



# Influence of the cast iron melting processes on environment using BAT

M. Holtzer\*

Faculty of Foundry Engineering, AGH University of Science and Technology, Reymonta 23, 30-059 Kraków, Poland

\*Corresponding author. E-mail address: holtzer@agh.edu.pl

Received 22.06.2007; accepted in revised form 03.07.2007

## Abstract

The object of the article is the problem of Best Available Techniques (BAT) utilized in processes of melting cast iron. It is possible, with help of these methods, to fulfill the accessible emission values as well as raw materials and energy consumptions values recommended in the Reference Document BREF and thus reduce considerably the negative influence of melting processes on the environment. The fulfilling of the above requirements is an indispensable condition for foundries to get the integrated permissions according to the EU Directive IPPC.

**Keywords:** Cast iron, Environmental protection, Melting furnaces, BAT, Emissions

## 1. Introduction

Cast iron can be melted in the cupola furnace, induction furnace (generally of coreless type, but very occasionally can be the channel type – for holding) or in the rotary furnace. The electric arc furnace is only very rarely used for the preparation of cast iron. The cupola is the leading device for re-melting iron in Europe. It is responsible for some 55% of the tonnage of iron castings produced in Western Europe. Nowadays, the cupola is increasingly facing major challenges to its market domination. This is partially due to its flue gas quality, which requires treatment. Faced with the possible financial burden of investing in, and then depreciating, a stack gas treatment installation, may small and medium sized units have turned to electric or oxygas melting units. Thus the number of cupolas used in foundries is falling, but their average size is increasing. There have been major changes in the market for cupolas in Europe in recent years, particularly due to the restructuring of the coke industry, leading to a decreased number of suppliers and a need to import coke into Europe [1].

## 2. Properties of melting furnaces for cast iron

Table 1 presents an overview of the typical properties of melting furnaces used for cast iron and emission data.

### Cupola furnace

The charge is usually melted in a cold blast cupola (CBC), hot blast cupola (HBC) or cokeless cupola. In order to reduce the CO-emission and increase the energy efficiency, the conversion of cold blast furnaces to the hot blast furnaces may be considered. However, for medium-size foundries producing up to 2000 tons/month of good castings, the hot blast cupola will be difficult to consider because of the large investment it requires. The use of hot blast cupola is also restricted to continuous melting, otherwise the running costs are too high. The HBC remains the most widely applied melting device for mass production foundries, e.g. for parts for the automobile industry, centrifugal casting, road accessories. HBC are normally set up for long campaign operation, in order to minimize process switch overs and maintenance time and effort [2 – 5]

Table 1.  
Typical melting furnace for cast iron properties and emission data

Process	Cast Iron					
	Induction furnace	Cupola furnace				Rotary furnace
Type						
Subtype	Coreless	Cold blast	Hot blast	Hot blast-long campaign	Cokeless-duplex	
Energy source	Electricity	Coke	Coke	Coke	Gas/fuel	Gas/fuel
Thermal efficiency <sup>1</sup> (%)	50-60	30-40	40-45	35-45	50-60	50-60
Primary thermal efficiency <sup>2</sup> (%)	15-20	30-40	40-45	35-45	45-50	35-45 <sup>3</sup>
kWh/tonne metal charge	520- 800	950-1200	800- 900	810- 1100	700- 800	600- 800
Batch/continuous	Batch	Continuous	Continuous	Continuous	Continuous	Batch
Production rate <sup>4</sup> (tonnes/h)		2 -10	8 - 70	8 - 70	>5	
Furnace capacity <sup>5</sup> (tonnes)	0.01-30					1-20
Meltdown time (h)	1-2					2-4
Raffining ability	No	Yes	Yes	Yes	No	No
Capital costs	High	Medium	High	High	Medium	Low
Slag production (kg/tonne metal charge)	10-20	40-80	40-80		40-80	20-60
Dust production <sup>6</sup> (kg/tonne metal charge)	0.06-1	5-13	4-12		0.8	0.3-2.9
Waste gas <sup>7</sup> emission (kg/tonne metal charge)						
CO <sub>2</sub> <sup>8</sup>	Depending on power generation	400-500	350- 480		100-120	120
CO	n.a.	Possible <sup>9</sup>	0.5-2.5		<10	1.0-1.5
SO <sub>2</sub>	Minor	1- 2	<1		Fuel dependent	2.5 - 3.0
NO <sub>x</sub>	n.a.	<1	<1		0.5	0.3-0.4

<sup>1</sup> Indicated values give an order of magnitude but largely depend on exploitation conditions, such as metal temperature, furnace capacity and production rate.

