Coke Making from Coal : Scope for SSI

Ram Pravesh Bhagat
National Metallurgical Laboratory
Jamshedpur - 831 007

Preamble

The technological developments have opened up new avenues for small scale industries (SSI). The SSI sector has proved its mettle even in the changed liberalised economic environment of the nation. The SSI sector is riddled with certain problems. It is therefore need of the hour to strengthen the SSI sector and enhance its competitiveness domestically and globally – for this the sector must be provided sustenance through suitable measures. A significant contribution to the SSI sector in India comes from the metallurgical industries, particularly from the foundry metallurgy. Considering the fact that the developed nations, like, USA, UK, Germany etc. have dissociated themselves either partially or fully from the job of foundry metal-smelting in view of labour cost and environmental implications, there remains an ample scope for the foundry industries in India, China and other developing nations to go globally to meet their requirements in metal processing. Since then India became a member of GATT, the situation has provided an opportunity to the foundry industries to restructure themselves and produce and supply value added items to the advanced countries on one hand, also these industries face threat of competition from the producers of China and other developing countries on other hand.

Coke is an important component of the metal smelting in foundries. Like an iron blast furnace, the performance of a foundry depends on the quality of coke charged into it which in turns depend on the nature of coal and the process of carbonisation. Compared to the furnace coke, foundry coke is relatively a minor product. Nevertheless, the technologies that will affect future furnace coke markets also apply to foundry coke markets, but to a lesser extent. During the process of transforming coal into coke, which we call carbonisation (a) Coal tar, (b) Light oil, and (c) Coal gas are also obtained as by-products. These are important sources of chemicals including resins and dye-stuff and a significant scope exists for SSI to recover value added intermediates and fine chemicals from these co-products. An account has been in the present article about the scope for SSI sector and technologies for making quality coke for foundry industries. Besides, ways and means for the recovery of chemicals from the coke oven co-products are also mentioned.

Problems and Prospects of Foundry Industries in SSI Sector

There are about five thousand foundries in both organized and un-organized sectors in India with a total installed capacity of 3.4 MT castings (A C Ray: Indian Foundry Jour. **47,** Feb. 2001, p.44.). Most of these foundries are in SSI sector which contribute significantly to the Indian economy and all efforts should be made to help these industries. This is especially important in the post liberalization of Indian economy which has opened doors of the global markets to the Indian foundries. However, the industries has to accept the challenges of globalization for their survival and more importantly for their growth. In India , the technological status of SSI foundries varies from adequate to poor and enough scope exists for its up-gradation as evident from the performance norm given below (source : Technology evaluation and norms in ferrous industry, CDIR May 1990; An Indian Industrial and German Market Perspective, Indo-German Export Promotion Projects : A C Ray: Indian Foundry Jour. **47,** Feb. 2001, p.44) :

Parameters	**Indian Foundries**	**Overseas Foundries**
Yield, %		
(a) Cast iron	65	76
(b) Ductile iron	53	56
© Steel	50	55
Energy for melting, kWh/t	700-900	600
Capacity utilization ,%	45-55	60-70
Productivity, t/man/year	12-20	80(Germany),10-30 (China)

The foundries in India have to export castings to developed nations their survival. It is learnt that China is exporting the ductile castings at a price of Rs.20-24 per Kg. In order to compete with China they have to bring down the cost of production to match these prices. A well balanced divided blast cupola with a good pollution control equipment may deliver molten metal at 14-20-1480oC, at spout when using 12% ash hard coke. A low `P' and low `S' pig iron can be used with the charging of calcium carbide in order to restrict sulfur pickup in molten metal. The metal can be super-heated in an induction furnace at a relatively low cost of power and chemistry can be balanced to produce good

S.G iron molten metal. The following Table is an indication pertaining to the cost of production by duplexing cupola metal and induction furnace (N.D. Mimani : Indian Foundry Jour., **47**(April 2001), 29-30 :

Item/Description	**Quantity**	**Unit rate (Rs.)**	**Total (Rs.)**
Molten metal from cupola	500 Kg	9500/T	4750
M.S. Scrap	500 Kg	7000/T	3500
C.P. Coke	30 Kg	10/Kg	300
Ferro-silicon	10 Kg	35/Kg	350
Ferro-manganese	02 Kg	30/Kg	60
Si-Mg alloy	18 Kg	55/Kg	990
Incolution	04 Kg	35/Kg	140
Power	450 Units	4.50/Unit	2025
Others			200
Total			**12315**

Cost of production/T of castings (6% loss) :

65% yield : Rs. 15,300

70% yield : Rs. 14,800

The Indian foundries suffer from the following problems:

- High energy costs
- Poor surface appearance of the product
- Lack of quality consistency during manufacturing
- High emission and waste levels

Cost due energy happens to be an significant component of the melting for cast iron. More than 66 % of energy utilized in an iron foundry are used for the melting and holding and any improvement in this area can bring about considerable difference to the profitability of the foundry- based small scale industries (SSI). Amongst the two popular melting units for cast iron, namely cupola and induction furnace, cupolas have a bit too many variables as compared to induction furnace.

