ABSTRACT

The Indian image of the cupola as a dirty, polluting and energy inefficient melting method of small, foreman operated cast iron foundries producing non-graded, unduly repaired, poor quality, general engineering castings is changing, but not as fast. On the opposite, the image abroad is of highly energy efficient, eco-friendly, modern, very high melting rate, water cooled, long campaign, versatile to produce all grades of grey and ductile irons. This paper is based on the experience of an academic base foundry men with practical working experience of more than 40 years in all type of foundries is an attempt to expedite this change of attitude for the good of our next generations.

The paper first brings out the salient differences between ordinary coke fired cupola, divided blast cupola, LPG/CNG fired cupola and the induction furnace. The features compared are raw materials and fuel, capital cost, energy efficiency, melting cost, productivity, local atmospheric pollution and ecological factors directly related to global warming.

It is concluded that keeping a balance of all the above features

1. Small coke fired cupola units must expedite the change to genuine divided blast cupolas. It is very much possible to control the metal composition and temperature for FG 260-300 grade CI castings with right tensile strength/hardness and microstructure for all applications.

2. For superior grade thin walled castings the cupola metal has to be duplexed into low powered induction furnaces.

3. For high tonnage units the expensive and high powered induction furnaces should be replaced with cupolas and suitable low powered furnaces for duplexing for minor chemical composition adjustments and temperature. The number and capacity of the cupolas will depend on how soon we can develop a cost efficient, durable and result oriented APC for large cupolas to meet the stringent SPM requirement of 150 mg/m3 max against 450 for cupolas up to 3 t/hr for which a simple APC is in use.

4. The gas fired cupola is a solution for all above problems in one go. These are most energy efficient, pollution free and least CO₂ producing and melting cost efficient, but unfavorable in plant cost. This high cost and some problems have resulted in their poor progress in Agra. The Agra entrepreneurs have been able to save their ‘trade’ by simple change in design of cokeless cupola and materials changes. But the metal composition problems still exist. Large scale units as such or for expansion plans should very seriously consider gas fired cupola for their melt shops. The gas availability areas are growing fast and new units can choose location accordingly. For smaller foundries the cluster approach will go a long way in getting gas connections.

Key words – Divided blast, Cokeless Cupola, Carbon Footprint, Melting, Iron foundry, Duplexing
INTRODUCTION: The need for sustainable development and mitigation of climate change has taken a prominent place over and above energy conservation. The climate change and many other adverse effects of the greenhouse gases on the very existence of the human race is no longer disputable. National and universal efforts are vigorously on to combat these effects.

Metals and metallurgy related industrial activity has been rated as most energy intensive, energy inefficient, polluting and greenhouse gas emitting. Out of these, foundry sector plays a major role (closely followed after steel industry and aluminum extraction). Amongst the foundry operations metal melting accounts for 55% energy consumption,(1,2) followed by molding and core making (20%), post casting operations (7%), heat treatment (6%) and balance other activities. Thus energy consumption during metal melting indirectly affecting environmental pollution and carbon footprint (green house gas generation) is a major concern in all foundries – tiny, small scale, medium scale and large scale. The melting process selection is directly based on scale of operation, capital structure, space required and availability, quality requirements of the casting, metal being melted, cost of production etc. Additionally, energy efficient operations and carbon footprint of melting process selected must be given due importance. An attempt is made in this paper to do that and find out which is the best cast iron melting method in Indian conditions from all three considerations of cost, energy efficiency and Carbon footprint.

MELTING FURNACES FOR METALS

A large number of melting furnaces starting from a tiny coke fired crucible furnace to cupolas of very high melt rate, tens of tons per hour, running for weeks / months at a stretch or large induction furnaces pouring tens of tons every hour through a press pour and other modern technology like auto in stream inoculation. They have their own area of application – starting from 2 mm wall thickness electrical connection covers at Aligarh in a 5 kg crucible to say 100 tons apiece of special high quality casting in SG iron for blades and gear boxes for wind turbines for power generation. Details of these melting units can be found in any book on foundry technology.

