A CASE FOR USE OF CUPOLA IN CAST IRON FOUNDRIES, ENERGY CONSERVATION AND GLOBAL WARMING CONSIDERATIONS.

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Abstract

The traditional melting unit in cast iron foundries is being replaced by induction furnace by high quality foundries. Thermal efficiency, cost of equipment and melting costs has been overlooked due to quality and raw material problems. Some foundries have used technologically upgraded versions of the cupola with improvement in thermal efficiency and resultant cost savings and ecological considerations. A review is of utmost importance in view of the changed circumstances of energy conservation and global warming, technological improvements in cupola design and practice, availability of better raw materials, pollution control and modern developments. This paper presents best possible estimates of thermal efficiency and elemental carbon consumed per unit weight of CI melted for different methods of cast iron melting. The carbon consumed is directly proportional with the main greenhouse gas, carbon dioxide, responsible for global warming. The findings can be used as a guide for judicious process selection.
Introduction
The traditional melting unit in cast iron foundries, the cupola has been / is being replaced by induction furnaces by high quality, high production mechanized foundries. All new foundries are also coming up with induction furnaces. The reasons have been

1. Lack of chemical composition control
2. Low pouring temperature
3. Air pollution and ecological considerations.
4. Final product quality (mechanical properties and casting defects assigned to cupola melting, often erroneously and without proper analysis).
5. Lack of availability of good quality coke (ash content and friability) and pig iron (Chemical consistency and high phosphorus content)
6. A mental block that induction furnace always produces better quality castings. This is definitely true for leak proof auto castings like cylinder blocks, heads etc. which cannot tolerate phosphorus content above 0.08%. Due to high phosphorus content (0.15 -0.4 %) of pig iron produced by our steel plants (the only source till recently) and widely varying carbon and silicon content, direct cupola metal cannot be used for these castings. Duplexing can take care of compositional adjustment and temperature but not phosphorus.

Indian automotive foundries like TELCO Jamshedpur , ENNORE Foundries and DCM Engg. Products were forced to produce synthetic cast iron from MS scrap, ferrosilicon and low sulphur and phosphorus carburizers in induction furnaces. Even then, phosphorus levels below 0.1% were difficult to achieve. While large capacity cupolas were very popular and are still being used in USA, Europe, China, Japan etc., due to above problems, a German mechanized charging cupola of high melting rate of 8 tonnes per hour was dismantled after a couple of years of operation at TELCO Jamshedpur works around 1975. Either direct induction melting or duplexing from arc furnace was the new practice. Now arc furnaces too have been dispensed off. The trend continued thereafter and almost all new foundries have used induction furnaces with one notable exception. Punjab Tractors foundry near Chandigarh continues to melt in a hot blast cupola for all tractor castings except blocks and heads. Some foundries duplex cupola metal in induction furnaces. In this change over scenario, naturally thermal efficiency, cost of melting equipment and melting cost in induction furnaces had to be overlooked.

Apart from these modern foundries, a large number of traditional foundries (about 5000 in number) continue with cupola and produce general quality castings. There are large clusters all over the country – Agra, Howrah, Batala, Ludhiana, Rajkot etc. Their contribution to countries cast iron casting production is very significant (estimated to be 70%). Characteristics of traditional cupula are improper design, poor operating practices use of inferior coke and raw materials and therefore poor metal and casting quality. Fuel efficiency is low and melting
costs are high. Typical coke rate varies between 1:4 and 1:5, i.e, 4-5 kg melting per kg of coke.

After liberalization in early 90’s the scenario was changing in favour of cupola due to
1. Availability of consistent quality pig iron of low phosphorus content from mini blast / low shaft furnace producers.
2. Technology of upgraded divided blast cupola (DBC) developed by BCIRA has become popular and design is freely available. [1]
3. Availability of online checking of carbon equivalent carbon and silicon by thermal cooling curve method. This supplemented the chill test on which the operator was solely dependent earlier.

