ENERGY CONSERVATION IN FOUNDRY INDUSTRY
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Introduction : There have had been several group of material systems including metals (ferrous, non ferrous, Rare earth, Transition )and non metallic like polymer, ceramics and composites identified useful for mankind not only in earth but some of that other planets too. But, still steel remains to be the queen of highly consumable engineering material followed by cast iron in spite of increase in usage of non ferrous (Al, Zn, Ti and Ni) and polymers or composites that are welcomed in view of Environmental consideration and or so-called modernization. Depends upon the identification including usage of material by ancient men, it can be classified as Stone age, Bronze age and then Iron age. The later Iron Age is the one where many developments on infrastructure and transportation really needed at that time became possible. This of course did translate ancient men’s perception into practical reality in an astonishing, sound way besides lift from Stone Age to modern age. To be accurate, among the material known to men, easy processing nature, excellent, unique properties and abundance of resource availability find with steel being driving force behind the selection and dominance of steel in industrial sector. Cast iron though similar to steel and belongs same family, the glass-like brittle nature and processing restrictions, consumed only where its own desirable properties are found useful (E.g. Lathe Bed or Brake Drum – subjected to higher vibrational load and frictional heat where Graphite flakes in microstructure is useful for absorbing load and reducing heat generation. It is because of slip system nature of HCP crystal structure of graphite flakes which on subjected to compressive loading lie one over other and promote cushioning effect. This is why cast iron is preferred for damping, lubrication related applications). Cost factors also have had imparted its impact on material or process selection even tie up been found between many specific materials against process. For instance cast iron is always processed by casting but not by forming or powder metallurgy. As far as heavy engineering, dynamic applications considered steel (formed/cast) and or cast iron are found useful to match with service requirements.

Energy – Need of Hour : There are known commercial metal/material processing techniques, namely Metal forming (rolling, forging, drawing, coining), Machining, Powder Metallurgy, Welding and recently developing Diffusion bonding, laser assisted processes which are found major industrial use at various
levels. Each above said process has advantages and drawbacks that decide the suitability of that particular process for particular use. Casting/Founding route is widely accepted as unique, due to the ability of bringing desired complex shapes at less cost incurred compare with other processes for producing same component. But, this is true that molten metal preparation (i.e., Melting) is a highly energy (either in the form of electricity or fuel) and hence cost consumable, profit eating practice found in most of the foundries. However, this is ‘Energy Era’, developing nations are in search of finding energy by drilling down the earth, smashing/breaking atomic bonds, and slashing breeze. So this is need of hour for Indian foundry industry to start work on ‘Energy conservation, saving and proactive implementation. So, Here is an attempt made to initiate and highlight the possibilities of various energy saving theoretical measures (could become practical) to be taken in our foundry industries in order to keep ready to face energy and pollution related challenges in short coming future. Focus is given on melting as the metal must be melted irrespective of other parameters.

What a Metal is all about?

Before get into start understanding melting, one must understand what a metal (solid) is made of other than atoms. Basically metals extracted from their respective ore are processed to be available either in rigid lump or powder form, which in both the cases comprising atoms bound by bonding, primarily metallic bonds. Metal atoms due to bonding are seen microscopically cube or box like cells called Crystal. Besides bonding, there may be also some defects, dislocations and twin bands generated on solidification, but which are beyond the scope of discussion. Depending the periodic placement of atoms over the length of the bond, metals have any of the crystal structure namely BCC (Body Centered Cubic), FCC (Face Centered Cubic) or HCP (Hexagonal Close Packed) Crystal structure. The bond length is maintained by electrostatic repulsion of electrons. Some metal systems also possesses different crystal structure at different temperature (E.g. Fe – BCC at room temperature, FCC – 723° to 1392° C, BCC - 1430° C to 1535° C ) called allotropy. In general all metals are good thermal and electrical conductors On which applying heat energy to convert metals from solid to liquid state, initially the bond get weakened losing rigidity, turns the solid to semisolid finally liquid. Again there are lot of differences in aforementioned steps which varies with heat transfer mode and vessel where heating take place (i.e., heating mode). Since cast iron is being processed in bulk quantity in foundry industry, this discussion is confined to cast iron melted using Cupola and Induction furnaces.

