POSSIBILITIES OF PRODUCTION AND USE OF SPONGE IRON IN THE ARAB COUNTRIES

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THE Arab countries, being short in coking coals while having petroleum, natural gas and low grade coals, are studying the possibilities of producing sponge iron from their local iron ores using these raw materials instead of imported coke which costs them a lot of hard currency.

Proved reserves of iron ores, natural gas and coals in the Arab Countries are given in Table (1)[1,2].

Studies performed for the production of sponge iron

The studies performed can be classified into three categories:

(1) Reduction of iron ores with reducing gases.
(2) Reduction with liquid hydrocarbons (petroleum products).
(3) Reduction with solid carbonaceous materials.

Reduction with gases

Research work, both on the laboratory and pilot scales, was performed mainly with hydrogen by virtue of the fact that hydrogen is the main and most important reductant produced through reforming natural hydrocarbons (petroleum products and natural gas). Reduction with mixtures of hydrogen and carbon monoxide was studied too since these two gases represent the actual reducing power of reformed natural hydrocarbons. Natural gas and reformed natural gas were also used for reduction to compare between the merits and demerits of using natural gas as it is or after being reformed.

As for the reduction with hydrogen, the effects of temperature, gas/ore ratio, ore nature and porosity, particle size and characteristics, and gas flow rate on reduction were studied. The reduction rate increases, generally, with the increase in temperature, with the increase in gas/ore ratio, increase in ore porosity, decrease in particle size and increase in gas flow rate; temperature and gas/ore ratio having major effects while the other factors have only minor effects [3-4]

Three reduction systems were used; a simple horizontal tube furnace arrangement[5], reduction of fine particles under free suspension as a cloud in the reducing gas,[6-8] and reduction in the fluidized state[9-13]. Reduction of the particles under free suspension was found to be impracticable. Reduction in the fluidized state proved itself and the phenomena of sticking between the partially reduced particles was well studied and efforts to delay it were successful.

Table I. Reserves of iron ores, natural gas and coals in the Arab Countries.

Country	Iron Ores Million tons	Iron Ores %Fe	Natural Gas Billions cu. m.	Coals Million tons
Algeria	1500	50-60	4500	Bit. Coal 32
Egypt	300	40-55	150	Sub. Bit. 30
Gulf Emarates	—	—	900	
Iraq	—	—	570	
Kuwait	—	—	1200	
Libya	700	45-50	900	
Morocco	50	50-55	1.0	Anthracite 28
Saudi Arabia	350	40-60	1500	
Sudan	35	60-63	—	
Syria	60	30-40	21	
Tunisia	57	50-55	30	Lignite 20

Other reserves are not yet estimated.

In a trial designed to enhance the reduction the effects of catalysis and gamma-irradiation were investigated but were found to be not promising [14-15]. Hydrogen being the main constituent of any reducing gas produced from natural hydrocarbons whether before or during reduction, its effect on the different impurities present in iron ores was also studied intensively [16-20]. The reaction between hydrogen and oxygen in the presence of partially reduced iron ores for the development of part of the heat requirements of the process was investigated. [21-22]

As for the reduction with mixtures of hydrogen and carbon monoxide the reduction rate, under the same conditions, increases with the increase in hydrogen content. [23] However, the reduction rate minimum observed for the reduction of dense ores with pure hydrogen [24] was not observed here except for the reduction of porous ores, and the temperature at which this minimum occurred changed; the rate minimum was more pronounced as the carbon monoxide content in the reducing gas increased. As for the slowing down phenomenon in reduction rate which took place for the reduction with pure hydrogen, its extent changed here, under the same conditions with the constitution of the gaseous mixture according to reduction temperature and ore porosity.