Conventional cupolas are used in low profile, small scale industries known to produce average quality castings in a wide weight range. The entire technology is traditional, away from basic knowledge of foundry technology. They have their own contribution to the casting tonnage produced by India, the second largest producer of castings in the world (3). It is estimated that more than 35% of the CI castings are produced by these foundries in India.

There has been a change in scenario in favor of these traditional cupola foundries since the liberalization in the nineties.
1. Availability of much better quality inputs: Pig iron of consistent quality with well controlled chemistry and low phosphorus in place of rejected pig iron from steel plants of unknown composition earlier. Coke of low ash (12%) ash is also available, though at a very high price recently, against unknown ash content. Even the high ash coke (30-35%) is better in friability now days.

2. Quick shop floor chemistry check instrument, CE meter, is now easily available at affordable cost and gives good enough control for FG-260 castings.

3. The mental block in the casting users that the cupola metal is of inferior quality as compared to an induction furnace is now melting away. A majority of the automobile producers do not insist on induction metal except for blocks and heads. A large number of foundries, with cupolas as basic melting unit and some with induction furnace to superheat and adjustment in composition (duplexing) are supplying to major auto and machine building companies.

4. Lately many of the cupola foundries have added machining facilities to get an advantage and to diffuse the difference between cupola and induction furnace cast iron in the minds of consumers.

A number of developments in cupola practice, i.e. hot blast, oxygen enrichment of blast, oxy-fuel injections etc were not found suitable in Indian conditions. Divided Blast Cupola (DBC) leading to lowering of coke consumption, increase in tapping temperature and melt rate has been found suitable for introduction. But the cleaner melting and ease of composition control in INDUCTION FURNACES and abnormal increase in fuel oil price have led to their popularity. The availability at an affordable cost, small induction furnaces and their technology is typically an Indian feature Power cost and availability, pollution; green house gas generation was of no concern. Moreover rapid development of auto component industry in the seventies and eighties and inability of cupola units even to supply simple GR 25 castings to them forced Telco, Ennore Foundries and DCM foundries to install large size induction furnaces producing auto-castings using steel scrap and alloying in place of so called pig iron. A full description of this is available elsewhere (4)

As a result of these changes, there was overall increase in Auto casting supplies from larger foundries, and smaller foundries contributed largely to general castings market. Out of the developments in cupola melting abroad one became noticeable in India. That is the DIVIDED BLAST CUPOLA (DBC). This is not to be confused with equi blast or balanced blast cupolas tried by some people unsuccessfully.

DIVIDED BLAST CUPOLA AND POLLUTION CONTROL

During 1980’s BRITISH CAST IRON RESEARCH ASSOCIATION developed the concept of a divided blast cupola published in the form of a report (5) and a number of cupolas based on these
principals were installed in UK and Europe. In India, initiative was taken by NML in 90’s and a design was licensed to TERI (then Tata Energy Research Institute). TERI with the support of SDC (Swiss Agency for Development), ABB India, Sorane SA Switzerland and Casting Development Centre UK demonstrated an energy efficient design of DBC along with a pollution control system, APC. (6) This reference is an excellent review of TERI-IIF joint work on DBC till date.

As pointed out earlier, the backbone of foundry industry in India was labor intensive, unmechanised cupolas developed by experience and tradition only. There was complete disregard for energy / coke consumption, pollution and environment. TERI initially has a very tough time in convincing the foundryman to take advantage for their profit by reduction of coke consumption and cleaner atmosphere for workers and surrounding population. The ventury scrubber based APC was efficient but not cheap enough for the money minded foundrymen. It consists of top cap, ventury scrubber, dewatering cyclone, draft fan and a separate chimney. At the present rates cupola of 3T/hr costs about 8 lakhs and the APC costs 15 lakhs (7). In the meantime, The Punjab State Council of Science and Technology working on many projects for fuel efficiency and pollution developed in 1994 a very simple TOP CAP WASHER meeting CPCB pollution specification for up to 3T/hr Cupola. It costed about Rs. 50 thousand only and was adopted by all DBC’s of TERI or other organizations and individuals (8)

