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A Novel Method for the Production of Pig Iron in “Hadisolb” Company (Industrial-Scale Experiments)

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ORIGINAL STUDY

A Novel Method for the Production of Pig Iron in 'Hadisolb' Company (Industrial-scale Experiments)

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Abstract

The chairman of 'Hadisolb' submitted a memorandum in 1977 in which he claimed that the company would not be able to achieve its planned production capacity unless harmful impurities, in particular high alkali metals and manganese dioxide, were removed from the blast furnace feed. Meanwhile, D.R. steelmakers are facing challenges due to the accumulation of scrap containing more than 67% Fe, no alkali, and small amounts of MnO. The innovative concept presented here involves discovering the optimal ratio between El-Gedida ore and waste material (WM). A previous study involved a series of pilot-scale sintering tests, which ultimately resulted in the mixture being found to contain 70% WM and include 30% of the ores gave the most favorable results. In the current study, a series of industrial-scale experiments were performed focusing on sintering the above-mentioned optimal mixture and then using the resulting sinter as the only iron-containing component within an industrial blast furnace experimental load. The technical and economic indicators of the large-scale trials carried out demonstrate the plausibility of this innovative concept, which involves the use of a mixture of 70% WM and 30% of El-Bahareya ore (El-Gedida) as specialized ferrous material in the 'Hadisolb' blast furnace to eliminate harmful impurities present in El-Bahareya iron ore.

Keywords: Alkalis, Blast furnace, Iron and steel, Iron ore, Pig iron

1. Introduction

Iron ore was first discovered in 1903 at 'Ghorabi' in Egypt's Eastern Desert, and subsequently in Aswan in 1907 and 1917 (Rasoul et al., 2021). These discoveries sparked the dream of starting a steel production company. This dream came true in 1954 when the German company 'Demag' submitted an offer to the Egyptian Industrialization Authority to develop the Egyptian Steel Company (Hadisolb) in Helwan. At that time, 'Hadisolb' consisted of two small blast furnaces (each with a size of 575 cubic meters), a mixer, and two small Tomas converters (because of the relatively high P_2O_5 content in Aswan's iron ore). At that time, 'Hadisolb' had to import the coke required for the blast furnace. 'Hadisolb' was founded in the city of Helwan, near Cairo. At the same time, the iron ore is located in the east of Aswan City, 1000 km south of Helwan, the birthplace of the 'Hadisolb' company, while the imported coke is located about 300 km north of Helwan.

It did not take long (about 10 years) for 'Hadisolb' to discover that the iron ore from Aswan no longer met the agreed specifications for the blast furnace. 'Hadisolb' recognized that the introduction of selective mining operations was responsible for this disastrous situation. Therefore, 'Hadisolb' urgently needs to miraculously find another local iron ore of equal quality and price. In 1964, 'Hadisolb' was lucky when geologists from the Geological Survey of Egypt announced the discovery of ore mines deposits in the El-Gedida area of the El-Bahareya Oasis. The iron ore from the El-Gedida site consists of three sites, as shown in Table 1 (Rassoul, 1985).

2. Procedure

Ore from all three sites is mined and stored in separate warehouses before being fed into the process of individual crusher cells, each of which is

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Table 1. Average chemical composition and reserves at three sites in El-Gedida (Rassoul, 1985).

Locality	Iron %	Chlorine %	Manganese oxide %	Silicon dioxide %	Calcium oxide %	Aluminum oxide %	Reserves M. Tons
Plateau	58.2	0.74	1.4	10.5	4.5	3.6	39.6
West Valley	50.2	0.47	3.75	8.5	3.5	3.5	60.0
East Valley	48.8	0.22	1.55	12.20	3.5	2.0	11.98
Total Reserves							111.58

ground to a uniform quality of appropriate size and known average chemical composition, then sent to a large mixer or added to a blender. This is shown in the qualitative flowchart in Fig. 1 (Abderrassoul and Rassoul, 1996).