The results of the reduction with reformed natural gas confirmed, more or less, those obtained with mixtures of hydrogen and carbon monoxide since the reduction rate increased with the increase in the hydrogen content of reformed gas. [25]

Natural gas reduced the ore slightly at temperatures below 600°C. As the temperature increased reduction rate increased and so did the extent of formation of soot and some oily and tarry material. The study is going on; however, recent work in this direction in some other countries, not only proved the possibility of the direct use of natural gas in iron ore reduction, but also indicated its superiority over the use of reformed gas from the point of view of reduction efficiency and cost. [26-28]

A process was devised and proved on the pilot scale for the gaseous reduction of iron ores [29-30] It makes use of fine rather than lump ore by virtue of the recent trend towards the preconcentration of the ore and the belief that to re-agglomerate the ores after concentration would be wasteful of time and money. The fluo-solid technique is used for reduction since it represents the most efficient means of mass and heat transfer between gas and solid. A five-compartment reactor is used, ore preheating and reduction being achieved in the same unit. Most of the heat requirements of the process is developed inside the reactor through oxygen injection. Up to 95% reduction could be attained at 650°C using a hydrogen/48% Fe ore ratio of 2.0 n.cu.m./kg. (excess hydrogen would be recycled).

This reactor can be used as well for the reduction with liquid hydrocarbons after being vaporized. The fine sponge iron produced may be briquetted or charged as it is to melting or smelting furnaces according to its iron content and extent of reduction.

Reduction with petroleum products

Naphtha produced in big amounts in the petroleum refineries of some Arab countries represents a problem to those countries which have to sell it with quite a low price, (other distillation products are of value to the petroleum industry). If this naphtha is used for iron production a great benefit will result; the naphtha produced in Egypt alone suffices the annual production of about one and half million tons of steel and thus can save us more than fifty million dollars hard currency (the cost of imported coke).

Naphtha, being a mixture of hydrocarbons, when its vapour passes over heated iron oxide (which acts as a catalyst), cracking of the hydrocarbon molecules takes place resulting in the formation of hydrogen, carbon and lighter hydrocarbons. These reducing agents reduce iron oxide with the formation of steam, carbon monoxide and carbon dioxide. These gaseous reduction products react simultaneously with precipitated carbon and the gaseous hydrocarbons reforming hydrogen and carbon monoxide again and so forth. The freshly reduced iron helps, catalytically, all these reactions while the simultaneous regeneration of the reducing gases from the gaseous reduction products is a big favour to the reduction reaction according to the law of mass action. This means that all the reactions occurring during reduction with naphtha, and in general during reduction with hydrocarbon gases and vapours, help each other which raises greatly the efficiency of the process; the ultimate result being the reduction of iron oxide to metallic iron and the formation of different types and amounts of gases with the precipitation of carbon.

As an example of the results obtained; one litre naphtha could reduce five kilograms of a 48% Fe ore at 900°C to 85% reduction, depositing two hundred grams of carbon and producing about one cubic meter of gases which can be used for reduction or for providing the heat requirements of the process. The deposited amount of carbon is sufficient to eliminate the remaining oxygen in the ore by direct reduction leaving 3.7% carbon in the reduced sample.[31]

Reduction with carbonaceous materials

In this study the sub-bituminous Maghara coal of Egypt, and the petroleum coke produced by delayed coking of an Egyptian crude residium, were used as reductants.[32] The aim was the production of pre-reduced pellets suitable for charging in steel making or iron smelting furnaces. The study consisted of preparing mixtures, of the fine ore and carbonaceous material, of different compositions, pelletizing these mixtures, and then firing the produced pellets at different temperatures for varying periods of time in absence of air. The extent of reduction of the fired pellets at different conditions, their residual carbon, crushing strength and in some cases their sulphur content were all determined.

As an example, table II collects some of the results obtained for pellets at different compositions fired at 1000°C for twenty minutes.

[Similar studies could be performed for other Arab countries which have low grade coals or petroleum coke as Algeria, Morocco, Tunisia, Yemen and Syria (a study is being conducted for the latter), and as will be seen promising results could be achieved.]