The pollution specifications of Central Pollution Control Board were and still are the following:

<table>
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<tr>
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<th>For Cupula up to 3 tons/hr melt rate</th>
<th>Larger melt rate melt rate</th>
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<tbody>
<tr>
<td>SPM</td>
<td>450 mg/Nm$^3$ max</td>
<td>150 mg/Nm$^3$ max</td>
</tr>
<tr>
<td>SO$_x$</td>
<td>300 mg/Nm$^3$ max</td>
<td>300 mg/Nm$^3$ max</td>
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Typical figures for SPM are 150 to 300 mg/Nm$^3$ and Sox about 50 mg/Nm$^3$ for 3T/Hr cupola with top cap washer. The low Sox values are obtained by controlling the Ph of wash water by addition of soda ash. The top cap washer was soon accepted by most of state Pollution Control Boards. About 550 units of cupolas in Punjab alone have adopted the wet cap and 150 are waiting for PPCB license. Thus small cupolas up to 3T/hr are comfortable with top cap with pollution laws. The top cap washer has been installed in most cupolas in India, especially in northern part of India irrespective of melt rate. TERI’s APC has not found a place due to high cost. Conscious larger units installed other cheaper APCs’ by consultants to get clearance only. Therefore the need for an APC for larger cupolas with stricter norms of SPM (150 mg/ Nm$^3$) is most urgent for the cupola foundries. IIF should take a concrete step for in this direction.
Divided Blast Cupola has the following features leading to fuel economy.

1. The total air of calculated and measured volume as per the size of the cupola has to be blown in separately through two sets of wind belts and tuyers rows. The two wind belts could be formed from one only by a horizontal partition. The number of tuyers and their size depend upon diameter and air quantity required. The vertical distance between two rows tuyers centre line is 1 meter. Air from the same blower of requisite size and H.P of motor is bifurcated and tangentially joined to the two wind belts. Plate valves or baffle valves are incorporated in the two airlines after bifurcation to change the air volume independently in two rows of tuyers. The pressure and volume of air is measured separately by two sets of manometers and volume flow meters. The control panel showing the CE meter and the flowmeters of our foundry are shown on next page bottom.

2. Height of cupola above tuyers is more than regular cupolas to accommodate 6-7 charges up to charging door. Stack height is generally about 16 ft as against 4-6 ft in conventional ones. Coke combustion at lower tuyer level is oxygen deficient and hence substantial quantity of CO is formed. As the hot gases go up further quantity of CO is formed due to carbon loss reaction $\text{CO}_2 + \text{C} = 2\text{CO}$. The whole purpose of the secondary air is to burn this CO to $\text{CO}_2$ to give the balance of calorific value of carbon. Final CO content at the top (ideally zero) is the measure of the efficiency of cupola design and distribution of air among the two rows.

The thermal balance of a conventional cupola is compared below with that of a DBC. It clearly shows the diversion of heat wasted as CO is utilized in melting (40% to 5%) Leading to an increase in overall heat to metal from 35% to 59%)

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**Thermal Balance of Conventional Cupola**

- **Metal**: 40%
- **Latent Heat of CO2**: 13%
- **Slag**: 10%
- **Sensible Heat of Exhaust Gas**: 35%
- **Heat Loss Through Walls**: 2%
3. This complete combustion of carbon and preheating the charge due to height are two key factors to reduce the coke combustion. The coke saving ranges from 20-45% depending on pre-existing coke rate, cupola design change, quality of coke used and overall efforts done. The figure of 20-25 % (1:5 to 1:4) has been upgraded to 9-12 % (1:11 to 1:8). The payback period is estimated to be 6 months (for modifications in existing cupola) to eighteen months for a new DBC. With all out efforts of TERI, PCST Punjab, Foundation of SMSE Clusters, PPDC Agra, UNIDO sponsored IIF programs and few individuals the concept of DBC has dug in and about 100 units have been set up or existing cupolas modified in all corners of the country. The cluster approach has lately speeded up the process.

Control Panel showing CE meter and flow meters of Trudimet Castings DBC.  

