PYROMETALLURGICAL PILOT PLANTS(*)

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For understanding the probability of a metallurgical process and to ascertain its economic feasibility, pyrometallurgical pilot plants have contributed a great deal for the establishment of metallurgical industries. Extensive trials on large scale, as for example in industrial furnaces, are very costly and difficult to organize. It is obvious that after the successful conclusion of investigations in laboratory scale, the process cannot be adapted in plant scale, as the gulf between the two is too wide to be bridged. The pilot plant, therefore, forms an intermediate step and if it is of proper dimensions, the experiences gained in its operation can be safely extrapolated to assess the process in commercial scale. It is possible to reduce to scale reasonably and still obtain fruitful results. The question often arises as to what will be correct size of a pilot plant. Generally the size of the experimental unit has been decided on the ability to handle the requisite raw materials, space available, equipments available for handling raw materials, availability of water and power, man power for its operation and chiefly the funds available for its installation. A more appropriate selection of the size of an iron smelting furnace for example, should be such as to be able to burn a proportionate amount of carbon per unit of hearth area per unit of time and the CO/CO_2 ratio of the exit gas should be identical to the conventional blast furnace. It would also be desirable to have similar gas velocities in both the cases. It is obvious that the grain size of raw materials have to be appropriately reduced. The object of this brief paper is to review the contributions of a few selected pyrometallurgical pilot plants for the development of new iron and steel making processes which have since been adapted in modern industrial plants. The initial investigations in the pilot plants have either made the domestic raw materials amenable for exploitation in industrial plants or have completely revolutionized the metallurgical process so as to make it more economical both for its installation and for its operation.

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Pilot Plants for the Alternative Methods of Iron Production:

It is well-known that the conventional blast furnace is the most convenient and cheapest method of producing pig iron, but the grade of raw materials are either in short supply or not at all available in certain countries.

Low-Shaft Furnace Pilot Plant - East Germany

In the absence of any deposit of metallurgical coal for producing coke and iron ore suitable for smelting in the conventional blast furnace, it was realised in East Germany that the development of the iron and steel industry depends on the simultaneous utilization of the available low grade iron ore (21-27% Fe, 22-40% SiO_2) and brown coal (or lignite) vast deposits of which exist. At Maxhutte, East Germany, smeltings tests were initially conducted in a 2 tons/day experimental furnace.

The object was to find out whether sufficiently high temperature can be obtained by the combustion of low grade fuel and whether the chemical reactions can be controlled by adjustment of normal operational variables. Although fuel consumption was very high, pig iron was obtained from very poor iron ores containing 20-30% Fe and inferior grade of coke.

Based on the experiences gained in this small experimental furnace, a furnace ("Donaworth") with a hearth area of 7.32m^2 and effective height of 3800 mm having a capacity of 40 tons/day was erected.

It is interesting to note that although the initial tests were conducted with a furnace of round hearth, a rectangular hearth was employed for further investigations. The hearth width is governed by the ability of the blast to penetrate to its centre with minimum dust losses. Circular hearth of equivalent area will necessitate higher air blast pressure. While the shorter height of the furnace widens the choice of raw materials, the reaction time in a low shaft furnace becomes 1/3 to 1/5 of that in a blast furnace. The preparation of the burden is therefore necessary. The tests in this furnace not only confirmed the results obtained in the 2-ton furnace but actually yielded better results with lower fuel consumption and carbon absorption was higher. On the basis of the results obtained with this furnaces, 10 low shaft furnaces were constructed having hearth areas of 9 m^2 and 11 m^2 with rated capacity of about 80-100 tons/day. This plant has a special significance as it is the only commercial plant consisting of a battery of 10 low shaft furnaces.

Low Shaft Furnace Pilot Plant of Demag
Humboldt Niederschachtofen, West Germany:

It has been mentioned that chief interest in the low-shaft furnace operation lies in the utilisation of low grade ore fines and inferior grades of fuel. Though West Germany is not directly affected by the want of suitable raw materials for blast furnace operation, extensive investigations are being conducted for the production of commercial pig iron from non-coking coal and ore fines.

DHN Water Jacketted Low Shaft Furnace Pilot Plant:

For the understanding of the metallurgical processes involved in the one stage smelting of self-fluxing iron ore-limestone-coal briquettes a small low shaft furnace pilot plant was constructed.

The hearth of the furnace was removable and the double jacketted furnace shell above the hearth having an internal diameter of 900 mm was cooled by water circulation.