Table II. Effect of reductant countent on fired pellets characteristics

Reductant	Carbon Countent Stoichio-metric	Reduction Extent %	Residuel Carbon %	Crushing Strength kg/pellet	Desul-phuri-zation %
Maghara	0.25	69	0.0	52	39
Coal	0.35	100	0.5	80	
	0.50	100	2.7	10	
	1.00	100	12.1	1	
Petroleum	0.25	55	0.0	21	46
Coke	0.50	92	0.3	40	
	1.00	98	6.1	6	

It could be concluded from the results of this study that reduction extent of the pellets increases with the increase in the reductant content in the pellets and with the increase in the volatile matter content of the reductant. The increase in temperature and time of firing raises both the reduction extent and crushing strength while it brings down the residual carbon; the crushing strength being favourably affected by the increase in reduction extent and decrease in residual carbon. The 0.375 value of the stoichiometric carbon required for complete reduction is considered as the optimum value in case of using Maghara coal while that for petroleum coke is 0.5; the difference being due to the higher volatile matter content of Maghara coal. The optimum value is that at which maximum reduction extent, minimum residual carbon and highest crushing strength are obtained.

The extent of desulphurization depends mainly on the volatile matter content and the forms in which sulphur is present in the carbonaceous material. Although considerable portion of the sulphur present in the reductant could be removed during firing, separate desulphurization studies were performed using different techniques and over 90% desulphurization could be achieved.[33,34]

The future of sponge iron making and utilization in the Arab countries

Although many Arab countries, as for example Algeria, Morocco, Saudi Arabia, Libya, Iraq, Kuwait and Egypt, are thinking seriously, each on her own, of manufacturing sponge iron for steel production, and many techno-economic studies were done for this purpose, an interesting article was presented by the Industrial Development Center of the League of Arab States (IDCAS) to the Second Conference on Industrial Development in the Arab Countries sponsored by UNIDO and held in Kuwait during October 1971, proposing the establishment of an Inter-Arab integrated iron and steel plant based on the gaseous reduction of iron ores.[35]

After presenting the situation of the iron and steel industry in the Arab countries, the consumption per capita of the different varieties of steel products at different years, volumes of local production and imports; and taking into consideration the expansions scheduled in the existing iron and steel plants and the production of the projected plants till 1980, the study concluded that in that year (1980) the total annual production of steel products will be about six million tons while the total consumption of the Arab countries will be no less than seven million tons. Accordingly the Arabs will be still in need of at least one million tons, mainly of R.C. steel bars and wire rods.

Hence, the study proposed that this one million tons should be produced through the sponge iron—electric steel making route, and a detailed description of the proposed plant together with its capital, running and production costs were presented. The site of the project is to be on or near a sea port on the Mediterranean or on the Arabian Gulf near natural gas resources. If this plant proves itself future iron and steel plants in the Arab countries would follow the same technology.

An example of the local efforts conducted in this direction in some Arab countries is the studies going on in Egypt.

The first steel plants erected in Egypt were built after the second world war to make use of the accumulating scrap in the western desert. Two small factories one based on electric steel making and the other using the open-hearth furnace practice converted this scrap to R.C. steel bars. A third plant based on the open-hearth furnace technology was built in 1953. The three plants depend now on imported scrap and their total annual production amounts to two hundred thousand tons. According to new expansions their production will be doubled by 1975.