Cupola Operation

A cupola consists of a vertical and cylindrical steel shaft lines with fire clay bricks (Fig. 1) . It is provided with a door near the top for introduction of the charge, which consists of alternate layers of coke, limestone, pig iron and scrap. Air is introduced into the cupola through tuyeres evenly spaced around the circumference near the bottom. The coke burns in the blast of air, and the heat generated is sufficient to melt the iron, which trickles down to the base of cupola. The combustion products leaving the charge pass through the upper portion (called `stack') to the atmosphere. Below the tuyere level, the cupola is provided with tap holes for withdrawing slag and molten iron periodically. The whole furnace is supported above floor level on pillars.

The molten iron trickling over the incandescent coke absorbs small amount of carbon, as well as sulfur and phosphorous . The oxides of iron, silicon, and manganese, as well as the oxides associated with the charge and the ash of coke are fused with limestone at the cupola temperature to form slag.

Role of Coke in Foundry Cupola

The properties of coke influence the operation of cupola significantly and the efficient operation of a cupola depends on the fact that coke of uniform combustibility, size and good mechanical properties are used in the cupola and charged properly vis-à-vis the air blow rate is adjusted. The ideal properties of a foundry coke are given below (M. Arasu: Indian Foundry Jour. **47** (Dec. 2001), p.23):

Property	**Acceptable range**
Moisture, wt.%	Less than 3.0
Volatile matter, wt.%	Less than 2.0
Fixed carbon, wt.%	More than 86.0
Ash, wt.%	Less than 12.0
Sulfur, wt.%	Less than 8.0
Size w.r.t cupola diameter	50-125 mm Below 1/10-1/12