3. Beneficiation of El-Gedida iron ores

Optimization techniques were applied to set a plan for using the three localities. Calculations for determining the proper quantities of ore from each locality to be blended to suit the cut off limits for: Fe greater than 51%, Cl less than 0.06%, MnO less than 2.4%, SiO_2 less than 8.5%, CaO less than 8%, and Al_2O_3less than 3.5%. Other alternatives for optimizing the time span of utilization and to produce that blend which 'Hadisolb' tolerates effectively are given in (Rassoul, 1985).

In 1963, after exploring and evaluating the El-Gedida mine, the company, known as 'Hadisolb,' began looking for ways to expand its operations. At the same time, Teagrom's export authorities expressed willingness to achieve the goals sought by 'Hadisolb', leading to a formal agreement between the two parties in 1964. According to the established agreement, 'Hadisolb' is said to have a sinter plant with an annual output of more than 2.4 million tons of sinter that meets the above specifications. This means that the iron-rich material in the blast furnace feed consists entirely of sinter.

Under the agreement, 'Hadisolb' will have a blast furnace plant equipped with all necessary equipment and accessories. Both new blast furnaces are medium-sized blast furnaces with a capacity of 1033 m^3 each, similar to the Soviet blast furnaces at Cherepovets. According to the agreement, the output of each blast furnace should be 2500 m.t. pig iron/day, according to the expected production capacity specified in the agreement, while furnaces of the same size were manufactured only in Cherepovets.

One thousand seven hundred thirty m.t of pig iron (Abderrassoul and Rassoul, 1996), and the blast furnace of the size 1520 m^3 in Armco Steel Corporation is the one which is capable of producing ~2500 m.t./d, according to the same reference. Meanwhile, the Teagrom export authority ought to choose such size of blast furnace for 'Hadisolb'; the BSc students in the Department of Mechanical Engineering of Assiut University had concluded in 1965 in their graduation project titled 'Design of a blast furnace capable of producing 2500 m t of pig iron/d', the valuable volume for such a blast furnace is 1550 m^3, which is very close to that in Armco Steel Corporation.

The selection of smaller-sized blast furnaces was not the sole drawback identified in the technical report. The most prominent drawback was the disregard for the substantial presence of alkalis in the Ore. This oversight resulted in numerous complications during both the Sintering and blast furnace processes, encompassing (Rasoul et al., 2021):

(1) Formation of scaffolds and scraps on the furnace lining which reduces its useful volume,

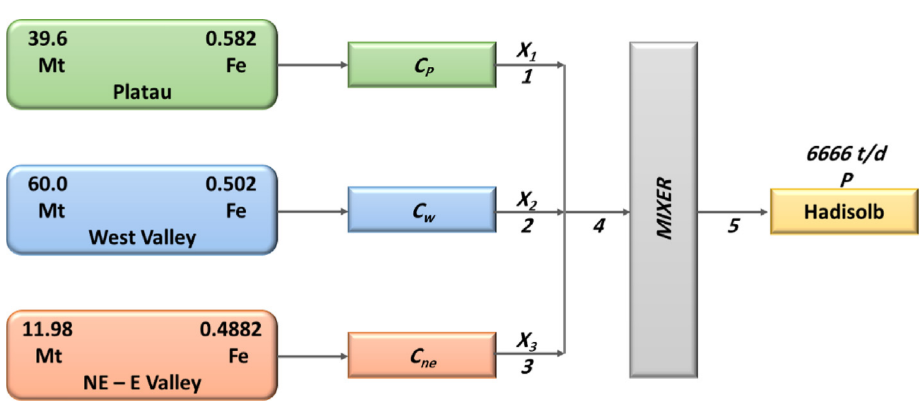

Fig. 1. Flow sheet for blend preparation (Abderrassoul and Rassoul, 1996).

(2) Excessive coke disintegration which leads to higher coke consumption,
(3) Enhances the swelling properties of the iron-bearing materials,
(4) Shortens the lifetime of the lining,
(5) Shortens the lifetime of the sintering machine.