The effect of the binders from coal, oil derivatives and organic substances on the property of ore-coal-limestone briquettes and their behaviour on smelting were thoroughly investigated in this furnace, the removable hearth of which allowed the furnace to be stopped immediately after each operation. It is obvious, however, that the loss of heat in such a furnace was excessive to assess the fuel rate.

12-15 Tons/Day Low Shaft Furnace Pilot Plant:

A 12-15 tons per day low-shaft furnace pilot plant was erected at Cologne, West Germany. The furnace has a slight oval cross section 1.3 m x 1.0 m., of 1.04m^2 and effective hearth area of 0.82 m^2, effective charging height of 3.2 m from tuyer level to the stock line and 4 tuyers of 90 mm. diameter.

In the DHN process, carbonisation of the coal, and reduction of iron-oxides occur during the passage of the briquettes through the furnace. Iron ore containing 55% Fe and non-coking coal containing 35% V.M. and 6% ash were employed. It was found that a compressive strength of 30-40 kg/m^2 was sufficient to prevent the briquette from crumbling into pieces. The behaviour of the briquette in the furnace is influenced by the reducibility of the ore and coking index of coal, and the grain size of ore and fuel has to be properly adjusted.

DHN 100 Tons/Day Low Shaft Furnace Plant:

Based on the experience gained, the DHN have built a 100 tons/day commercial low shaft furnace plant at Troisdorf, near Cologne. It is of rectangular section. The preheated air blast enters the furnace through 10 tuyers. Although a certain amount of lumpy raw materials are employed in the initial stages, the ultimate aim however, is to employ briquettes exclusively in the burden. The foundry grade iron is cast in a pig casting machine while the slag is granulated.

Both these examples will clearly indicate the importance of investigations in Pilot plants, which have been able to treat inferior grade of domestic raw materials for the production of pig iron.

Utilisation of Lignite in Yugoslavia:

In Yugoslavia, the blast furnace operation has to depend on imported coal. But Yugoslavia has extensive deposits of brown coal (lignite), the estimated reserve being over 80 million tons. The calorific value of the raw lignite is 2000 -2200 Kcal/Kg which is raised to 3000 -3400 Kcal/Kg at 15-18% moisture content. Investigations have, therefore, been taken up for the utilisation of lignite in low shaft furnaces and experimental blast furnace.

Low Shaft Furnace Pilot Plant in Yugoslavia:

Initial experiments were conducted in a small shaft furnace having a hearth diameter of 300 mm and effective height of 1800 mm.

Based on experience gained on the smelting of domestic ores (48-73% Fe_2O_3, 9-20% SiO_2, 0.2 -3.7% Al_2O_3) with soft coke in this experimental low-shaft furnace, a bigger low shaft furnace having a hearth diameter of 500 mm and effective height of 6200 mm. (approximately) with two rows of tuyers, has been built. The second row of tuyers at the bosh has been made with the intention of increasing the zone of reactions, which will produce more iron per unit hearth area. It was ascertained that the composition of the exit gas was not altered by the two rows of tuyers and it analysed 8% CO_2 and 32% CO.

Investigations were conducted on blending of coals with brown coal and lignite to obtain metallurgical coke.

A total of 2000 tons of coke was produced for smelting trials. Another blend was developed from domestic Kakanj coal and imported coal from U.S.A. in the ratio of 35% to 65% respectively.

The blend was carbonised at a temperature of 1250°C and 3000 tons of coke were made for conducting smelting trials.

Smelting trials were conducted in a 3300 mm. dia. small blast furnace at Sisac. The consumption of indigenous coke amounted to 155 ton/day in place of 149 tons/day of the normal coke, but the increased consumption was accompanied with slightly higher production of pig iron.

The International Low Shaft Furnace:

Considering various aspects of the problem a low shaft furnace of oval cross-section was built the dimensions being 3000 mm x 1200 mm with an effective height of 5000 mm (9-9" x 4' x 16' high) with hearth area of 3 m^2 (31 sq.ft.) with the aim of burning 66 tons of coke per day and producing 40 tons of pig iron. It may be mentioned that ore fines, coal, and fine grained coke have been utilized to produce iron.

Low Shaft Furnace Pilot Plant in Japan:

An experimental 3 tons/day low shaft furnace has been in operation in Japan. Smelting with weak coke 10-25 mm. in size and iron ore under 5 mm. in size showed that the consumption of fuel was higher and production was lower in comparison to the use of blast furnace coke. Ore under 1 mm. and coke 10-20 mm in size gave best results. On enriching the blast to 25% oxygen, the coke ratio was decreased by 20% and the production was increased by 38%.