**Divided blast Cupola.**
This lead to new installations / modifications of existing cupola to DBC by quiet a few foundries all over the country. Large amount of development work has been done by TERI [2-4] and others [5-8]. Details and the advantages of DBC i.e. higher temperature, higher melting rate and very significant increase in fuel efficiency (coke rate) are available in references [2-8].Characterestics of DBC are air supply by an optimum capacity blower through two separate windbelts, measured and regulated volume and pressure of air through two rows of tuyers located at a specified distance between them, specified coke bed height and stack height to contain at least 6 charges on the bed coke. These features incorporated in the improved design improve the fuel efficiency to a large extent. Coke rate of 1:9 with 30% ash coke and 1:12 with 12% ash coke (produced from low ash imported coal) have been achieved [8]. Number of such cupolas is estimated to be about one hundred in the country.

**Pollution control**
However in the meantime, there was a huge drag to cupola foundries due to newly introduced pollution control checking and norms by central and respective state pollution control boards. Many types of (at least 5) different designs [9] of pollution control devices / plants have been devised suiting different capacity and pollution level furnaces. These have been developed and used by many conventional / DBC cupolas [2-9] but the problem still remains unsolved. Everybody knows the fate of Agra foundries cluster. The status at Howrah is also not too good as has been very well reviewed by WBPCCB [9].

Pollution Control Device recommended by TERI [2-4], is a ventury scrubber device consisting of top cap, ventury scrubber, dewatering cyclone, draft fan and a separate chimney. This system has not found much favour as several other low cost alternatives are available [1, 7-9]. A wet arrester on top of the cupola has been recommended by BCIRA [1, pg 70]. It has been further developed by Punjab State Council of Science and Technology. Called a top scrubber, it has been accepted by Punjab, Haryana and Chandigarh State Pollution Control
Boards provided that pollution levels fixed by them are satisfied. The current norms are:

<table>
<thead>
<tr>
<th></th>
<th>For Cupola upto 3 tones / hr melt rate</th>
<th>For Cupola above 3 tones / hr melt rate</th>
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</thead>
<tbody>
<tr>
<td>SPM</td>
<td>450 mg /Nm$^3$ max.</td>
<td>150 mg /Nm$^3$ max</td>
</tr>
<tr>
<td>SO2</td>
<td>300 mg /Nm$^3$ max</td>
<td>300 mg /Nm$^3$ max</td>
</tr>
</tbody>
</table>

This top scrubber has now been fixed in many cupolas north of Delhi, even in larger cupolas. It has been reported that above pollution norms (SPM levels at least) are being met by all the DBC’s. This is definitely true for cupolas below 3 tones per hour. This device has been installed in our foundry and has been satisfactorily working for the last 6 years to entire satisfaction of PPCB. SPM levels have been checked repeatedly and are found below 400 mg / Nm$^3$.

The main factor in reducing the SPM and SO$_2$ levels in the DBC exhaust gases which can be taken care of by a simple low cost device, such as above, is the optimum amount of measured and controlled air fed from the two rows of tuyers from two different wind belts. The velocity and temperature of the exit gases near charging door is very low. During steady state operation the blast can hardly be seen and temperature is below 200° C. Coke consumption is reduced in DBC due to 1) use of optimum amount of air and 2) all the CO formed at lower levels is converted to CO$_2$ by upper tuyer air and therefore entire heat of combustion of carbon is utilized. CO content of exhaust gases has been analysed to less than 2% in our DBC.

Salient design features and performance data of DBC at Trudimet Castings, started in April 2000 is given in Table 1.

A number of other improvements on the conventional cupola, have been developed over the years and are being practiced all over the world [1, 10-13]. These are hot blast cupola, oxygen enrichment of blast, oxy-fuel cupola, natural gas / L.P.G. fired cupola, lining-less cupola, basic lined cupola for S.G. iron etc.

Due to the problems discussed above much attention has not been paid to these in India.

**Energy conservation and global warming considerations**

It is needless to emphasize the need and importance of energy conservation. The thrust has been due to 1) High cost and availability of fossil fuels and hence thermal power, 2) Various environmental issues and 3) cost competitiveness and other economic issues. All out efforts are being made for a number of years by all developing and developed countries and achievements have been extraordinary.