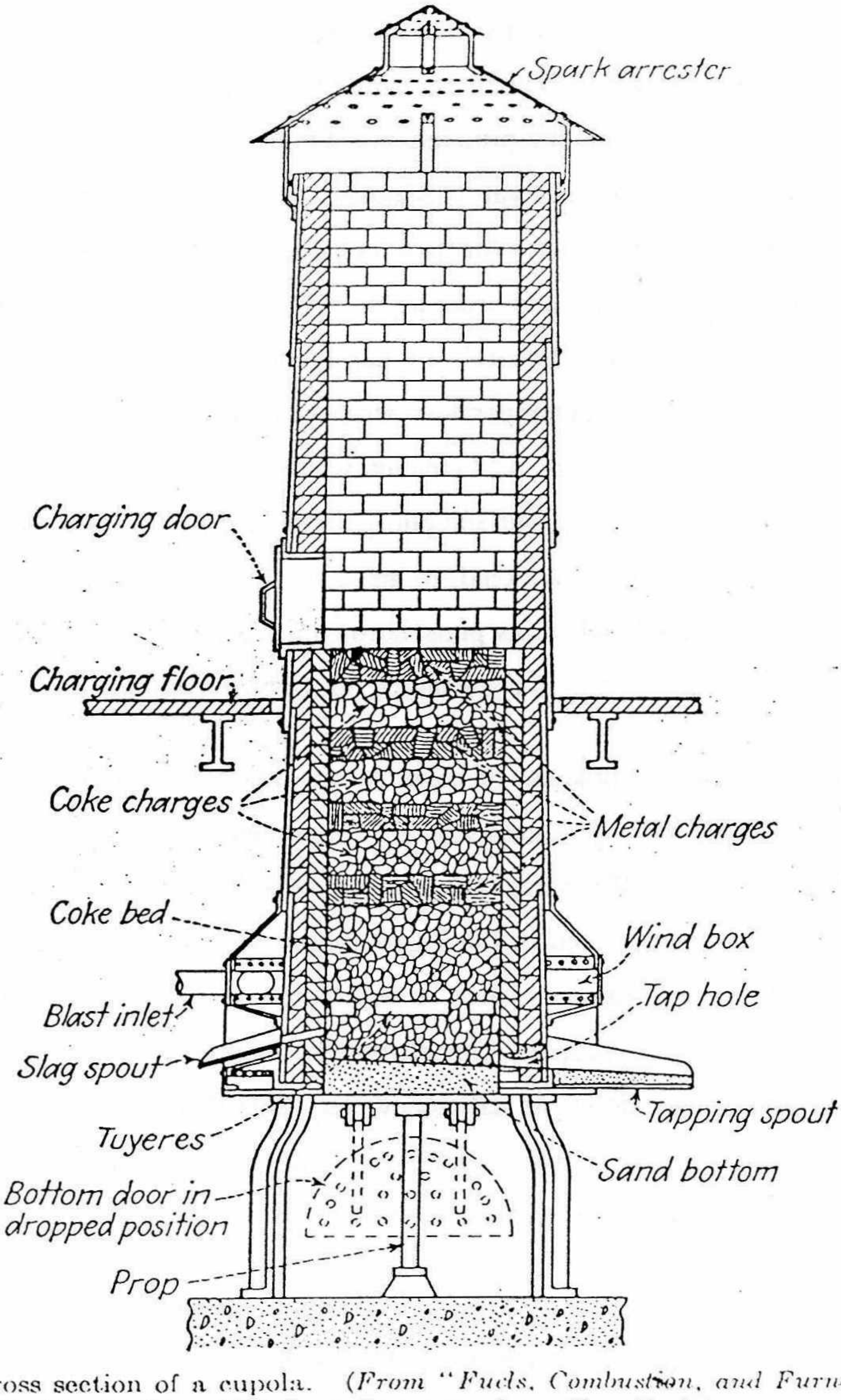

Fig. 1 Cross section of a cupola. (*From "Fuels, Combustion, and Furnaces," by John Griswold, published by McGraw-Hill Book Company, Inc., New York.*)

The moisture, volatile matter (VM) and ash of coke not only brings down the fixed carbon of coke, but also need extra thermal energy in order to expel them from the system. Ash from coke, which is acidic in nature (consisting of 60% silica, 30% alumina and 10% ferric oxide) forms the principal constituents of a slag. It is fused in melting zone and need fluxes for its removal. Obviously, higher the ash content in coke, higher would be the requirement of fluxes for its removal leading to a significant loss in energy since calcinations of limestone and bringing the CaO component to a higher temperature for its assimilation with acidic minerals are highly endothermic processes. VM is driven off from the coke at the cupola temperature and heat associated with it will not be utilized in the melting process. Therefore, VM content, which also represents the completeness of carbonization, should be low. Sulfur and phosphorous are picked up from the coke by the molten iron. A high sulfur content tends to make iron brittle when hot (the characteristics termed as `hot-shortness') where as phosphorous increases the brittleness of cold metal (cold shortness). Each element in coke should be very low.

Besides the chemical composition of coke, its size range as well as strength (cold and during reaction at high temperature) are important parameters in affecting the performance of a cupola. If the size range is large enough, then the smaller coke particles would occupy the voids created by the bigger particles of coke, thus adversely affecting the permeability of the cupola burden. A fragile coke create fines while handling and after being charged into the cupola. This disturbs the flow of air /gas and liquid metals in the furnace and brings down its efficiency very significantly. These parameters are influenced by the structure of coke: cokes with small cells and heavy walls are frequently strong, and the reactivity of the dense coke is believed to be low.

When coke burns completely to CO_2, the maximum amount of heat is released. The temperatures in the cupola are, however, high enough for the carbon dioxide to react with more coke with the formation of CO according to the reaction: $C + CO_2 = 2CO$ which is not desirable because of reduction in the thermal efficiency of the process. The reactivity of cupola coke with carbon dioxide to form carbon monoxide is increased by increasing the surface (area) of coke exposed to the gases by the use of either small size of coke, or a coke with open structure. A coke which has been thoroughly coked in the oven, so that VM is very low and graphitic carbon has formed on the surface , is less reactive with CO_2 than a less completely carbonized coke , and for this reason is preferred.

The rate of charging of coke and the rate of delivery of air must be compatible and accordingly controlled to have best energy operation in a cupola. The coke air balance is best indicated by the composition of flue gas which should contain 12-14% CO2 and 11-15 % CO. The air supply must be controlled as precise as possible since it can result in coke getting fully combusted. Normally, air requirement is about 8.5m3/Kg of coke (M. Arasu: Indian Foundry Jour. **47**(Dec. 2001), 23-27.

