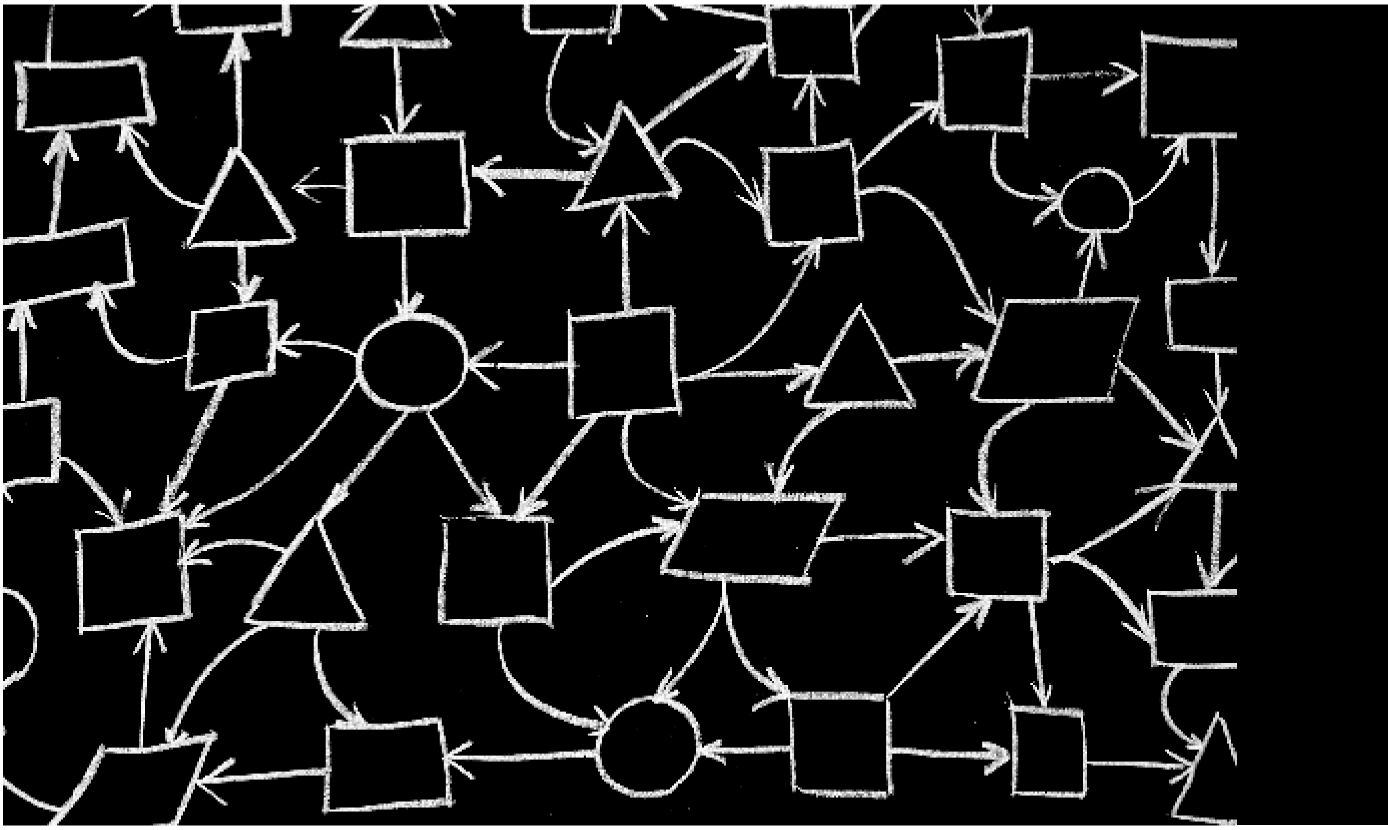

World over, scientists, engineers, policy makers and administrators are talking of energy conservation and energy efficiency. India also is not an exception to that. Why are we discussing all these issues? From India's point of view, the primary reasons are:

- Ensuring energy security
- Reducing global warming or GHG emission
- Promoting a cleaner and greener environment
- Cutting down the energy costs of industry and households

To bolster the above causes, the Government of India introduced Energy Conservation Act in 2001 and NMEEE (National Mission for Enhanced Energy Efficiency) in 2008. One of the major components of NMEEE is the PAT (Perform Achieve & Trade) scheme for industry. Under the first phase of this scheme, 490 major industries have been identified and their baseline SECs (specific energy consumption in TOE/ton of product) determined through energy audits. After this exercise, the industries have been given individual target SECs to achieve in the coming 3-year period. Energy auditing is a very crucial step in this whole exercise, as the company can be rewarded or penalized based on the audit findings. Hence its accuracy is of prime importance not only to the company but also to the apex governing body, Bureau of Energy Efficiency (BEE). Energy auditing is important in three different ways:

1. To determine the baseline energy consumption and present SEC
2. To find out potential areas of energy conservation/enhanced energy efficiency and advise the industry on how to achieve its target SEC
3. At the end of the 3-year cycle, to judge the performance of the industry and recommend the number of E-certs (energy saving certificates) the company is eligible to claim or liable to purchase.