12-15 Tons/Day Low Shaft Furnace Pilot Plant in India:

In order to assess the possibilities of making commercial grades of pig iron with raw materials such as, soft iron-ores, iron-ore fines, beneficiated magnetite iron ore, various high ash non-coking coals, or carbonised lignite, plentiful supplies of which are available but are unsuitable for exploitation in the conventional blast furnace, a 12-15 tons/day low shaft furnace pilot plant is currently in operation at the National Metallurgical Laboratory, Jamshedpur. It will be premature to finalize any result since the trials are currently in active progress.

Utilization of Anthracite in Experimental Blast Furnace:

An experimental blast furnace was employed to find out the maximum amount of anthracite that could be substituted for coke as fuel in the normal blast furnace operation.

The investigation in an experimental furnace indicated the possibilities of utilization of certain amount of anthracite in blast furnaces of low shaft height.

Investigations on Steel Making:

It is well-known that the production of low nitrogen steel is not possible in the basic Bessemer process. Decreasing the contact of nitrogen with the bath was expected to lower the nitrogen contents. A 1000 lb. basic lined surface blown hearth was employed in Battelle Memorial Institute for the purpose. Pig iron of a composition suitable for refining in basic open hearth furnace was blown. Efficient dephosphorization was obtained by double slagging process. The metal was uniformly low in nitrogen contents (0.003%). Based on the trials in 1000 lb. converter, a series of trials was conducted in a 30 ton basic lined vessel, when the results obtained in the pilot plant were completely corroborated.

Trials with Steam and Oxygen:

At the Hagen Haspe works in West Germany trials were conducted by Kosmider and Hardt to produce low nitrogen steel from basic Bessemer pig iron by blowing steam and oxygen through the bottom of a 2 ton basic lined converter. At the temperature of the bath steam dissociates into hydrogen and oxygen. A mixture of 60% oxygen and 40% steam by weight have the same thermal effects as obtained by blowing air, which can be introduced in two ways. In the first method, oxygen enriched air can be employed till the carbon is reduced to half followed by 63/37 oxygen steam mixture in which oxygen can be increased during the final stages. In the second method oxygen-steam mixture can be employed throughout the process.

Daubersey has reported the results of trials conducted in a 15 tons converter at the Esperance-Longdoz Works in Liege, Belgium, which confirmed the results obtained in the experimental converter.

Coheur and Kosmider have reported the nitrogen contents of Thomas steels made by blowing air, oxygen enriched air and oxygen steam mixtures. It has been reported that almost all Thomas converter plants in West Germany, France and Luxemburg have adapted oxygen-steam process for producing low nitrogen deep drawing steels.

Trials with Oxygen-Carbon-Dioxide:

Warrant furnished the details of experimental trials by blowing oxygen-carbon-dioxide mixture. Mayer, Knuppel, Darmann and Pottgiesser conducted tests in 25-30 ton converters and a oxygen-carbon-dioxide ratio of 1.5 to 1.0 gave the same thermal results as air. Pig iron analysing 3.6% C, 0.28% SO, 0.93% Mn, 1.78% P was converted into steels containing 0.002 to 0.006% nitrogen after a blowing time of 18 minutes. Kalling mentioned the results of tests conducted in 14 ton converter with 50 : 50 Oxygen-carbon-dioxide mixture, which was injected after the preliminary air blowing.

At La Sambre in Belgium both oxygen-steam and oxygen-carbon dioxide blowing are employed. It is, however, more economical to generate steam and superheat it, which explains the wider adaptation of oxygen-steam process for producing low nitrogen steels.

Top Blowing with Oxygen for Steel Making:

Durrer and Hellbrugge conducted experiments on blowing of almost pure oxygen in 2 to 2.5 ton converter at Gerlafingen, Switzerland for the conversion of pig iron of different compositions to low nitrogen steels.

Sen, Nijhawan and Chatterjea have reported that Indian pig iron containing 3.5 to 4% C, 1.5 to 2.0% Si, 0.7 to 1.0% Mn, 0.35 to 0.40% P and 0.035 to 0.040% S can be converted into steel in a double slagging technique by oxygen injected through a consumable lance of $\frac{1}{4}$" diameter in a 250 lbs. basic lined experimental converter.

Suess tried to make steel by blowing oxygen in a two metric ton converter. In the impingement area, metallurgical reactions readily occur. The pressure of oxygen and dimensions of vessel were adjusted. The process had favourable heat balance, obviously due to absence of nitrogen ballast.

In the background of these small scale trials, investigations were carried out where compelling factors like non-availability of sufficient scrap for open hearth operation and the composition of pig iron which does not lend itself for blowing in conventional converter contributed towards the development of top-blowing with oxygen for commercial steel making. The process known as the L-D process in which oxygen is blown downwards on the bath of metal is a revolutionary development.