Abraham and Staffansson, 1975 investigated the behavior and circulation of alkalis in the blast furnace. The most common species involved in the alkali circulation in a blast furnace are K and Na vapors, their cyanides in the solid, liquid, or vapor phase, and their carbonates or silicates either in the solid and/or liquid phase. The melting points of these species are given in Table 2 (Rasoul et al., 2021).

4. Utilization of El-Bahareya iron ores

In this investigation we shall be concerned with the minimization of the detrimental effect of the alkali halides in both the sintering and the blast furnace processes (Abraham and Staffansson, 1975; A-H and SMA, 1989; Davies et al., 1978). The iron ore deposits in El-Bahareya oasis in El-Gedida region are the only iron bearing material used in the Iron and Steel Company (Hadisolb) at Helwan. The iron ores in El-Gedida region are located in three localities, with different qualities and quantities. 'Hadisolb' requires 6666 m t/d (2.4 m t/y) of a blend in which Fe is greater than 51%, Cl less than0.3%, and MnO less than 2.4%.

An optimization technique was employed to formulate a strategic plan for utilizing El-Gedida ores within the burden. The optimal proportions of each specific region within the mixture were ascertained to adhere to the prescribed thresholds for Fe, Cl, and Mn concentrations.

The novelty inherent in this proposed methodology lies in discovering an additional fourth locality or source characterized by an exceedingly low alkali content of nearly zero percent, along with minimal traces of MnO. This newfound locality will be incorporated into the blending process alongside the other three existing localities. It is worth noting that four steel companies in the Dominican Republic have the potential to generate significant quantities of iron oxide fines and sludge as byproducts. Table 3 provides the chemical composition of the waste mentioned above materials (WM).

Table 2. Melting and boiling points of the most common alkali species which may exist in a blast furnace (A-H and SMA, 1989).

Substance	m.p. °C	b.p. °C	Substance	m.p. °C	b.p. °C
K	62.3	760	KCN	634.5	
Na	97.5	880		622.0	1625
KCl	790.0	1500	NaCN	563.7	1496
NaCl	800.4	1413		562.0	1530
$CaCl_2$	772.0	1600	K_2CO_3	891.0	Dec.
	772.0	(1935)		907.0	Dec.
K_2O Sub.	881.0		K_2SiO_3	076.0	
Na_2O	01132.			997.0	
			Na_2SiO_2	1089.0	

4.1. Materials and industrial-scale experiments

'Hadisolb' is a vertically integrated corporation that employs the sintering-blast furnace – B.O.F. pathway, thereby requiring the utilization of superior-grade iron ore from the initial stages, producing high-quality sinter. In addition to the iron ore, the sintering charge typically comprises the necessary quantities of limestone (L.S.) as a flux, coke, and water (Davies et al., 1978; Fang, 2010). It is evident that the El-Bahareya iron ores, despite their inherent limitations, are essentially regarded as the sole economically viable iron-bearing resource accessible to 'Hadisolb'. In the memorandum submitted by the chairman of 'Hadisolb' in 1977, it was asserted that the company ought to devise a strategy to mitigate the presence of harmful impurities, namely alkalis and a reduced percentage of MnO, within the iron ore.

The previously determined blend ratios from the three localities of El-Gedida mines in El-Bahareya oasis –after so many years of exploitation (>40 years)- became unable to fulfill the previously agreed upon obligations. A discovery of another source besides the three localities became very necessary. Here, the metallurgists had discovered that source. It was lucky to find that this source contains zero% alkalis and very low MnO%. This source was nothing but the WM resulting in the DR steel companies.

A series of pilot-scale sintering experiments for different blends of WM with El-Gedida ores were performed to determine the best blend that will be

Table 3. Chemical composition of waste material from DR companies.