<sup>2</sup> Efficiency of electrical Power generation assumed to be 35%.

<sup>3</sup> Taking into account energy consumption for oxygen production and the raw materials, such as graphite and FeSi, to substitute the oxidized elements during melting.

<sup>4</sup> For continuous processes only. <sup>5</sup> For batch processes only.

<sup>6</sup> Indicated values are general values found in literature. <sup>7</sup> Indicated values are general values found in literature.

<sup>8</sup> Assuming complete combustion. <sup>9</sup> Depending on local exploitation conditions and construction.

The advantages of the cold blast cupola operation may be summarized as follows:

- the investment cost is 125000 – 150000 EUR per tonne installed per hour, inclusive of a dedusting installation,
- different kinds of (cheap) scrap can be used due to the cleaning and carburizing operation,
- the thermal efficiency is acceptable if appropriate measures are utilized.

The disadvantages of cold blast cupolas:

- the production regime is not flexible,
- difficult production management because of the slowness of the system,
- expensive charge with pig iron and little steel scrap,
- no quick alloy change possible,
- sulphur pick-up,
- environmental burden is caused by the foundry; i.e. lots of dust. Slag and refractory lining,
- big dedusting installations are needed because of the high flue-gas rate.

The advantages of the hot blast cupola operation may be summarized as follows:

- reduced coke consumption,
- high tap temperature,
- high melting rate,
- reduced sulphur pick up,
- possibility to use different kinds of cheap lower grade ferrous scrap,
- increased carbon pick-up and hence the ability to substitute steel scrap for pig iron in the furnace charge.

The disadvantages of the hot blast cupola:

- very expensive investment, due to the additional environmental measures required,
- production regime is not flexible,
- difficult production management because of the slowness of the system,
- limited to iron alloys only, no quick alloy change possible,
- environmental burden is caused by the foundry; i.e. lots of dust. Slag and refractory lining,
- big dedusting installations are needed because of the high flue-gas rate.

In the cokeless cupola the metal charge is heated by the combustion of natural gas. Instead of the traditional coke bed, a bed of refractory spheres on a water-cooled grid supports the metal charge. The life of the spheres exposed to the superheating temperatures of the metal is limited. A cokeless cupola is therefore run at a reduced temperature (1400°C instead of 1500°C) and superheating of the liquid metal is done in an attached gas-fired or induction furnace (duplex operation). The oxidizing atmosphere and relatively low flame temperature cause increased oxidation losses. This limits the possibility to feed in steel. Maximum amount of 35% of steel is used in production of nodular iron, though 20% can be considered general practice.

The combustion of natural gas instead of coke has the following consequence for the flue-gas:

- less dust (0,8 kg/t metal charge instead of 10 to 15 kg/t metal charge for cold blast furnace),
- the cokeless cupola emits five times less flue-gases than the HBC. As a consequence, the cokeless cupola can be equipped with smaller flue-gas treatment system
- NO<sub>x</sub> and SO<sub>2</sub> emission levels are low compared to current emission limit value,
- the cokeless cupola emits less CO<sub>2</sub> (120 kg/t metal charge instead of 450 kg/t metal charge for CBC).

For the operation of cupola furnace melting cast iron BAT is all of the following, to [1]:

- use divided blast operation (2 rows tuyeres) for CBC,
- use oxygen enrichment of the blast air, in a continuous or intermittent way, with oxygen levels between 22 and 25% (i.e. 1-4% enrichment),
- minimize the blast-off periods for HBC by applying continuous blowing or long campaign operation; depending on the requirements of the moulding and casting line, duplex operations must be considered.
- apply good melting practice measures for furnace operation,
- use coke with known properties and of a controlled quality,
- clean furnace off-gas by subsequent collection, cooling and dedusting; BAT for dedusting is to use a bag filter or wet scrubber,
- apply post combustion in the cupola shaft of CBC; for HBC use a separate combustion chamber and recover the heat for blast air preheating and other internal uses,
- evaluate the possibility of waste heat utilization from holding furnace in duplex configuration and to implement heat recovery if applicable,
- prevent and minimize dioxins and furans emissions to a level below 0,1 ng TEQ/Nm<sup>3</sup>,
- use a wet scrubber system when melting with basic slag (basicity up to 2).

Residues produced by cupola melting include dust, slag and coke breeze. BAT for residue management is all of the following, to:

- minimize slag forming,
- pretreat the slag in order to allow external re-use,
- collect and recycle coke breeze.

