COMPARISON OF SINTER AND PELLET USAGE IN AN INTEGRATED STEEL PLANT[1]

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Abstract

Global iron ore production has grown dramatically in recent years to meet increasing world steel demand, especially in Asia. High grade lump ore resources are being depleted and a greater amount of fine concentrate/pellet feed will enter into production as lower grade deposits are mined. Integrated steel plants need to make convenient use of the available iron ore resources to optimize operation and the cost of steel. The advantages and disadvantages of using greater amounts of iron ore concentrate are discussed, focusing on the production and use of fired pellets in the blast furnace. Hot metal production using sinter and pellets in the blast furnace is compared, considering aspects like; blast furnace productivity, environmental performance, solid waste management, slag-coke rates, and the steel plant energy balance.

Key words: Iron ore; Pellet feed; Sintering; Pelletizing; Blast furnace.

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1 INTRODUCTION

In recent years, fine iron ore concentrate production, also referred to as pellet feed increased as the availability of new lump ore and high quality sinter fines declined during a period of rapidly expanding demand driven by the Asian steel industries. As a result, iron ore miners developed lower grade resources that must be finely ground and processed to increase their Fe content to the levels required by the marketplace. This trend will continue as lower grade resources must be exploited to meet the continuing growth in global steel production.

Most pellet feed will be sold in the seaborne trade rather than being captive to a dedicated steel plant. A fraction of these finely ground concentrates has been and will continue to be blended with sinter feed and processed on sintering strands. The application of concentrate in sintering is ultimately limited as permeability and quality limitations are reached, hence global pellet production will inevitably increase to consume the concentrate that will enter the marketplace. Steelmakers will need to increase the pellet consumption in their blast furnace burdens, or in the extreme case switch to all-pellet blast furnace operation.

Hatch compared the merits of using both pellets and sinter as the main constituents of the blast furnace burden, focusing on blast furnace productivity, environmental performance, solid waste management, and the steel plant energy balance. For this exercise, only sinter fines and fired pellets available in the seaborne market were considered. Lump ores were not used in the burden mixes studied due to the expected decline in lump availability in the coming years.

2 BACKGROUND

2.1 Trends in the Seaborne Iron Ore Market

The global seaborne iron ore market including sinter feed, lump ore, pellets and pellet feed has rapidly increased over the last decade. While sinter feed sales dominate the global seaborne trade, pellet feed and fired pellet sales have grown at a faster rate. Hatch anticipates that fired pellet and pellet feed sales will further accelerate at the expense of sinter feed due to declining availability of high-quality sinter fine resources. In Figures 1 and 2, the growth of the seaborne trade and Hatch's projection of the global seaborne iron ore trade to 2040 are presented.

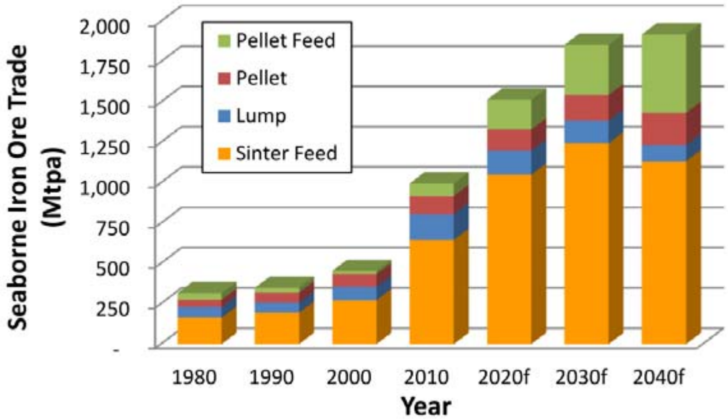


Figure 1. Historic Growth and the Future Projection of the Global Seaborne Iron Ore Trade.(1)

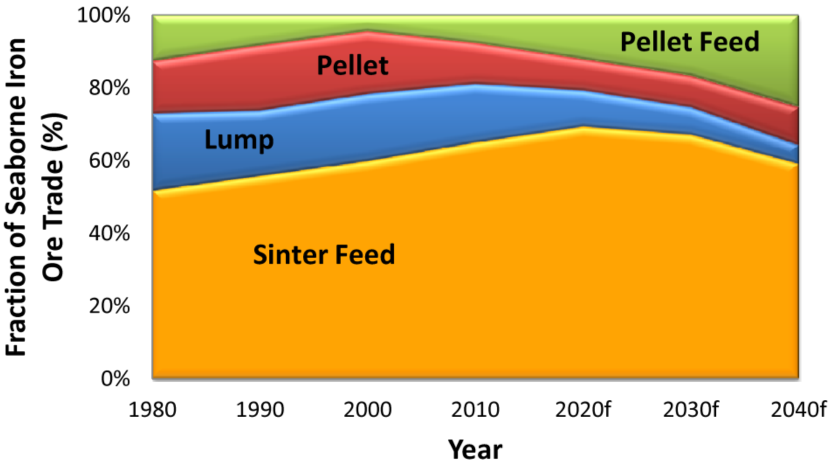


Figure 2. Projected Product Sales Distribution for the Global Seaborne Iron Ore Trade.(1)

The increasing importance of fired pellets and pellet feed in the global seaborne trade will push steel producers to increase their utilization in the blast furnace. Some of the additional pellet feed will continue to be added to the sintering mix despite productivity loss and the inherent environmental disadvantages of the sintering process. The remainder will have to be pelletized and added to the blast furnace burden to replace declining sinter and lump ore supplies.