Waste material	Iron %	Calcium oxide %	Silicon dioxide %	Aluminum oxide %	Manganese oxide %	Alkalis %
Oxide fines	67.8	0.8	1.1	0.16	0.1	nil
Sludge	68.1	1.2	1.8	.16	0.2	nil

used in the industrial-scale experiments (Nicol et al., 2019). The best blend ratio was determined based on the indices of the produced sinter, accordingly, the sinter produced from a blend composed from 70% WM together with 30% of El-Bahareya iron ores had the best indices, and thus a blend with that ratio will be used in the industrial-scale sintering experiments.

4.2. Industrial-scale experiments

4.2.1. Sintering of a blend composed of 70% WM and 30% E-Bahareya ores

Researchers likely examined varying quantities of iron ore, coke, LS, and other additives during the sintering process as part of a systematic investigation into the different ratios tested. These experiments would have aimed to ascertain the optimal combination of these materials to achieve the desired sintered burdens for the blast furnaces. The investigations may have involved adjusting the ratios, evaluating the physical, chemical, and mechanical properties of the resulting sintered products, and subsequently analyzing the outcomes. Assessments of its mechanical and chemical composition were probably conducted concerning the iron produced. These examinations are crucial for evaluating the quality of the iron and ensuring that it meets the specified requirements for the blast furnaces. Mechanical tests would have entailed the evaluation of strength, hardness, and impact resistance.

Conversely, chemical composition tests would have scrutinized the levels of various elements in the iron to guarantee adherence to the necessary standards. These tests are vital in quality control, ensuring the iron produced suits its intended application. The partnership protocol resembles mutually beneficial projects and can be regarded as a paradigm for cooperation among various companies in various industrial sectors.

Based on the results of the previous investigations, a blend composed of 70% WM, which has 67% Fe, zero% alkalis and traces of MnO, and 30% E-Bahareya iron ores, in which Fe is 45% and Cl is ~0.8% and MnO is 2.5%.

Fig. 2 illustrates the sintering machine with hearth area of 50 m^2 used in performing the experiments. The bed depth for all experiments was 30 cm. The details of the sintering process in order to get self-fluxed sinter was described in (Nicol et al., 2019; Upadhyaya, 2009). The chemical analysis and mechanical properties of the produced sinter are given in Table 4 (Rassoul and Rassoul, 2021).

4.2.2. Pig iron production

The selection of the industrial experimentation apparatus involved the deliberate choice of a compact furnace with a volumetric capacity of 575 cubic meters, meticulously engineered by the esteemed German company 'Demag'. The objective of these experiments was to assess the integrity of our innovative proposal regarding the amalgamation of El-Bahareya iron ore, containing ~45% Fe, ~2.5% MnO, and alkalis at about 0.8%, with WM, which possesses 67% Fe, no alkalis, and negligible amounts of MnO. The ratio of WM to B.O. was maintained at 7:3.

The operational data attributes about the selected blast furnace, as outlined in (von Bogdandy et al., 1971), are as follows:

The blast furnace's adequate volume is 575 m^3, with a hearth diameter measuring 5.49 m. The blast volume is 74 000 m^3/h, while the blast temperature reaches 800 °C. Additionally, the blast pressure is estimated at 1.24 kg/cm^2. The consumption of coke

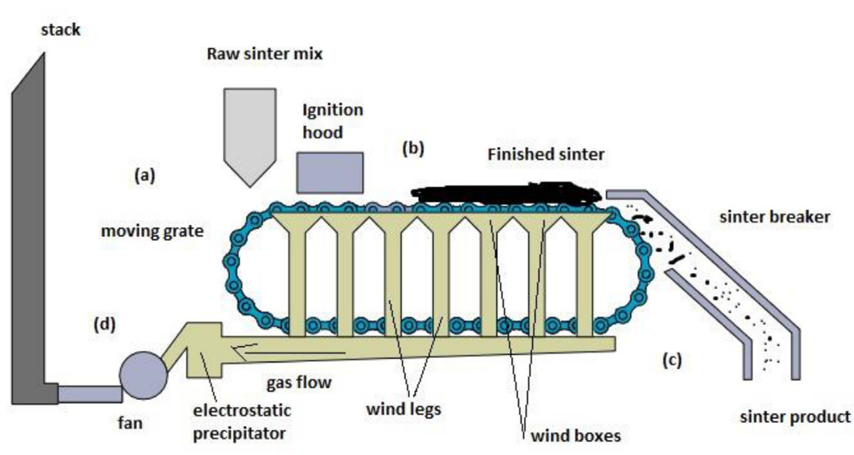

Fig. 2. The sintering machine used in performing the experiments (heart area = 50 m^2).