Induction, Cupola Melting: Cupola is still used in many small scale foundries and Induction furnace emerging as an optimal for holding and melting cast iron, steel and few non ferrous alloys, Al. Cupola the charge get just heated up by conduction and free convection utilizing heat produced from burning, burnt coke. This is basically Endo, exothermic reactions involved during process that determines, influences the amount of fuel consumed for melting and Superheat-tapping of a specific amount of metal. Whereas in Induction furnaces the principle is quite different where current passing through conductive coil, usually copper, induces perpendicular, alternating magnetic field which could generate secondary current on charge materials kept inside. Copper coil is used
as heating element because of its less electrical resistivity (1.7 x 10^-8 Ωm, for Al it is 2.65 x 10^-8 Ωm), less oxidation resistance even at higher temperature and excellent strength developing property upon cold working, higher thermal conductivity (385 x W/mK, it is 201 for Al). Here the principle of melting is by ohmic law, Eddy current loss I²R/ joules heat effect which is commonly known as I²Rt loss. So bringing as well keeping the charge above the liquidus temperature with continual charging, current must be continuously flowing through the coil without interference. Depends upon heat capacity of added charges, current is drawn. In cupula predetermined coke must be added along with every charge in order to favor burning and hence phase transformation to liquid state. It seems it is difficult to calculate the amount of useful heat available inside cupola for liquifying iron, steel charges, excluding the heat lost through furnace lining, wall and preheating downcoming charges. Again for closer approximation of actual energy consumed/required for effective melting of charges can be calculated by knowing the amount of metal tapped against total coke added up to the combustion zone (by inserting thermocouples at various height of cupula combustion zone height to which coke added and Volume/weight of same can be read). This would give result with minimum error rather than calculating with CO₂ or CO gas coming out of furnace top vent, which may vary according to coke bed porosity and hence diffusivity. By knowing the exact temperature of each zone, coke that is effectively participating in melt down the charge accompanying heat generating gaseous reactions can be determined. To assist faster efficient burning of coke hot blasting is done and this helps reducing loss of alloying elements primarily iron, carbon and silicon from melt droplets also takes place. Energy is conserved in hot blast cupulas yet frequent relining to be done.

Energy Conversion in Cupola: The typical iron to coke ratio that is practiced with cupola furnace usually varies between 6/1 and 11/1 yet many factors govern them. Those are cupola size, hot blast rate, ash, sulphur, and fixed carbon content in coke, coke size, strength, charging sequence, oxidation tendency of alloying elements, pressure inside cupola, slagging and Deslagging frequency, heat transfer rate or heat loss rate and so on. Depends upon the reaction involved inside a cupula, it is identified as three or four zones as follow.

Bottom – Coke Bed Zone:
1. Wood + Coke is Kindled with help of natural draft. Charging over coke bed takes place, preceded by Mild air blast.
   - C (coke) + O₂ → CO₂  ΔH= -12796 BTU/lb Carbon  ......Eq 1
   - CO₂ + C (coke) → CO   ΔH = -5182 BTU/lb Carbon  ......Eq 2
   - 2C + O₂ → CO   (Balanced Equation) ......Eq 3
   - C (Coke) + H₂O → CO + H₂  ΔH = - 3766 BTU/lb Carbon ....Eq 4

   Even mild blasting tends to heavily oxidize the expensive alloying elements including silicon present in cast iron/ steel charge materials and also down coming melt droplets in later period of process.
   - Si + O₂ → SiO₂  
   - Fe + CO₂ → FeO + CO  
   - Mn + O₂ → 2MnO.

Continuous monitoring of flame through tuyers and controlling blast rate is important for energy efficient, environment friendly, cost effective quality melting.
Coke bed height is leveled by adding coke after ignition commenced then charging of pig iron/cast iron, flux, returns, steel scrap, and alloying addition are done.

Coke act as both carburizer and fuel in cupola, it is beneficial studying how carburization of steel scrap or cast iron depending carbon potential of coke (i.e., the ability of coke to supply carbon to counterpart when there is concentration variation) helps lowering the energy consumption and achieving homogenous quality melt of desired carbon equivalent.

\[
\text{Fe} + \text{CO} \rightarrow \text{Fe-C} + \text{FeO} \quad \text{Eq 4} \quad \text{(Melt Zone)}
\]

\[
\text{Fe} + \text{CO} \rightarrow \text{Fe}_c + \text{FeO} \quad \text{Eq 5} \quad \text{(preheating Zone - 700°C above)}
\]

An empirical formula has been derived for calculating the amount of heat available for different Fe/coke and CO/CO2 ratios,

\[
\text{MBTU (per ton Fe)} = 4350(1+2.344\frac{\text{CO2}}{\text{CO}+\text{CO2}})\times\text{CA} \times 10
\]

Similarly air blast required to produce above CO/CO2 ratios and to achieve a satisfactory melt rate is,

\[
\text{Blast Rate (Cubic Feet per Minute)} = 2.519 \times 10^3 \times (1+\frac{\text{CO2}}{\text{CO}+\text{CO2}}) \times \text{TPH} \times \text{C}^\ast
\]

Where CA – amount of carbon available as fuel in coke excluding carburization of steel to desired value; TPH – (metal tapped) tons per hour; \( \text{C}^\ast = \text{CA}/\text{Charge added}. \)

Theoretical heat requirement for a ton of iron (with 4.3 % C) to reach ~2750°F (1500°C) is ~1.06 MBTU.