### Induction furnace

Induction furnaces can be designed to operate at any frequency from 50 Hz upwards. The lower the frequency of the primary current, the more intense is the stirring. Therefore, in a mains frequency furnace working at 50 to 60 Hz, the turbulence is greater than in one operating at higher frequency. Because of the high turbulence, the power input to a mains frequency furnace is restricted to around 250 kW per tonne of capacity. The frequency of operation also affects the current penetration. The higher frequency, the lesser the penetration depth. This affects the minimal charge piece size and the effective furnace size. 50 Hz furnaces are not practicable at capacities below 750 kg. Medium frequency (250 Hz) furnaces have a higher power density (up to

1000 kW/tonne) than mains frequency (50 Hz) furnaces (300 kW/tonne). Additionally mains frequency units need to be operated with a molten heel of up to 2/3 of the crucible capacity to optimize specific energy consumption and also require specific starter-block for cold start-up. Medium frequency furnaces can readily be started with a cold charge and can be emptied at the end of each working shift or melting batch.

Due to its multiple advantages, the induction furnace is increasingly being implemented. Its main advantages are:

- higher flexibility in alloys and melting regime; as such it is an ideal melting techniques for jobbing foundries and special alloys,
- short melt down times,
- lower environmental burden caused by the foundry,
- little maintenance, depending on the life time of the refractory lining,
- good process control: computer support and fully automatic operation is possible, which allows optimal temperature control,
- maximum thermal efficiency is possible, if process parameters are locally calculated and set up,
- intense stirring in the bath makes the melt homogeneous,

The disadvantages of the induction furnace:

- because of the monopoly of the local electricity supplier, the operator is fully dependent on the connection conditions of the local electricity grid, the energy costs and any possible extra costs,
- the energy costs are more expensive than the costs of using fossil fuels,
- the cleaning action of the induction furnace on the melt is limited because of the small amount of slag and the relatively small contact area between the slag and melt; this requires the use of a high quality, and thus, more expensive charge than cupola furnaces,
- the installation requires a high investment, although the operator can save on additional environmental investments. The net cost per tonne installed furnace content is around EUR 375000,
- other technique are more suitable for capacities > 15 tonnes per hour (cupola furnaces),
- it has a low holding efficiency during holding because of the heat losses in the water-cooled induction coil [5]

Two major categories of emissions can be distinguished. The first, and major, category relates to the charge cleanliness, e.g. rust, dirt, foundry sand, paint, oil, galvanized or soldered metal, all of which are elements which give rise to the emission of dust and fumes (organic or metallic). The second category relates to chemical reactions at high temperatures (e.g. while holding or adjusting the metal composition) which give rise to metallurgical fume due to oxidation. Additionally the refractory lining may add a small amount of dust particles to the emission.

For the operation of induction furnaces, BAT is all of the following, to:

- melt clean scrap avoiding rusty and dirty inputs and adhering sand,

- use good practice measures for the charging and operation,
- used medium frequency power, and when installing a new furnace, to change any mains frequency furnace to medium frequency,
- evaluate the possibility of waste heat recuperation and to implement a heat recovery system if applicable,
- used a hood, lip extraction or cover extraction on each induction furnace to capture the furnace off-gas and to maximize off-gas collection during the full working cycle,
- used dry flue-gas cleaning, taking into account BAT associated emission levels,
- keep dust emissions below 0.2 kg/tonne molten iron.

### Rotary furnace

The rotary furnaces has been used in non-ferrous melting for many years. In this application traditional oil-air burners can provide the relatively low melting temperatures. The development of oxygen-air burners has enabled the induction of cast iron production, using higher relative amount of steel scrap and applying graphite for carburization. Due to its batch character, the rotary furnace provides an equal flexibility as the coreless induction furnace in the cast iron foundry. The investment costs however are lower. A 5 tonne furnace costs EUR 500.000 – 600.000, of which 30% are for the exhaust system and dedusting. Rotary furnace is also a good alternative for the small-scale cold blast cupola, due to its higher flexibility and lower environmental costs. Rotary furnaces are used for melting volumes of 2 to 20 tonnes, with production capacities of 1 to 6 tonnes per hour.

Its main advantages are:

- quick change of alloy possible,
- melting without contamination, e.g. without sulphur pick-up,
- low investment costs,
- small dedusting system because of low flue-gas rate,
- easy to maintain.

The disadvantages of the rotary furnace:

- easy burn-out of C, Si, Mn,
- gas and oxygen use can be high if not operated continuously,
- the energy consumption increases if more steel is added to the charge [5]

For the operation of rotary furnaces, BAT is all of the following, to:

- implement measures to optimize furnace yield,
- use an oxyburner,
- collect the off-gas close to the furnace exit, apply post combustion, cool it using a heat exchanger and then to apply dry dedusting,
- prevent and minimize dioxins and furan emissions to a level below 0,1 ng TEQ/Nm<sup>3</sup>.