Hatch has compared the merits of using sinter and pellets in the blast furnace to help steel producers evaluate the impact of increased pellet usage in the blast furnace burden.

2.2 Comparing Sinter and Pellets

Sinter and pellets are agglomerated forms of iron ore, both suitable for use as blast furnace burden materials. The principle difference between sinter and pellets arises from the type of raw materials used in their preparation and the nature of the sinter and pelletizing agglomeration processes.

Sinter is a clinker-type iron bearing material that is produced when a mixture of iron ore fines known as sinter feed, finely ground fluxes, carbon (coke breeze or anthracite) and various recycled iron bearing materials are uniformly fired along a continuous traveling grate reactor. Fuel in the sinter mix is ignited and generates temperatures high enough for the fine particles to fuse together into a porous clinker material which is subsequently crushed and sized after cooling to room temperature. The resulting sinter is suitable for use as a blast furnace burden material, but is not sufficiently strong to withstand long distance transportation. As a result, sintering plants are normally located in close vicinity to the blast furnace, usually within an integrated steel works.

Fired pellets are hard iron bearing balls that are produced to a specific size range by forming iron concentrate into unbaked green pellets and then heat hardened these green pellets in a dedicated induration furnace. The main feed materials are finely ground iron ore concentrate, finely ground fluxes and, in the case of hematite ores, finely ground carbon (coke breeze or anthracite). Magnetite ores do not require carbon additions as the magnetite oxidation in the induration furnace provides enough heat to sustain the process. The mixed materials are formed into small 8-16 mm diameter balls through the action of rotating drums or discs at a controlled moisture and with a binder such as bentonite. The green balls are then fired at controlled temperatures in an induration furnace which can be one of two types: a single straight grate induration furnace or a train of three reactors consisting of a travelling grate, rotary kiln and cooler, known as the grate-kiln process. The high temperatures produced in either process heat harden the green pellets, producing fired pellets which are strong enough to be used as blast furnace burden materials. Due to their higher physical resistance compared to sinter, pellets can survive long distance transportation and are thus an internationally traded commodity. Depending on their final user, pellets are often categorized between blast furnace (BF) pellets and direct reduction (DR) pellets, the latter having a higher Fe and lower gangue content consistent with the requirements of the direct reduction process. The focus of this paper will only be on BF pellets.

Sinter and BF pellets differ significantly in both their chemical and physical properties and their performance inside the blast furnace is dependent on both. This paper will focus only on the chemical properties, as those have a greater impact on the variables analyzed; blast furnace productivity, coke rate and slag rate. The typical chemical properties of sinter and BF pellets, the latter corresponding to those available in the seaborne market are listed in Table 1.

Table 1. Typical chemical properties of sinter and BF pellets(1,2)

	Sinter	**BF Pellets**
Fe, %	55.0 - 58.0	62.0 - 66.0
SiO_2, %	5.0 - 6.0	2.0 - 5.0
Al_2O_3, %	1.0 - 1.3	0.4 - 1.0
CaO, %	9.0 - 11.0	1.0 - 4.5
MgO, %	1.4 - 2.0	0.2 - 1.3
CaO / SiO_2	> 1.7	0.8 - 1.1

From Table 1, it is evident that the main differences in the chemical properties between sinter and BF pellets are the total iron (Fe) content, the total acid gangue (SiO_2 + Al_2O_3) content and the binary basicity (CaO/SiO_2). The following subsections discuss the impacts of these parameters on blast furnace performance.

2.2.1 Iron content

The typical iron (Fe) content of sinter is around 55-58%, while BF pellets are normally 62-66% Fe. BF pellets have a higher Fe content as they are manufactured from low-grade ores that are finely ground prior to undergoing mineral beneficiation treatments. During beneficiation, gangue materials are removed through a variety of mineral processing methods, such as gravimetric separation, magnetic separation and froth flotation. Iron is concentrated to a high degree as these mineral processing techniques efficiently eliminate gangue materials. By using clay binders, the pelletizing process can operate at lower basicity compared to the sintering process, requiring much lower flux additions as a result. Flux additions have a net diluting effect on the Fe content, so it follows that the Fe content of pellets is less diluted than that of sinter.

The higher Fe content of pellets increases blast furnace productivity as more iron units are charged to the blast furnace per unit ton of burden material. Shipping costs are reduced as more iron units and less undesirable gangue are shipped to the final blast furnace user.

2.2.2 Total acid gangue content

The total acid gangue content, defined as SiO_2 + Al_2O_3, is significantly lower in pellets compared to sinter as pellets are manufactured from low-grade ores that underwent a significant degree of beneficiation to increase their Fe content as described in the previous sub-sections.