Showing plate valves and bifurcation of blow line and pressure gauge of DBC.
The progress of this beneficial changeover has been slow due to the following reasons:

1. All three advantages of the DBC, namely coke rate reduction, high melting rate and increased tapping temperature all can’t be taken simultaneously. If the sole aim is to save coke only, the melting rate can’t be increased very much. The control of DBC for maintaining right pouring temperature and chemical composition for graded castings is little difficult to maintain but possible. We at our foundry have been successfully doing it for last 12 years as OE suppliers to Swaraj Mazda and Punjab Tractors (now Mahindra’s). For thin walled graded castings with good machinability, some foundries duplex the metal in a induction furnace and can afford to lax on control of temperature and composition of the cupola metal.

2. The attitude of owners of not bothering what is going on. Foreman is the profit earner and all in all. Fear of falling into a financial trap also plays a role. They have had adverse experience of some consultants who could not deliver the promised advantages.

*General view of DBC of Trudimet Castings Pvt. Ltd. Derabasi showing unusual height.*
COKELESS OR GAS FIRED CUPOLA

The concept or practice of replacing hard coke in cupola by gaseous and/or liquid fuels in not new. Mr. Richard Taft started the development of gas fired cupula at Hayes Shell-cast, U.K. in mid sixties and came in operation with 5 t/hr cupula in 1970. Soon after Mr. Taft started his own business of selling cokeless in the name of COKELESS CUPOLAS LTD, UK after patenting it. Later he operated in coke deficient, oil/gas producing countries starting from UK and then to Egypt, Mexico, Iraq etc. In 1981 Ducker of Germany started a natural gas cupola of 12T/hr. In 1990 Okatomo Co. Ltd set up a 5T/h cupola in Japan and since than many units are in operation in the world.

In India the first was a demonstration unit at Agra by NML set up with collaboration with Agra Foundries Association (9) but was soon shutdown due to operational and other problems. The next unit was a 3T/hr natural gas cupola set up by Wesman Engg Kolkata under license from Cokeless Ltd at Agra, M/s Anil Steel Industries Ltd. The data of its successful operation is reviewed by Dr.Basak (10).

The cupola consist of a shell as usual fired by three high velocity short flame burners just above the metal well and can use different fuels natural gas, LPG, CNG, Diesel oil, propane etc. The firing of the burners and fuel/air ratio is controlled by PLC’s. Super heating is done by special refractory balls supported by a water cooled grating of special steel tubes refractory coated
supporting the spheres a little above the burners. After the balls are heated to white hot, charging with usual materials is carried out and molten cast iron starts collecting in the well and is poured as usual either continuously or intermittently.

The most important advantages of cokeless cupola are:

1. Very low dust (SPM) and Sox, Meets all pollution requirements in India without treatment.
2. No sulfur pick up at all favoring direct production of SG iron castings.
3. Excellent melting energy efficiency.

Similarly the disadvantages are:

1. Problem of maintaining the water cooled grating leak proof.
2. Excess of lining erosion and high consumption of refractory balls.
3. Insufficient research work into metallurgical factors. Decarburization takes place during melting and graphite powder has to be injected.
4. Shortage of operators to efficiently run the cupola.
5. Refractory ball consumption goes high with superheat and therefore maintaining low pouring temperature of 1350°C with duplexing is more economical and energy saving.
6. Very high cost of ceramic balls and availability.
7. Very high cost of the furnace, unaffordable by small/ medium foundries.

Due to above and some other problems the first and two more units installed at Agra are no more operative. Further three other units elsewhere in India installed later are working satisfactorily by duplexing for grey and SG iron.