Coal, Coke and Coal Chemicals : Introduction & Historical Background

Coal is a carbonaceous rock, it is not a mineral with fixed composition. Consequently, it does not have a fixed formula. It is known that coke was an article of commerce among the Chinese over 2000 years ago and in the middle ages it was used in the arts and for domestic purposes, Nevertheless, it was not until the 1620 AD that there is a significant record of producing coke in an oven. In this year Sir William St. John was granted a patent in England for the beehive oven. Until the middle of 19^{th} century, coal tar and tar products were regarded as wastes, to be either thrown away or burnt under coking retorts. In the years about 1845 AD tar began to be used in Germany for making roofing felts: distillation products of tar were applied through impregnation as a wood preservative. A year or two earlier , in England, coal-tar naphtha had been successfully employed as solvent for India rubber- a use still common today. The synthesis of the first coal tar color by Sir William Perkin in 1856 caused a great demand for the crude coal tar and it became a commercial product of increasing value. Perkin, by his discovery of the brilliant violet dye laid the foundation of world's coal dye industry.

The process of making coke from the coals, which we call carbonization can be broadly categorized into two:

- Low temperature carbonization (temp. range of 450-750 °C) to produce mainly liquid products, and

- High temperature carbonization (temp. above 900°C) to produce mainly gaseous products.

Carbonization is a very complex process involving physical and chemical changes and cannot be defined by a given set of chemical equations. The function of coke oven plant is not only to produce coke of desired specification, but also to generate and utilize the by-products, namely coal tar, coal gas and light oils effectively. Figure 2 is schematic of a modern by-product coke oven plant which happens to be an integral part of an iron and steel industries.

Technological Options for Improving Quality of Coke

The quality of coke plays a major role in the performance and economics of cupola operation. Several technologies have been developed in the recent past in order to improve the coke quality. Some of them are mentioned below:

Use of Additives Eureka pitch (Petroleum pitch) and coal tar derivatives improve the M_{10} value of coke by 1-2 points.

Crushing Index of Coal Even with 80% crushing of –3 mm size fraction of coal, + 6 mm fraction in coal is about 8-10 % which act as center of weakness in the coke matrix. Therefore multi- stage crushing of coal with screening out – 3 mm size fraction at every stage need to be incorporated in order to obtain coal of uniform size before its carbonization.

Group-wise Crushing of Coal Blend Components Different coals have different grinding characteristics. Therefore, it is essential crush them separately and mixed together in order to get optimum result.

Carbonization Temperature and its Duration Because of high inert content in coal and increase coking period (also lesser coking rate) than that in abroad the +80 mm size fraction in finished coke is high. Also, the strength of coke is lees. The carbonization condition need to be optimized for obtaining good coke.

Partial Briquetting of Coal Charge The strength of finished coke increases when about 30% of coal blend is charged in the form of briquette. This improves the overall bulk density of the coal charge from , say, from 770Kg/m^3 to 830Kg/m^3.