Realizing that the establishment of integrated iron and steel industry is important for the developing countries, a plant was erected in 1958 at El-Tebbin near Cairo. It consists of two small blast furnaces, four Thomas converters and rolling mills for the production of about quarter a million tons per year of plates and light sections. By 1975 two extra blast furnaces, three oxygen-steel converters and the necessary rolling mills will be in operation in the same factory. Out of its total production, about quarter a million tons of pig iron will be exported and about the same amount but of steel billets will be rolled to R.C. bars in the three steel works mentioned above to make use of their surplus rolling capacity, thus increasing their production to six hundred thousand tons of R.C. bars and wire rods per year. The annual production of El-Tebbin complex will be about one million tons of other steel products which makes the total local annual production 1.6 million tons by 1975.[1]

It is estimated that by 1980 an extra half a million tons of steel products will be required per year; accordingly two alternatives were studied. The first is the erection of an integrated plant at Aswan in Upper Egypt based on electric smelting and oxygen-steel making to make use of the cheap abundant electric power produced from the High-Dam, and of the by-product oxygen produced from a near-by fertilizer company. Alexandria was chosen for the site of the other alternative plant which is based on the sponge iron-electric steel making route. Natural gas from Abu-Keer well, thirty kilometers east of Alexandria, will be used both for reduction and electric power generation.

Aswan iron ore together with Maghara coal and petroleum coke are to be used for iron production in the Aswan plant and hence was the study performed on sponge iron production through the formation and firing of iron-carbon pellets.[32] The firing of the pellets is supposed to take place in vertical shafts superimposing the electric smelting furnace, in shaft furnaces independent from the smelting furnaces, on rotating hearths or on travelling grates.[36,37] The volatiles produced during firing, from the carbonaceous material, can be used as a fuel to provide the heat requirements of the firing process. In spite of the high sulphur content of both Maghara coal and petroleum coke; being mixed in small percentages with the ore (15% and 10% respectively), and since about half their sulphur content is expelled during the firing operation, the sulphur content of the fired pellets will be quite low.

These pellets should be continuously charged while being still hot from the firing operation, to the smelting furnaces, to save some of the electric power consumption. Charging of pre-reduced material to smelting furnaces results in a saving of up to 50% in coke or electric power consumption and increases production by about the same per cent.[38]

As mentioned before, when reduction of Aswan iron ore was performed with naphtha a product of 85% reduction was produced which contained enough carbon to eliminate the remaining oxygen in the charge by direct reduction during the smelting operation, giving rise to a pig iron of 3.7% carbon. Accordingly this pre-reduced material is equally suitable as a charge to the electric smelting furnaces of the Aswan project.

Natural gas has been discovered recently in some parts of Egypt. One of these locations is at Abu-Keer near Alexandria. Other natural gas resources in Egypt were made use of in some projects. It has been suggested that the Abu-Keer natural gas would be used for sponge iron production. A project for the erection of an integrated iron and steel plant similar to the proposed Inter-Arab plan but of half its productive capacity is being studied. Since the H.Y.L. process is the only gaseous reduction process that has been proved on an industrial scale for a long time, it was recommended to be used in this plant. Samples of El-Baharia ore were sent to the H.Y.L. people in Mexico and U.S.A. through UNIDO to examine their suitability for this process. Beneficiation and reduction tests were performed on both laboratory and pilot scales and the results sent to the Egyptian authorities are promising. Sponge iron produced in the plant will be converted to steel in ultra-powered continuously charged electric-arc steel making furnaces to increase the economy and the productive capacity of the plant.[39]

Whether the Alexandria or Aswan plant will be given the priority for execution depends on many considerations which have not been decided yet. However, a high level governmental committee have concluded recently that due to the vast expansion in housing and other constructional items the total requirements of R.C. bars will amount to eight hundred thousand tons by 1977. Since, according to present plans the total production of R.C. bars will be only six hundred thousand tons the committee urged the erection of a new steel plant for the production of this extra two hundred thousand tons.

Consequently former plans have to be revised particularly since this new decision results in an extra load on our hard currency expenses because of the scrap and other raw materials that have to be imported.