ENERGY EFFICIENCY AND CARBON FOOT PRINT OF DIFFERENT MELTING TECHNOLOGIES

Since a few years ago, when the phenomena of global warming due to green house gasses was firmly established over and above energy conservation, some of the foundrymen started thinking in these terms. The author worked out the energy efficiencies and CO2 generation of different cast iron melting technologies from first principles. First the heat energy required to superheat cast iron to its melting point, latent heat of fusion and again heating to pouring temperature was calculated from reliable values of its specific heat in solid and liquid
conditions and its latent heat of fusion. This figure comes to about 370 kWh/ton when converted to electric power units. This figure is in complete agreement of 370 kWh/ton calculated by Shifo and Radia (1). Then heat liberated by complete burning of carbon of the hard coke of different ash content was worked out from the heat of reaction $\text{C} + \text{O}_2 = \text{CO}_2$ and converted to kWh. The heat of combustion of gas fuels was worked out from their calorific values, specific gravity and carbon and hydrogen contents. Then the actual figures of consumption of the fuels from published data and own experience was taken. Dividing the heat of melting by liberated heat gives the fuel efficiency. All heat wasted and/or utilized in non melting operations is thus hundred minus the calculated efficiency. The elemental carbon burnt in melting in % of metal and converted directly to $\text{CO}_2$ gas at NTP is the carbon footprint of the melting process responsible for global warming. In no way these figures can be taken as absolute, but more than requisite for comparing the processes. The results of these calculations are shown in the following bar charts for different processes of melting.
The above three charts show the results of these calculations. The most striking and surprising findings of these charts (to someone uninitiated in the subject) are the very poor thermal efficiency of (25%) and very high carbon print (1450 Kg CO₂ per ton) of induction furnace against 90% and 150 to 200 for cokeless and 60% and 350 for DBC. Immediate reaction after believing these figures would be, what we are doing to ourselves and our future generations and the mother earth by neglecting cupola and encouraging IF. The basic reason is that theoretically based on Carnot cycle, we can’t get more than 39% efficiency of conversion of thermal energy to mechanical power and then to electricity in thermal power plants. Then the efficiency of the furnace itself is about 60-65%, balance going to air and cooling water and electrical losses and giving a final efficiency of 25%. In case of cupola melting the charge comes directly in contact with the hot gasses and heat transfer to melt the charge. The figures are better for the cokeless as compared to coke cupola as large quantity of heat goes as heat of reaction between ash of the coke and lime, melting and superheating of the slag formed.
In the literature on energy conservation and carbon footprint of there are a large numbers of indirect references that the carbon footprint of electricity consuming hardware are much higher than efficient direct combustion applications. Direct comparison of carbon footprint of large scale foundry operations using cupola or induction furnace is given by Schifo (11).

<table>
<thead>
<tr>
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<th>GREY IRON CUPOLA</th>
<th>INDUCTION MELTING FURNACE</th>
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<tbody>
<tr>
<td>Electricity</td>
<td>0.5</td>
<td>2.47</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.19</td>
<td>0.35</td>
</tr>
<tr>
<td>Coke</td>
<td>0.45</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1.16</strong></td>
<td><strong>2.86</strong></td>
</tr>
</tbody>
</table>

Induction melting foundry producing more than two and a half times CO2 than a cupola foundry for same production.

Therefore we should not hesitate in saying that cupola melting of both types is far far better than induction furnace from both points of views, energy conservation and global warming. Except India all over the world cupola of high melt rate and very long campaigns are very widely used and all kinds of new developments are in progress. Examples are water cooled/lining less super high melt rate very long campaign cupolas for direct pouring of SG iron, hot blast, oxygen enriched air, oxy-fuel, plasma and/or laser heated, above charge / below charge take off cupolas, shuttle charging, supersonic oxygen injection lances, intelligent process control of cupola operations through neural networks and other artificial intelligence computer controls etc. In fact the cupola is contributing to more than 70% of world CI/SG production (1).

On the other hand we are continuing with conventional cupolas, at the most, painfully modifying to DBC, trying to promote high cost cokeless not affordable by small and medium foundries, and installing low, medium and high capacity induction furnaces which have no or very little scope for further energy conservation.

These induction furnaces became popular decades back when dirt cheap stainless scrap disappeared from the western markets and these furnaces switched over to steel production of second quality for mini rolling mills etc and multiplied in numbers to include CI melting. And our casting users mistakenly degraded the cupola to poor old dirty technology incapable of
producing automobile quality castings. The times have changed but we have not moved with
time in this regard.