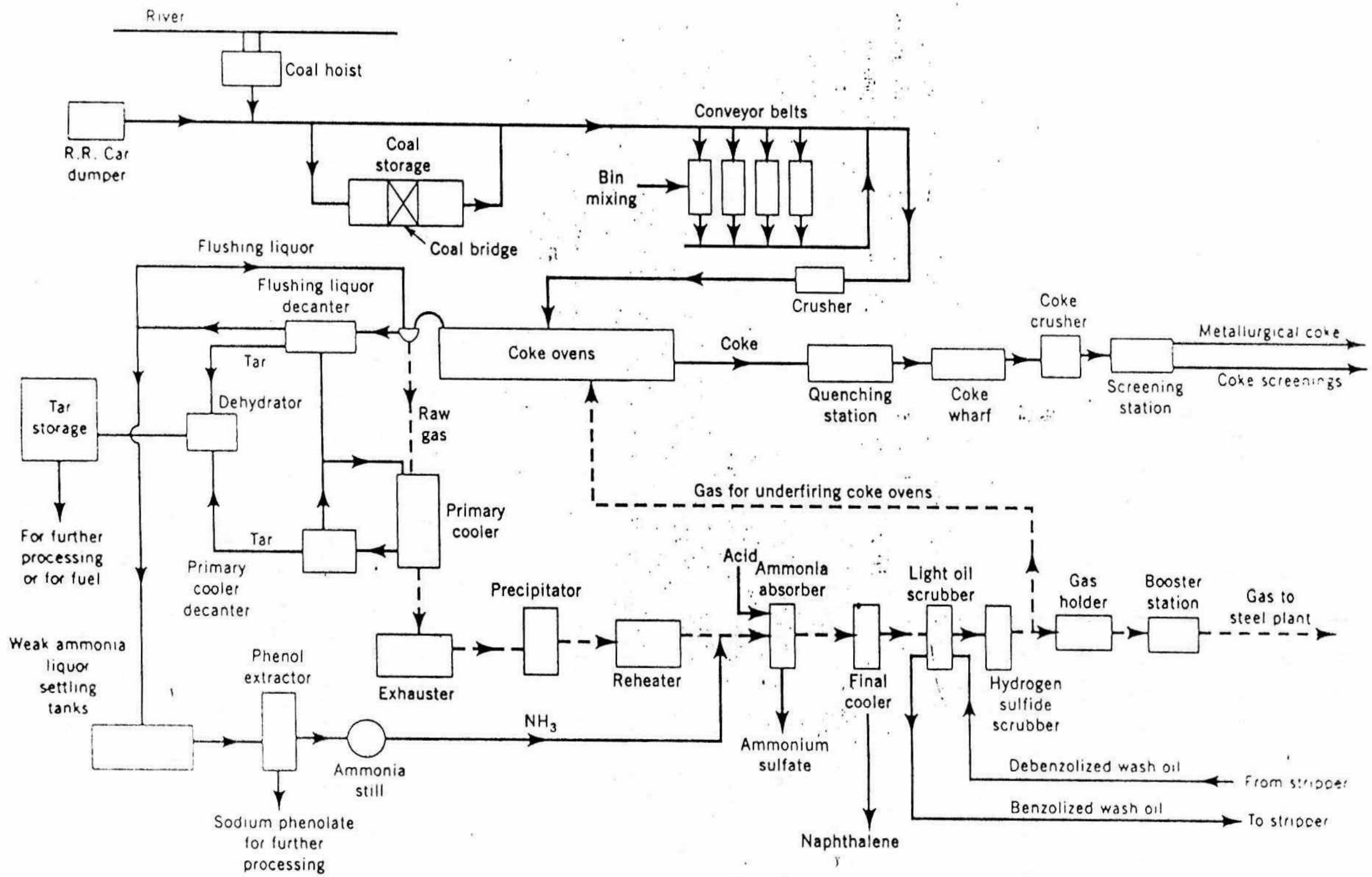

Fig. 2 Schematic for a by-product coke plant (9).

By-Product Recovery

The tar products being recovered from the carbonization are naphthalene, crude anthracene, phenol, various tar oils and pitch. Out of these products, more profitable utilization of anthracene, other tar oils and pitch merit consideration to the SSI naphthalene and phenols are produced by the coke oven plants in the Iron & Steel sectors and no difficulty is presently faced for their marketing.

Anthracene Up-gradation The tar plants in the Indian steel industries are designed to produce crude anthracene of 20-25% purity. Since this product has no ready market, it is mixed with coal tar fuel. If up-graded to 90% purity, the product could be used to anthra-quinone which is very useful intermediate for dyestuff industries.

Carbon black from Coal Tar Oil The yield of coal tar is 30-36% of crude tar processed. At present, these tar oils are used to produce coal tar oils by mixing with pitch and fuels are consumed internally in the steel plants. The anthracene oil could be more profitably used as a feedstock for the manufacture of carbon. The anthracene oil, due to low sulfur content in it is more suited than the petroleum based feed stock for this purpose.

Production of Pitch Coke At present in most of the steel plants, coal tar pitch is consumed internally as fuel. The pitch coke has huge market potential in the aluminium industries, graphite electrodes etc.. Therefore, the production of pitch coke could be considered by the SSI in view of the fact that there is a big gap in the demand and availability in the country and pitch coke is a better substitute for petroleum coke.

Concluding Remarks

The performance of the cupola depends on the quality of coke being used in it. Besides the coal characteristics, the technique of carbonization as well as post carbonization handling and treatment of coke play important role in affecting the coke quality quite significantly, and therefore need to be addresses by the concerned industries. This is more important in view of the fact that the quality of coal is guided by the natural constraints and one has little control over changing its quality significantly apart from its beneficiation which is normally under purview of the large scale coal washeries. The process of coke making for the foundry industries and recovery of by-product from the coke oven gases and liquids happen to be interesting areas before the SSI sector.