BEE, the apex body for energy conservation in India, has published some guidelines on how to conduct an energy audit in industries. The said guidelines mainly speak of utility components, which are more or less the same across the various industries.

industrial energy audit - a process approach is a must

While conducting energy audit for a plant, in general energy auditors look at the utility side only and mostly ignore the process areas. However, a chunk of savings may emerge from the process side if it is examined properly. Even in utilities, for example, in a furnace, a lot of process elements could be involved which cannot be overlooked while making data interpretation and efficiency calculation.

Avijit Choudhury

BEE, the apex body for energy conservation in India, has published some guidelines on how to conduct an energy audit in industries. The said guidelines mainly speak of utility components, which are more or less the same across the various industries. For example,

- Steam generation and distribution system (boiler)
- Heating systems like furnace, thermo pack etc.
- Compressed air system (compressor)
- HVAC/Chiller system
- Electrical distribution system (transformer) & motors
- Pumping units, fans & blowers
- DG sets
- Cooling towers
- Lighting system
- CHP (combined heat power cycle).

But in process industries, there are many other equipments or subsystems whose energy performance analysis becomes critical in the absence of defined efficiency parameters or energy performance indicators (EnPI). This becomes more relevant for those industries that are trying to implement energy management system (EnMS) as per the new standard ISO-50001. Given below are a few examples:

> The efficiency of a dryer is best defined by the drying rate, i.e., the time taken to reduce the moisture level of any substance from point A to point B. However, drying rate is dependent on a number of variables that are rarely noted by any plant.

Drying unit

Drying operation is very prominent in the process industry. Now, as an energy auditor, how can you say whether the dryer is energy efficient or not? How can you describe the efficiency of a dryer? The efficiency of a dryer is best defined by the drying rate, i.e., the time taken to reduce the moisture level of any substance from point A to point B. However, drying rate is dependent on a number of variables that are rarely noted by any plant, like

- Nature of material (porous/non-porous etc.): drying is faster in porous materials because of easy capillary action

- Percentage of bound and unbound moisture: surface moisture goes off at a much faster rate
- Temperature, relative humidity and flow rate of the drying medium (air or flue gas)
- Critical moisture content of the material
- Case hardening and shrinkage of the material in the last part of the drying curve.

Hence, to judge the performance of a dryer, a lot of laboratory tests and measurements are necessary when the above primary data cannot be furnished by the client. Because of such practical difficulties, we generally do not try to measure the efficiency of a dryer, but rather define an EnPI like kilograms of moisture separated per kg of fuel burnt (HSD, FO etc.).

If a 200 mm and a 25 mm screen are installed before and after the crusher respectively, then it can be assumed that all feed and product particles are of 200 mm and 25 mm size, respectively. Now by applying Bond's crushing law and work index theory, the ideal power requirement can be calculated. This ideal value is then compared with the actual power consumption (measured with a power analyzer) to calculate the efficiency.

Crushing/Grinding Unit

Crushing/Grinding is very common in industry, especially in coal-based power plants. The main purpose of the crushing operation is to increase the specific surface area (surface area per unit volume) of the fuel or the material under process. When the material is broken into pieces a number of new surfaces are created. In this operation, force is applied on the material particles to create distortion (stress and strain). When the particles are distorted beyond their ultimate cohesive strength they suddenly rupture into fragments. Therefore, the theoretical requirement of crushing energy is just to apply forces up to this rupture point. Alternatively, the energy requirement can be found as the sum of the surface energy of the final product particles less the sum of the surface energy of the initial feed particles. Whatever additional energy we supply to the crusher ultimately gets dissipated as heat. To calculate the theoretical energy requirement one must know the particle size. But there is a practical difficulty in this. Neither the feed nor the product has uniform particle size. Hence, to ascertain the particle size/cut diameter, one needs to carry out a screen analysis of both the feed and the product, which is seldom done in any industry. How then can we measure the crusher's efficiency? In such cases the auditor is left with no option but to go for approximation. But, if a 200 mm and a 25 mm screen are installed before and after the crusher, respectively, then it can be assumed that all feed and product particles are of 200 mm and 25 mm size, respectively. Now by applying Bond's crushing law and work index theory, the ideal power requirement can be calculated. This ideal value is then compared with the actual power consumption (measured with a power analyzer) to calculate the efficiency.

Mixer

Performance of a mixer is best measured by its mixing index, and the challenge lies in determining the mixing index for solid-liquid or solid-solid mixing assignments. Mixing index is a function of the type of material, power load and mixing time. It is to be understood that the essence of mixing is homogeneity. A perfectly mixed product should have the same composition throughout the pack. To check homogeneity, industry mostly uses the tracer technique. A measured quantity of a tracer material is mixed with the batch. Different samples are drawn at different times, and the tracer concentration is measured. When two consecutive concentration readings are identical, mixing is said to be complete. This is a way to optimize the mixing time, thus avoiding unnecessary running of the mixer. However, when such measurements are not possible the auditor just takes into account the specific power consumption of the mixer.

