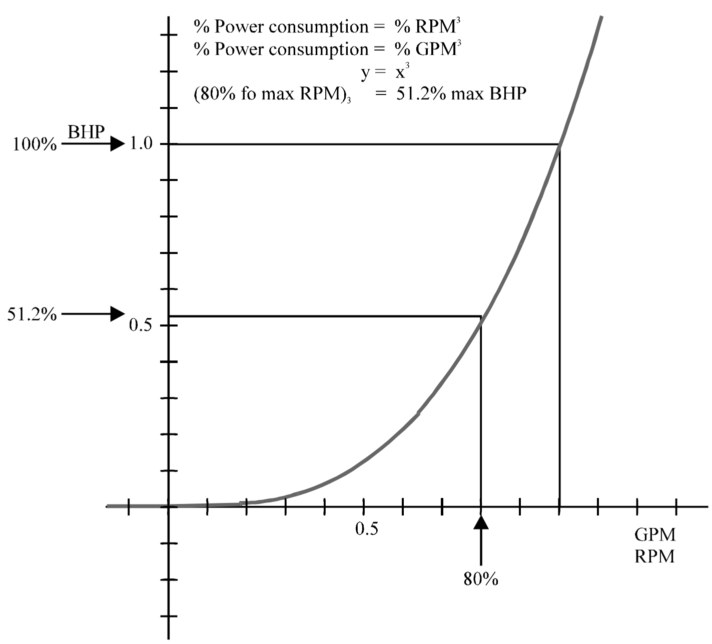

Fig. 1: Affinity curve for centrifugal pumps

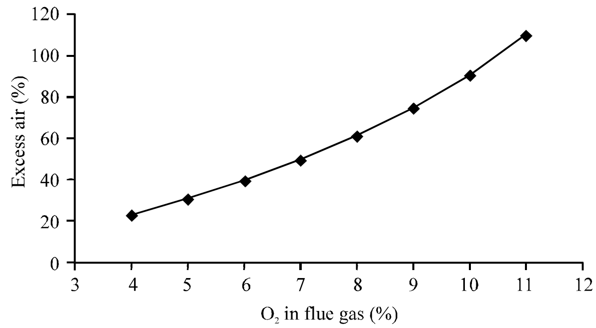

Fig. 2: % O_2 in the flue gas vs. excess air percentage

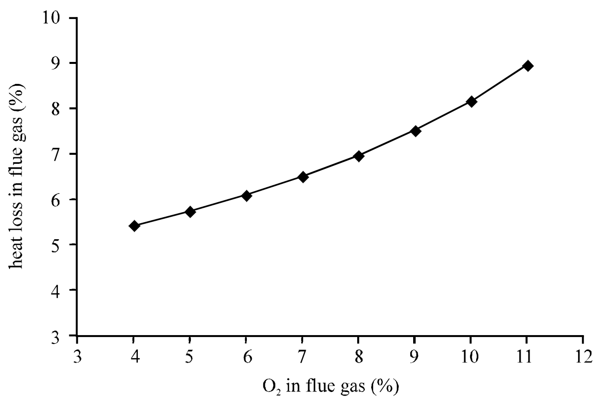

Fig. 3: Effect of excess air on % heat loss in the flue gas

optimum of air should be supplied in excess and that can be achieved by frequent checking of operating parameters.

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