For the production of nodular iron, nodularisation is performed. BAT for nodularisation is to:

- select a nodularisation techniques with no off-gas production or to capture the produced MgO smoke, using

a lid or cover equipped with extraction equipment or by using a fixed or movable hood, and to,

- dedust the exhaust gas using a bag filter and to make the dust available for recycling.

Table 2.  
Comparison of liquid cast iron costs – June 2003. Mass production – 10 t/h [6]

Units	Grade	Lamellar cast iron (ENGJL 250)				Nodular cast iron (ENGJS 400 – 15)		
		Cold blast cupola	Hot blast cupola	Cokeless cupola	Induction furnace	Hot blast cupola	Cokeless cupola	Induction furnace
EUR/t	Melting device							
	Metallic charge	95,80	59,52	96,68	72,97	49,75	73,52	59,80
	Ferrous alloys + additives	7,62	13,09	27,22	25,72	5,27	24,17	24,85
	Energy and fluids	33,14	35,26	20,29	27,28	40,12	21,07	27,28
	Linings	3,73	4,29	8,79	1,47	4,55	8,79	1,47
	Personnel costs	10,05	10	11	9,10	10,42	11	9,10
	Maintenance	1,55	3,15	0,16	0,93	3,15	0,16	0,93
	Environment	4,50	4,30	3,15	0,55	4,30	3,15	0,55
	Desulphurisation					10,33		
	Depreciation of investment	5,92	14,81	8,89	8,89	14,81	8,89	8,89
	<b>Total per tonne charged</b>	<b>162,31</b>	<b>144,42</b>	<b>176,78</b>	<b>146,91</b>	<b>142,70</b>	<b>150,75</b>	<b>132,97</b>
%	Fire loss	5	5	5	3	5	5	3
EUR/t	<b>Total per tonne liquid</b>	<b>170,85</b>	<b>152,02</b>	<b>185,45</b>	<b>151,45</b>	<b>150,31</b>	<b>158,68</b>	<b>136,98</b>
%	Returns percentage	35	40	35	40	50	50	50
EUR/t	<b>Total per tonne of casting</b>	<b>262,85</b>	<b>253,36</b>	<b>285,31</b>	<b>252,42</b>	<b>300,42</b>	<b>317,37</b>	<b>273,96</b>

### 3. Conclusions

From the discussions mentioned above, the following generalities can be deduced:

- Metal type: electrical furnace better placed for nodular or alloy cast iron,
- Continuous production: cupola is better placed,
- Batch production: electrical or rotary furnace is better placed,
- Flexibility towards input material type and cleanliness: cupola is better placed
- Flexibility towards alloy charge: induction or rotary furnace is better placed,
- Environmental consideration:
  - cupola is better placed only if well de-dusting, cokeless show better environmental performance than HBC or CBC,
  - induction furnace has lower CO, SO<sub>2</sub>, NO<sub>x</sub>, dioxin, slag, but this it needs to be borne in mind there will

also be emissions from the required electricity production,

- availability of raw materials: when cheap scrap is available, the cupola is better laced.

In fact, all these criteria must be considered together. On the basis of the stated criteria, the replacement of the cupola by induction or rotary furnaces may be considered. The selection of induction or rotary furnaces is given priority over cold blast cupolas for small foundries casting a variety of products in several European countries.

Table 2 summarizes the costs of cast iron calculated for the 3 main cupola types compared with coreless induction furnace [6]. Some items greatly depend on the melting device and the grade: energies and fluids, metallic charge and ferrous alloys.

### Acknowledgements

Paper financed by the scientific grant in years 2007-2009 as a Research and Development Project No R07 012 02

## References

- [1] Reference Document on Best Available Techniques in the Smitheries and Foundries Industry. May 2005, European Commission.
- [2] BAT for the Abatement of Atmospheric Pollution in the Ferrous Foundry Industry. European Commission – DG XI.E.1. CAEF (1997).
- [3] Cupola Melting of cast Iron in Iron Foundries (Good Practice – Guide 58), Energy Efficiency Office – Department of the Environment. ETSU (1993).
- [4] P. Godinot, Evolution of the Cupola in Europe, Fonderie Fondateurs Aujourd’hui (2001), 205, 28-40.
- [5] Beste Beschikbare Technieken voor de Gieterjen, Vito, ISBN 90 382 0312 8 (2001).
- [6] Godinot P. „The economical future of cupola”. International cupola conference. Trier (2004).