If a cupola with Fe/Coke ratio of 8/1 and blast rate of 6402 cfm is being operated, it will involve energy production of ~1.54 MBTU/ton according to the above mentioned formulae. The exhaust gas would contain 18.2 wt %CO, if it is combusted to CO2 would add 1.27 MBTU more. This excess energy produced by utilizing more volume of blast air is carried away by exhaust gases going upwards without serving any purpose other than negligible preheating and incoming blast, if regenerator is used. Energy lost is aggravated if more CO transforms to CO2 as blast is continued at constant rate. But exothermic CO2 gas generating reaction is beneficial in view of which, both energy conservation and environmental prevention, it is advisable to maintain Fe/Coke ratio on upper side. and varying adjustable blast rate in order to keep CO/CO2 ratio fixed one and so energy lost under control.

Kinetics of Melting in Cupola: Exothermic \( (\Delta H +ve) \) reaction taking place inside cupola Provides major portion of heat energy required for melting while endothermic gasification reaction by CO2 generated in above reaction and H2O derived from moisture in the blast reduces available heat. This is why hot/dry blast cupola is preferred. Further 15 – 75 % of the CO2 generated reacts endothermically with coke giving out oxygen (Oxygen liberalization/deoxidation) with CO, this liberalized oxygen is useful for continual reactions, reducing excessive consumption of atmospheric air. There must be a compromise made between CO and O2 considering which is essential and economical from environmental view. But, however one way of reducing coke consumption in a cupola charge is to minimize the rate of C formation. This is possible by applying Lee – Chartler principle where in a reversible reaction upon reducing the concentration of product or pressure or temperature (at which reaction take
place and product forms), the process can be altered to proceed in favorable direction. Development of any alternatives that could suck up CO2 gas as soon as it forms or reduces activation energy of CO2 or increase minimum energy that it must possess to react with coke, would appreciably bring down coke consumption.

Induction furnace: In general induction furnaces are recently increase in use due to many features,

- Higher heat efficiency (68 %, which is 35 %, 11 % higher than coke and gas fueled cupola.)
- Great control over charging, composition, melting and maintaining temperature.
- Reduced oxidation losses compare with cupola, arc furnaces.
- Continuous, less space occupying, easy lining repairable furnace.

Principle of Induction Heating: An induction can be compared with a transformer where heating coil act as primary while charge materials act as secondary one. The difference is output is taken from secondary coil of the transformer as voltage whereas in induction furnaces charge materials are closed. Theorem of Current, voltage and electrification proves that due to voltage (potential) difference electrons moving from one side to other counterpart is represented by flow of current in the direction opposite to electrons. In induction furnaces secondary current and heat flow across solid charge taking is not primarily due to voltage, but necessarily by magnetization. Magnetization of coil (Electromagnetic Induction) induces magnetization of charge known to happen as regular alignment of domains microscopically. Once current flowing through coil is cut, demagnetization (Misalignment) found. Alternating current produces consecutive rapid alignment then misalignment results in frictional force may be due to which vibrating electrons energized to go to conduction band. Magnetic materials naturally resist rapidly changing magnetic fields within the Induction coil and also produce additional heat. It helps electrons (from outer orbital electron cloud or sea) to cross conduction band which means current flow become Possible. It happens up to the metal reaches curies temperature (in case of Ferrous) or bond breaking stage (if it is non ferrous). Once bond between atoms lose its rigidity and softens turns to liquid where further current would be due to ions. These ions at high temperature conducts electricity and its own resistance in the form of liquid, produces enormous heating by again $I^2Rt$ loss.

Energy Conservation In Induction Furnaces: Understanding then analyzing electrical parameters is necessary to implement energy saving corrective actions in induction furnace.

Electrical Parameters:

1. Power Supply: Considering the power loss when transmitting current at low over a long distance ($P/V = I$, Power $P$ when transmitted through a coil of Resistance $R$ could produce current $I$) high voltage DC current is distributed. It cannot be directly used with high voltage for which Step down of voltage is done
using transformer. It is important how effectively done with minimum power loss. It relies over functional condition of transformer.