Now let us have a look at the cost of production of these methods. A detailed but very rough
calculation is given in the above chart considering the fuel, power and ceramic balls. The
melting cost is the highest at 3200/- to 3400/- per ton for both induction furnace and cokeless
with or without duplexing (MP4 to MP9) above. The biggest attraction to small foundries has
been use of turning/ borings (Burada) in I.F. Deducting the net saving on melting 300 kg Burada
per ton brings down the cost to about 2200/- No investigation has been done to evaluate the
ill-effects of Burada on the casting quality. Conventional cupola and low ash DBC is at 2700/-. High ash DBC is 1800/-(MP2) because of the huge difference in price of low and high ash coke.
On adding the duplexing cost of 80 kWh power per ton it comes to 2200/- Cokeless with either
of the two gasses and average 2% ceramic balls usage calculates to 3200/-to 3400/-. Duplexing
of cokeless metal from 1350oC to 1450oC in IF increases the cost by Rs. 400/- only. The melting
cost is the lowest for DBC metal with high ash coke and duplexing is 1900/- only. A 500 kg IF is
sufficient to duplex 25-30 tons a day from one cupola of 3 T/hr. Having two cupolas running on
alternate days and 500 kg IF a foundry can produce 500 tons/month as is the case with a
foundry well known to the author (12). The same group is installing a 3t/hr cokeless to enhance
production in their bigger foundry at Una ( H.P.) Duplexing and its advantages have been
highlighted by a number of authors.( 14,15,17)

The cost of the inputs taken for these calculations are (1) High ash (30-35%) coke Rs.15/-per kg,
low ash (12%) coke Rs.30/- per kg, power Rs.5/- per kWh, LPG Rs.58/- per kg, NG Rs.32/- per
NM3, Refractory balls Rs.37/-per kg. These prices are subject to variation as per local conditions.

The discussion will not be over without a reference to Agra. The foundrymen there has saved their business and the Taj Mahal by a change in practice. The coke and refractory balls have been replaced by graphite lumps in ordinary cupola run by natural gas. The melting heat is given partly by natural gas and partly by heat of combustion of graphite. The current melting cost has risen to about 2700/-per ton due to high cost of graphite, though the natural gas is available at subsidized rate of Rs.10/- per NM3. Work is in progress to reduce graphite consumed and use more gas.

CARBON CREDIT AS CDM PROJECT FOR CO2 REDUCTION FOR FOUNDRIES

Although this carbon footprint reduction should give the carbon credit benefit under the CDM(clean development mechanism) of UNFCC to the foundries, the procedure is very tedious, time consuming and expensive, no foundry or cluster has applied for the scheme to the best of author’s knowledge, it is worth considering for large units. A foundry of 1000tons/month can think of getting CRR’s worth Rs.30 lakhs annually for using DBC/cokeless in place of Ind.Furnaces.

CONCLUSIONS

Producing general castings with divided blast cupola and high quality thin walled graded castings after duplexing in suitable induction furnace is energy efficient (55-58%), most economic (Rs.1800-1900/ton) and eco-friendly practice (about 300kgCO2/ton)Next is duplexing after melting in cokeless cupola with much better energy efficient(80-90%), more eco-friendly(180kg CO2/Ton) but costly (Rs.3000-3400/ton). Last is induction furnace (25% efficiency), least eco-friendly (1450 kg CO2/ton) and equally expensive (Rs.3200/-per ton)

These figures will vary to some extent depending on local conditions but the trend will remain the same.

Small foundries must modify/replace their cupolas to DBC and start duplexing in small induction furnaces to improve quality and reduce rejections to save further cost.

Medium scale foundries being set up should install requisite numbers of cupolas with induction for duplexing.
Medium and large foundries must expand by installing requisite number of cupolas to
duplex in existing induction furnaces. Little new power connection increase and claim for
carbon credits will be extra gain.

The foundries thus will save the valuable electric power to divert to uses for our well being
in daily life which is based traditionally on electricity use and cant change overnight.

By installing cokelss with duplexing to produce more and more SG iron, India will secure the
second position in the world production as USA is very much ahead of us in SG
production.(19)

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