The considerations of climate change or global warming have added further to the need of reduction of fossil fuels use. This issue of global warming and its
effects on the earth has been discussed over a number of years, their acceptance was not universal. It has been now proved that it is a fact based on pure scientific considerations and unless immediate, strong and sustained efforts are made by the world community, the very existence of the human race on the earth is jeopardized and very serious consequences will be faced in next 50-100 years. The awareness and impact of global warming is likely to be intensified due to award of Nobel prize to IPCC (Intergovernmental Panel on Climate Change) headed by Dr. R.K.Pachauri of TERI (The Energy and Resource Institute). The final report of the UN backed IPCC recently released in Aug 07 is based on detailed analysis of more than one lakh research papers by more than 600 top scientists from 113 countries over a period of more than five years substantiates the terrible sounding consequences of global warming.

The term global warming denotes the accelerated warming of the earth surface due to anthropogenic(human activity related) release of greenhouse gases due to industrial activity and deforestation. Carbon dioxide is the main greenhouse gas. The exorbitant increase of its concentration in the atmosphere is the basic cause of global warming. Due to rapid industrialization, burning of fossil fuels (coal, petroleum, natural gas etc.) has increased manifold in all activities like power generation, transportation, industrial heating etc. Rapid deforestation has added fuel to the fire as plant life reduces carbon dioxide and gives the vital oxygen. These considerations along with efficiency of the fossil fuel burning equipments are directly related to energy conservation. Therefore all attempts and results of energy conservation are directly responsible for reduction in global warming and are a part of our efforts to give a better life to our future generations. Use of alternative source of energy is the other equally important activity for the same end result.

In this context, it is worthwhile to consider the energy efficiency of the different metal melting methods in foundries. The melting cost is next only to raw materials in foundries. Since the context is on global warming, it will also be necessary to compare the different methods of melting in terms of CO$_2$ produced per unit of quantity melted. These figures have been calculated using best possible estimates and are given in table 2.

The table clearly indicates that cupola melting is very considerably advantageous from both points of view as compared to induction and arc melting. Globally, cupola is widely used and all kinds of developments have been done in its design, fuel efficiency, computerization etc. and are in progress [1, 10-15]. We have neglected the cupola due to reasons discussed above. However, due to grossly changed scenario, it is high time we follow the global trends. We are seriously lacking in know-how of modern cupola, especially for large ones, with respect to cupola design engineering and pollution control equipment design to suit pollution levels. No foundry equipment engineering company or supplier worth its name is available in India. Almost no work has been seriously done on
the problem of pollution control and foundries in their own way try to satisfy the pollution boards.

Foundries in groups or associations (maybe the clusters being implemented by the Govt. agencies) can plan such an energy conservation / carbon dioxide reduction and earn carbon credits under the Clean Development Mechanism of the UN. These will fetch very good money when the noose on the developed countries is tightened 2012 onwards under the Kyoto Protocol.

**Conclusions**

1. The Divided Blast Cupola upto 3 tons per hour melt rate with a simple and low investment top cap washer is the answer for small foundries today.
2. For larger capacity cupolas, a properly designed cost effective and simple to operate PCD acceptable to the boards and foundrymen has to be developed. Till then, TERI’s ventury scrubber system is the best.
3. The LPG/NG fired cupola is the best in energy efficiency and CO$_2$ generation. We have made a start with indigenous [16] and imported technology [13]. We will have to wait for a year or two to see if the technical problem of carbon loss, availability and cost of refractory balls and cost of gas (piped or from installations) will affect its commercial viability.
4. From these two points of view and the changed scenario, induction furnaces should be used only for SG iron, alloy cast irons, steel castings and alloy steel/special steel production etc.
5. A huge scope exists for modification of design and operating practices of conventional cupolas to DBC or otherwise as a cost saving and greenhouse gas reduction measures.
References