2. Power and Power Factor: Power $P = VI$ (Direct Current) ….. $F_1$;
But for AC circuit, $F_1$ gives apparent power.
So real power is $P = VI \cos \phi$;
Where $V$ – Voltage (V); $I$ – Current (Amp), $\cos \phi$ is called Power Factor.
Real Power is the power used fully to do serve useful purposes, heating, lighting or motion. Reactive power is the one used to maintain electromagnetic field which is important for an Induction furnace. So reactance is invariably present in AC circuits, resulting in phase difference between voltages and current which is called power factor. As far as induction furnaces considered reactive power tends to increase with induction effect, keeping total power same by reducing real power. This is represented by lagging power factor (Current lag the Voltage), $PF < 1$.
Amount Power decides the relative speed/rate of heating as well melting rate achieved. As Power supply, power density increases heating become quicker.

Importance of Power Factor: Improving the power factor by adding capacitors to an AC circuit will reduce power losses and so electricity cost. Too much capacitance in a circuit will cause overheating and damage to equipment. It must be consulted to determine the proper size, type and location of capacitors.

Current, continually flowing through the coil, generates enormous amount of heat which in turn results unavoidable heat loss. This will result excessive power consumption and also prolonged melt time. To avoid such thinks water is continually circulated inside the hollow copper coil. The excessive heat around the coil is transferred to water which is taken out and cooled by heat exchangers or cooling towers then recycled. Puncturing of any coil when current is flowing around the coil, may lead to short circuit and immediate fire hazard or explosion sometimes. So glass fiber tape coil is wrapped around the coil, over which varnish applied to prevent coil puncturing and also heat losses. The efficiency of heating in Induction furnace involves the efficacy of its accessories.

Frequency, Resistivity: As stated earlier misalignment of magnetic domains found in charge materials require higher coercive force to get demagnetized, if it is hard magnets. This indicates that current drawn (till Curie point) is more and sensible heating taking place if operating frequency applied and charge size used are higher. This is further explained by relationship that the relative higher resistances of larger size charges compare to smaller and higher induced frictional forces promote quicker heating. This may support the practice why starting block or lump pig iron is charged and heated in the initial stage of melting.

$$P = (5030 \sqrt{r})/(\sqrt{F \mu}) \text{ OR Depth (cm)} = \frac{1}{2\pi} (\sqrt{\Psi/\mu F})$$
where $P$ – Depth of penetration of current (cm); $r$ – resistance of charge (Ω/cm);
$F$ – Frequency (Hz); $\mu$ – Frequency (Hz); $\Psi$ - Resistivity (ohm cm * $10^{-9}$).
This is why for preparing Base metal in an Induction furnace it is the usual practice to start with starting block and or pig iron that offer more resistance helping quicker melting. In case of high frequency furnaces as frequency
increases, depth of current penetration decreases and area over which current flow takes place is less leading to rapid melting.

Power Sector in Future: According to recent updating in India 70% of total power generated is contributed by thermal (coal or gas) power plants which is about 115,544 MW at the end of 2004-05 while remaining 40% is by hydro, nuclear plants and wind mills sharing at 26%, 2.5%, 1.5% respectively. But stringent pollution control against thermal plants, scarcity of renewable resources, risk factors associated with nuclear plants may put barriers on those technologies and prevent the establishment, expansion of same in near future. Moreover other technologies like solar-photovoltaic and Biomass power generation may or may not be able to meet huge power demand from Industrial sectors. Consistent hike in fuel prices and participation of private sectors in power generation urging more investment will enable the country to shine with more power but at higher cost. By clearly stating, Electric power would be the one commodity that industries have to pay more for it. It means power, the very costly commodity that foundry must subscribe to ensure that Metal is melted fully and raised to its superheating temperature before tapping for pouring.

Energy Saving Measures: other than above highlighted technical determination, each foundry industry must follow as much as energy saving measures in regular activities. It is very important for large scale industries where not enough procedure is followed against power consumption.