Table 4. Average chemical composition and drum results for the produced sinter (70% WM and 30% El-Bahareya area) (Rassoul and Rassoul, 2021).

Blending ratio %	Iron %	Iron oxide %	Silicon dioxide %	Aluminum oxide %	Magnesium oxide %	Calcium oxide%	Chlorine	Basicity	L.O.I.[a]	Mechanical Pr. drum test −5 ml%
70% WM 30% Ore	60.1	19.6	5.6	1.6	1.6	6.05	0.09	1.03	To 100%	10.5

[a] Loss on Ignition.

stands at 600 kg/ton of pig iron, with a gross burden of 1500 kg/ton of iron. The basicity is reported as 1.04, and the slag volume amounts to 350 kg/ton of pig iron. The daily pig iron production is documented as 900 tons, and the blast furnace coefficient is calculated as 1.56 tons/cubic meter. The burden consists entirely of self-fluxed sinter material. It is pertinent to note that, based on the validated data from 'Hadisolb,' a notable correlation has been established. Specifically, for each incremental rise of 1% in the iron composition within the burden, there is a corresponding augmentation of 1.8% in the resultant pig iron output, accompanied by a reduction in coke consumption by 1.1 kg/metric ton of pig iron.

5. Discussion and conclusion

The objective of this study is to establish the integrity of the novel proposition, namely, the feasibility of utilizing an iron-rich substance containing appropriate levels of alkali halides and MnO content to enhance the quality of El-Gedida iron ores in the blast furnaces operated by 'Hadisolb'.

The introduction of the novel proposal not only resulted in a reduction of the alkali halide concentration in the mixture but also yielded significant benefits for both 'Hadisolb' and the D.R. companies. These advantages are outlined below:

5.1. DR companies gains

Companies are transitioning to local cast iron sources like Hadisolb, promoting sustainability and self-sufficiency through an innovative exchange system that enhances efficiency and collaboration across industries. These could be summarized as:

(1) The companies will stop importing the cast iron they need, since they have a secure local source, 'Hadisolb' of course, by giving their WM to 'Hadisolb' and getting instead an equivalent amount of cast iron.
(2) The protocol between the partners is very similar to a win−win projects and may be considered a model for cooperation between other companies and in different industrial sectors.

5.2. 'Hadisolb' gains

WM with 67% Fe content extends El-Bahareya iron ore mine lifespan, reduces coke consumption, boosts blast furnace productivity, and improves steelmaking process by reducing manganese in pig iron. These could be summarized as:

(1) The WM composed of ~67% Fe and zero% alkalis with an annual generation of 1 million tons/y can be considered as a highly rich iron oxide mine of endless lifetime and increasing reserve.
(2) The lifetime of El-Bahareya iron ore mines will be extended.
(3) A noticeable decrease in coke consumption in both the sintering and the blast furnace processes.
(4) An increase in the productivity of the blast furnaces by about 200 kg/d, since 1% increase in the iron content in the iron-bearing material will cause an increase in the produced pig iron by 1.8%.
(5) The lifetime of the sintering grid and the rest of the sintering machine utilities will be extended.
(6) The lifetime of the L.S. quarries will be extended.
(7) The decrease of Mn in the pig iron will be positively reflected in the steel making process.

Author credit statement

The author confirms sole responsibility for the following paper: "A Novel Method for the Production of Pig Iron in "Hadisolb" Company (Industrial-Scale Experiments)", study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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Conflicts of interest

There are no conflicts of interest.

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