Three alternatives are suggested: either to start the erection of the Aswan plant so that its first stage (300,000 t/year) would be in production by 1977, or to do the same with respect to Alexandria project. The third alternative depends on the fact that the production of the steel shop in El-Tebbin Iron and Steel Complex is estimated on the basis of charging the oxygen—steel converters with only 15% scrap due to the shortage in local scrap production. However, since it became normal practice to charge the converters with up to 30-35% scrap, if this practice is followed in our case the annual production of the complex will increase by the required 200,000 ton. Since the projected continuous casting facilities can accommodate this extra production, the only installation required will be a small rolling mill.

To avoid importing scrap the third alternative recommends the erection of the first stage of the Alexandria project without the melting and rolling shops, that is to say the reduction shop only to produce the sponge iron required, as scrap substitute, for charging in the oxygen-steel converters in El-Tebbin plant. In this first stage high grade iron ore pellets will be imported since studies for concentrating and pelletizing the Egyptian iron ores will take some time. Should this stage prove itself, future policy concerning the scheduled second stage, and further expansions, should take into consideration not only the production of enough sponge iron to substitute as much as we can of imported scrap and to fulfil our requirements of steel products, but also to cover as much as we can of the future needs of some European Countries of sponge iron.[40]

In conclusion, it should be mentioned that following the sponge iron route in Egypt will save us no less than thirty five million dollars hard currency per every million tons of steel produced. Moreover sponge iron production may become one of our resources of hard currency in the near future; not only for Egypt, but also for many other Arab countries.

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DISCUSSION

Mr. Amal Chakravorty, (State Industrial & Investment Corpn. of Maharashtra, Bombay) Regarding the query I have raised during the symposium in connection with the paper presented by Said Y. Ezz, I would like to mention here that during the discussions, the Author mentioned that in the Sponge Iron carbon contamination will be around 3.7%. I was wondering to know, whether with this high percentage of carbon in sponge iron, will there be no problem in converting into steel, charging along with the steel scrap in the electric arc furnace? If I am correct, it is emphasised that the charging of sponge iron should be continuous in nature in the electric arc furnace too. Naturally, whether the scope of carbon reduction from the sponge iron will be left in the continuous process. If so, what should be the source of Oxygen? Should it be external? Then that means that there should be Oxygen blowing also to reduce the carbon to make it upto the limited range of the carbon in the finished steel. Is Oxygen blowing practice also made there? What will be the system of Oxygen Blowing in that case? Whether it should be periodical or it should also have continuous system? If Oxygen blowing is there, it is but natural that there should be a agetation in the furnace bath, and there will be operational difficulties and higher volume of slag will be there.

I should be grateful if the Author can throw some light about it. I shall be glad to know process of melting this sponge iron along with scrap in the electric furnace with higher carbon quantity.

Prof. Dr. S. Y. Ezz (Author)

As to the question raised by Mr. Amal Chakravorty concerning my paper to the Symposium, I beg to refer him to reference 31 in the paper and to the paragraph at the top right of page 38 of the paper which reads "As an example of the results obtained; one litre naphtha could reduce five kilograms of a 48% Fe ore at 900°C to 85% reduction, depositing 200 gm of carbon etc. The deposited amount of carbon is sufficient to eliminate the remaining oxygen in the ore by direct reduction leaving 3.7% carbon in the reduced sample."

This particular work was performed in conjunction with a project which was proposed to be based on the electric smelting of the Aswan low grade ore using the cheap electric power generated from the High Dam. By-product oxygen from a nearby fertilizer company at Aswan would have been used for converting the produced pig iron.

The aim of the work was to pre-reduce the ore before being charged to the electric smelting furnaces to cut down electric power consumption, and to dispense as far as possible with imported coke. There was no intention at all to produce sponge iron for steel making, as could be envisaged from the low iron content of the ore, the low extent of reduction and the high content of carbon.

It was only assumed that if no extra coke is added during the smelting operation, the carbon content of the partially reduced ore would be enough to complete the reduction leaving about 3.7% C (by calculation) in the pig iron produced. This would have been converted to steel in LD-AC converters in the normal way.