- Avoiding very frequent charging and keep the furnace lid closed state. So that could avoid heat loss through radiation. \( Q = 5.6 \times 10^{-3} A \xi (T/100)^4 \), \( A \) - surface area of molten metal, \( \xi \) - Emissivity, \( T \) - Temperature (K).
- Unburnt CO in fumes coming out from automotive engine is converted to CO\(_2\) by catalytic converters which foundries may procure and use for same purpose. The heat produced may be found useful.
- Preheating of charge materials, just before charging must be given importance. In melting cast irons, about 65% of total heat consumed for heating cold material to tapping temperature, 20% melt down and 24% superheating.
- Cupola coke must have less low temperature softening ash content as it retards effective combustion and diffusion of carbon from inner portion.
- In transformers wet/dry lubricants are used to counteract the effect of heat produce. Recently in transformer manufacturing, Directional oriented silicon steel and high purity copper having higher electrical conductivity are used widely which may be installed to reduce power loss.
- Motor coil winding repairing and rewinding is known to increase the excess power consumption with power loss. So new motors installing by initial less investment would save more money spent for electricity.
- Operating furnaces and other machineries in full swing when peak demand value is less.
- Foundries shall form fence with solar panels on its field not operated vacant place, which shall be useful for effectively tapping non-conventional energy sources.
- Creating awareness among workers to know of economical use of compressed air and other electrical utilities what smaller units usually does.
- Mathematical, physical modeling of energy consumption and related functions can be studied to optimize the same. Practicing application of Regression analysis and process control charts must be encouraged to evaluate existing procedure and make improvements upon it.
- Foundries must realize that availabilities of insufficient technological resources disable the industries to ‘know how’. Thermodynamic theorems must be thoroughly practiced and adapted by generating new theories applicable for foundries.

What an Engineer can do?

In foundry melting shops, it is essential studying the Effect of charging sequence on power/fuel consumption, volume output of metal per hour, improving slag making practice and quality of melt. It is inevitable for an Engineer to understand the stages in melting sequences, effect of process parameters, variables and hence implementation of ways reducing energy consumption. Emphasizes must be given on Kinetics concept (rate of reaction, Diffusion mechanism, i.e., Heat, momentum, mass transfer), Physical metallurgy principles, and Thermodynamic theorems those applicable are to be matched against melting stages for determining steps that would optimize the energy consumption. In a foundry dealing with castings of various grades or batch type production, it is possible doing optimization of melting different grades without not much excess energy by following ‘Operations Research’ calculation methods using available data. It is the practical observation in many foundries that recoverable, reusable material losses account 10 – 60 % (in the form of runners, risers, gating and so on) of total metal melted while irrecoverable metal loss account 5 – 10 % of total metal melted. This is governed by the yield of casting and metal with which it is poured. So, all necessary innovative steps must be implemented to improve the gating system designed and molten metal quality to attain maximum % yield of casting. In order to promote Directional solidification, foundries use large number of conventional or exothermic sleeve risers which finds most useful but reduce the final yield as well increase further excess energy consumption. On developing new products or modifying existing casting system, it is also vital considering the lip area of both furnace (Induction) and ladle as the volume flow of metal (tapping, pouring rate) varies with the same. This is predominant as far as pouring of SG iron concerned, the fading of which may result the whole think useless. Based on nozzle/lip area of ladle, volume of metal contained only pouring time is calculated. Any deviation with respect to this may invite unsound castings. In addition the rate at which ladle might be tilted, especially bigger ladles on pouring is to be extensively analyzed. This factor too must get accounted as faster tilting enable entrapment of oxygen and oxide formation by turbulent filling of metal in pouring basin and inside mold cavity. Even slag removal is done just before pouring, molten metal may
dissolve oxygen available at that time. Solubility of gaseous element (air -21% O2 + 79 % N2) is more in molten metal and so oxygen suddenly reacts with Residual magnesium, fading occurs. Design modifications for cupola promoting energy efficiency may be suggested.

Conclusion: As far as foundries in India concerned most foundries working on platform gained by prolonged practical observations and experience rather than strong theoretical foundation proven by concepts. It is crystal clear that, this fast changing, innovation insisted, technological surrounded world urges the industries/institution create new ideas to stay on line. Not just casting, but forecasting future has to be objective for foundries so that survival would never be a million dollar question behalf of any aspect, quality, productivity, consistency or comfort ability. Foundries must develop their own value added products soon suitable for shop floor uses. It would be favorable move from any foundry outsourcing secondary works to local bodies without fully outsourcing the chance of developing new technologies to counterpart nations. So that each foundry could develop its own indigenous proprietary items and processes according to own need. As far as Energy consumption concerned, whether it is large scale or small, foundries are in need to be economic and will be under compulsion to do so after regular review. Eco- friendly Foundries operating with Energy efficient, cost effective, consistent quality achieving melting plant could be the major global source for growing, domestic and international casting market.

“Energy can neither be destroyed nor be created but it can be surely saved”