L-D Process for Treating High Phosphorus Iron:

Normally the L-D process is not suitable for treating pig iron containing over 0.4% phosphorus. Springerum, Speith and Celsen investigated the possibilities of treating pig iron with 2.0% phosphorus in a 3 ton converter at Huckingen, West Germany. A large number of modifications have enabled the treatment of high phosphorus irons in the L-D steel making process.

As the analysis of iron in the States was somewhat different to that employed elsewhere for the oxygen steel making, investigations were conducted to produce high carbon low phosphorus steels low in nitrogen contents from pig irons containing upto 1.0% P by a pneumatic process without the application of external heat in 750 lbs. side blown basic lined converter. Molten pig iron analysing C - 4.0%, Mn 1.5%, Si 1.0% and P 0.24 -0.27% was charged with limestone iron ore sinter and scrap (25 lbs). The elimination of C and P progressed simultaneously and after 20 minutes of blowing phosphorus was lowered to acceptable limits while the bath still had about 1.25% C. Substantial sulphur is eliminated and nitrogen contents in steel varied from traces to 0.003%. On the successful attainment of the objective, the process was tried in commercial scale to produce 125 tons of steel/heat by modification of a 175 tons basic open hearth furnace, when no external fuel was necessary.

The 'Rotor' and 'Kaldo' Process of Steel Making:

Although no small pilot plant was employed the two other steel making processes which followed the L-D process were the Rotor and Kaldo processes.

With the aim of treating pig iron with low intermediate or high phosphorus contents, the 'rotor' has been developed in the works of Guttehoftnungshutte at Oberhausen, West Germany. The liquid pig-iron is placed in horizontally mounted revolving cylindrical furnace 50 ft. long with 12 ft. diameter. It revolves on its axis once in about two minutes. The combustion of CO to CO_2 inside the furnace results in better heat balance. In Rotor process almost all P is eliminated by the time 50% decarburization has taken place. It has been mentioned that the steel contains 0.003 to 0.005% nitrogen and its quality was comparable to open-hearth steel.

Two 100 ton Rotors are installed at the Vanderbihil Park Works in South Africa which can be removed from the rollers and put in vertical position to facilitate relining.

Another rotary oxygen steel making process,developed by Prof. Kalling and his colleagues is known as 'Kaldo' process. Kaldo is in commercial operation since May 1956 in Stora Koppenberg, Domnsfervet steel plant, Sweden.

Two 80 ton Kaldo converters are installed in a new steel plant at Oxelosund in Sweden. It may be mentioned here that in these rotating furnace oxygen injection processes pig iron of any phosphorus content can be refined.

Oxygen-Lime-Powder Injection (O.L.P.) Process:

It has been mentioned that the L-D process cannot normally treat high phosphorus irons of 1.2 to 1.8 per cent. In Austria fluxing agents like fluorspar or bauxite have been employed to treat pig irons containing 1.2 or lower amounts of phosphorus. A French steel Company la Societe des Forges et Acieries Ole Pompey has extended the limit of phosphorus to 1.8 per cent by the addition of mill scale.

(IRSID) has developed another industrial technique known as O-L-P Process for the treatment of irons of any phosphorus content. In this process varying contents of finely divided lime powder (86% CaO) is suspended in the stream of oxygen (99.5%). The technique eliminates the use of fluorspar and no foaming occurs due to high silicon in molten iron. The consumption of oxygen and lime are 2,200 cu.ft. and 310 lb. per ton of iron and about 600 lbs. scrap can be added.

The L-D -AC Process Developed By Arbed:

At ARBED - Dudelange oxygen injection with lime powder was employed in a new steel making process christened as "LD-AC". Investigations were done in a 25 ton vessel. The elimination of phosphorus before substantial decarburization is possible as in other oxygen steel making processes.

Summary and Conclusions:

The experiments initially conducted in low shaft furnace pilot plants for the production of iron with inferior grade of raw materials unsuitable for smelting in the conventional blast furnace have helped the development of a basic industry. It has been conclusively proved that poor quality raw materials can be suitably exploited to avoid importation of an essential basic material like iron.

In the field of steel production the lists initially conducted in pilot plants and finally corroborated in industrial plants have shown that the composition of pig iron, availability of adequate amount of scrap and the requisite fuel for heating the furnace, do no longer stand in the way of producing acceptable grades of steel.

In view of these examples it has been concluded that pyrometallurgical pilot plants have immense contribution on the study and development of hitherto unknown metallurgical processes in industrial scale and therefore justify their installation.

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