5. Late Mr. R.N. Bhargava, RK Foundry Works, Jaipur, Personal Communication

6. Mrs. S. Karkhanis, Foundry Friends, Pune, Personal Communication


<table>
<thead>
<tr>
<th>Item</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cupola size</td>
<td>61 cm (24 in.) I.D.</td>
</tr>
<tr>
<td>Lower Tuyers</td>
<td>6 nos 11.5 cm (4.5 in.) dia opening. CL 77.5 cm (30.5 in) above base plate</td>
</tr>
<tr>
<td>Upper Tuyers</td>
<td>3 nos 5 cm (2 in.) dia opening, CL 90 cm (36 in) above base plate</td>
</tr>
<tr>
<td>Height b/w Tuyers</td>
<td>90 cm (36 in.) centre to centre</td>
</tr>
<tr>
<td>Air supply</td>
<td>Blower capacity 10 HP</td>
</tr>
<tr>
<td></td>
<td>Supply through 15 cm (6 in.) dia separate pipes to separate wind belts</td>
</tr>
<tr>
<td></td>
<td>184 m³/min to 215 m³/min (600-700 CFM) through lower tuyers</td>
</tr>
<tr>
<td></td>
<td>123 m³/min to 153 m³/min (400-500 CFM) through upper tuyers</td>
</tr>
<tr>
<td>Bed coke height</td>
<td>77 cm (30 in.) above upper tuyer CL</td>
</tr>
<tr>
<td>Stack height</td>
<td>4.9 mts (8 feet) above upper tuyer CL</td>
</tr>
<tr>
<td>Melt rate</td>
<td>2 tons per hour plus</td>
</tr>
<tr>
<td>Coke rate, charge</td>
<td>1:9 (11%) for 30% ash coke</td>
</tr>
<tr>
<td></td>
<td>1:12.5 (8%) for 12% ash coke</td>
</tr>
<tr>
<td>Net coke rate</td>
<td>1:8.2 (12.2 %) for 30% ash coke</td>
</tr>
<tr>
<td>Liquid metal basis</td>
<td>1:11.5 (8.5 %) for 12% ash coke</td>
</tr>
</tbody>
</table>
Table 2 – Comparison of energy efficiency and carbon burnt / carbon dioxide produced for different melting methods of cast iron.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Method</th>
<th>Fuel / power consumed</th>
<th>Energy efficiency (%)</th>
<th>Carbon burnt per Kg of liquid metal (kg)</th>
<th>CO₂ produced per ton of melting (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conventional Cupola</td>
<td>4.5 kg liquid metal per kg of coke of 30% ash</td>
<td>35</td>
<td>0.16</td>
<td>587</td>
</tr>
<tr>
<td>2</td>
<td>Divided Blast Cupola</td>
<td>8.0 kg liquid metal per kg of coke of 30% ash</td>
<td>59</td>
<td>0.09</td>
<td>330</td>
</tr>
<tr>
<td>3</td>
<td>Divided Blast Cupola</td>
<td>10.5 kg liquid metal per kg of coke of 12% ash</td>
<td>62</td>
<td>0.085</td>
<td>312</td>
</tr>
<tr>
<td>4</td>
<td>Induction furnace</td>
<td>600 KWH per ton</td>
<td>25</td>
<td>0.4</td>
<td>1467</td>
</tr>
<tr>
<td>5</td>
<td>Arc furnace</td>
<td>500 KWH per ton</td>
<td>30</td>
<td>0.32</td>
<td>1173</td>
</tr>
<tr>
<td>6</td>
<td>LPG fired cupola</td>
<td>60 m³/ton LPG [13]</td>
<td>90</td>
<td>0.04</td>
<td>147</td>
</tr>
<tr>
<td>7</td>
<td>Natural gas fired cupola</td>
<td>85 m³/ton NG [16] NML</td>
<td>80</td>
<td>0.045</td>
<td>165</td>
</tr>
</tbody>
</table>

Calculation method:
1. Heat consumed during melting of cast iron is calculated based on specific heat of solid and liquid iron and latent heat.
2. Heat liberated is based on heat of reaction of carbon oxidation to carbon dioxide.
3. Gas data is based on specific gravity, carbon content and calorific value of the gases.
4. Theoretical power for CI melting is taken as 370 KWH/ton.
5. Average coal consumption in thermal power plants is taken as 0.8 kg/KWH for 20% ash, 20% VM, 60% FC coal.
6. All these figures have been taken from reliable sites on the internet.