Submerged Electric Arc Furnace

One of the sectors covered under PAT is the ferro-alloy industry. Now, look at the typical energy consumption pattern of a ferro-alloy unit presented in Table 1.

Table 1 shows that more than 80% of the energy is consumed by the furnace alone; hence efficiency measurement of the furnace becomes critical. In conventional heating furnaces, efficiency is calculated by dividing heat output by heat input. Heat input, if electricity, is measured by using a data logger for a batch, or for a particular period if the process is continuous. Heat output is calculated by measuring the heat content of the hot material that comes out from the furnace during the corresponding period. Heat content is simply $m.C_p.\Delta t$, where m is the mass, C_p is the specific heat and Δt is the temperature difference. However, in ferro-alloy furnaces the process is just not heating but multifarious. Here chromium oxide and ferrous oxide lumps or briquettes are charged along with solid pearl or lame coke, which is basically carbon and used as a reducing agent. The inside furnace temperature is around 2000 °C, and the furnace output is molten metal, molten slag and CO gas. The basic reactions are

$$Cr_2O_3 + 3C = 2Cr + 3CO - \Delta H_1$$

$$FeO + C = Fe + CO - \Delta H_2$$

ΔH is the heat of reaction, and the negative sign indicates exothermic reaction. Now let us see what the theoretical heat requirement for the furnace is.

- Sensible heat of the charged material: It is the heat required to take the particles up to the melting point. Melting point of iron and chromium oxide is around 2000 °C.
- Latent heat of fusion for Fe & Cr oxide: Please remember that Carbon does not melt but sublimates at the furnace temperature; hence the enthalpy of change of solid carbon to the vapour phase has to be considered for this purpose.
- Heat of reaction (ΔH): The actual heat requirement of the process is much lower than the above, as a lot of heat is generated in the process itself as the reduction reaction starts inside the furnace.

Table 1: Typical Energy Consumption Pattern of a Ferro-Alloy Unit

Energy Share Picture (of a Ferro-alloy plant)			
Total average production (Furnace I + Furnace II + MRP) = 8.25 tons/hr.			
Units	**Energy Consumption (kWh)**	**Energy Share (%)**	**SEC of sub-systems (TOE/ton)**
Drying Unit (GCV of HSD converted into kW)	3596.14	12.41	0.03748703
Metal Recovery Plant	78.46	0.27	0.000817886
Briquetting Plant	107.25	0.37	0.001118
Granulation Unit	174.12	0.60	0.001814976
Compressed Air System	106.6	0.37	0.001111224
Cooling Tower (including pump house)	392.17	1.35	0.004088075
Process Furnaces (2 no)	24139	83.31	0.251630788
CCP	126.33	0.44	0.001316895
GCP	254.22	0.88	0.002650051
Total (office buildings excluded)	**28,974.28**	**100**	**0.302034926**

Notes: MRP Metal Recovery Plant; TOE: Tons of oil equivalent; GCV: Gross calorific value; SEC: Specific energy consumption; CCP: Captive power plant; GCP: Gas cleaning plant.

In majority of the cases, the plant energy manager or production manager fails to furnish the desired data, as it is not available in their routine O&M manual. So ΔH has to be calculated by the auditor from the known thermodynamic reactions through equation balancing.

How to Calculate the Heat of Reaction?

In majority of the cases, the plant energy manager or production manager fails to furnish the desired data, as it is not available in their routine O&M manual. So what to do? ΔH has to be calculated by the auditor from the known thermodynamic reactions through equation balancing. The laws of thermodynamics tell us that the heat of formation is equal to the heat of dissociation. This means that if X is the amount of heat evolved in making FeO from Fe and O_2 (exothermic), then the same amount, X, of heat shall have to be supplied to produce Fe and O_2 from FeO (endothermic). Hence we can use the following basic equations, the ΔH values of which are known:

1. $2C + O_2 = 2CO + 2430$ kcal/kg of carbon
2. $4\,Cr + 3\,O_2 = 2\,Cr_2O_3 + 1.8$ kcal/kg of chromate
3. $2\,Fe + O_2 = 2\,FeO + 0.902$ kcal/kg of iron oxide

Using the above equations we get

1. $2\,Cr_2O_3 + 6\,C = 4\,Cr + 6\,CO + 57{,}775$ kcal
2. $2\,FeO + 2\,C = 2\,Fe + 2\,CO + 57{,}766$ kcal

These derived equations imply that for each kilogram of chromium oxide reduction, the process generates 190 kcal of heat. Similarly for each kilogram of iron oxide reduction 401 kcal of heat is evolved. These two extra amounts of heat have to be subtracted from the theoretical heat requirement while calculating the furnace efficiency.

Thus, while conducting energy audit in any process plant, an in-depth study and understanding of the process becomes a prerequisite. If this is not done, then possibilities are there that we may end up with a wrong interpretation and analysis of the field data.

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Mr. Avijit Choudhury is AGM-Energy Services with Enfragy Solutions India Pvt. Ltd., New Delhi, India.