The main advantage of lower gangue pellets to the blast furnace operation is a lower slag rate. As blast furnace slag is mainly composed of the gangue materials present in the ferrous burden, the ash content of coke, and the added fluxes it follows that utilizing a lower acid gangue material will produce less slag per ton of burden or hot metal. A lower slag rates directly translate into lower coke rates, as less thermal energy is required to form and melt the slag. In addition to lower coke rates, another direct advantage of a lower slag rate is that a smaller volume of by-product slag must be subsequently sold or disposed.

2.2.3 Binary Basicity

The third difference in the chemistries of BF pellets and sinter is shown by the binary basicity (B2) defined as the ratio of CaO/SiO_2. While for BF pellets the B2 ratio is typically around 0.8-1.1, for sinter this ratio is commonly greater than 1.7. Such a high basicity is required to improve sinter properties and achieve enough strength to withstand materials handling operations and for good performance within the blast furnace itself. Figure 3 below shows the dependence between sinter strength, defined as fraction > 10mm after tumbler test, and sinter basicity.

Figure 3. Relationship between sinter strength and sinter basicity.(1)

The higher basicity requirements of sinter compared to BF pellets negatively affects the operating costs of hot metal production in two ways. First, it requires a higher consumption of flux (limestone and/or dolomite) to achieve the target basicity. Secondly, it increases the slag rate, as the additional fluxes generate a higher slag volume.

3 METHODOLOGIES AND DISCUSSION

For a simple comparison between sinter and pellet use in the blast furnace, six specific scenarios where considered. In each case, the burden ratios of pellet/sinter, as well as fuel injection type were varied. Mass and energy balances were then performed for each of the six scenarios to obtain Key Performance Indices (KPIs) that would enable the comparison of blast furnace performance for each case. Table 2 summarizes the cases studied:

Table 2. Fixed Blast Furnace parameters for the different scenarios

Parameter	**Scenario 1**	**Scenario 1a**	**Scenario 2**	**Scenario 3**	**Scenario 3a**	**Scenario 4**
Sinter in the burden	65%	65%	-	65%	65%	-
Pellets in the burden	35%	35%	100%	35%	35%	100%
Fuel injection	PCI	PCI	PCI	NG	NG	NG

The chemical properties of the raw materials used in the six calculated scenarios are shown in Tables 3 and 4. Three different pellet types, consistent with grades widely available in the market were selected to reflect various BF operating scenarios:

- Pellet 1 – Low silica fluxed pellets, used for Scenarios 1 and 3;
- Pellet 2 – Acid pellets, used for Scenarios 1a and 3a;
- Pellet 3 – Super fluxed pellets, used for scenarios 2 and 4.

Table 3. Iron bearing raw material properties

Material	**Fe_{Total} (%)**	**SiO_2 (%)**	**Al_2O_3 (%)**	**CaO (%)**	**MgO (%)**	**CaO/SiO_2**
Sinter	57.7	5.0	1.5	9.0	1.1	1.8
Pellet 1	66.2	2.2	0.6	1.8	0.2	0.8
Pellet 2	64.8	5.0	0.6	1.2	0.2	0.2
Pellet 3	63.8	3.0	0.6	3.6	1.1	1.2

Table 4. Carbon bearing raw material properties

Material	**Ash (%)**	**Volatile Matter (%)**	**Carbon (%)**	**Energy Content (MJ/kg)**
Coke	13.0	0.5	86.5	30
PCI Coal	13.0	22.5	64.5	32
Natural Gas	-	-	73.7	40

The blast furnace charge rates of the ferrous burden, fluxes and fuels used for each of the six scenarios are summarized in Tables 5 and 6.

Table 5. BF burden composition

Description	**Units**	**Scenario 1**	**Scenario 1a**	**Scenario 2**	**Scenario 3**	**Scenario 3a**	**Scenario 4**
Sinter	kg/THM	1,020	1,029	-	1,021	1,029	-
Pellets	kg/THM	549	554	1,494	550	554	1,494
Limestone	kg/THM	-	17	30	-	4	16
Quartz	kg/THM	11	-	-	17	-	-

Table 6. Fuel rate comparison

Description	**Units**	**Scenario 1**	**Scenario 1a**	**Scenario 2**	**Scenario 3**	**Scenario 3a**	**Scenario 4**
Coke rate	kg/THM	328	331	310	362	366	345
PCI rate	kg/THM	180	180	180	-	-	-
NG rate	kg/THM	-	-	-	100	100	100
Adjusted fuel rate*	kg/THM	490	493	472	482	486	465

** Adjusted fuel rate (kg/THM) = Coke rate + (0.9 x PCI rate) + (1.2 x NG rate)*

As described above, the higher acid gangue content of sinter with its accompanying higher flux requirement, results in a larger volume of slag generated for all cases using sinter. Consequently, the coke rate increases as additional energy is required to melt the increased slag volume. The results of the calculations are shown in Table 7.

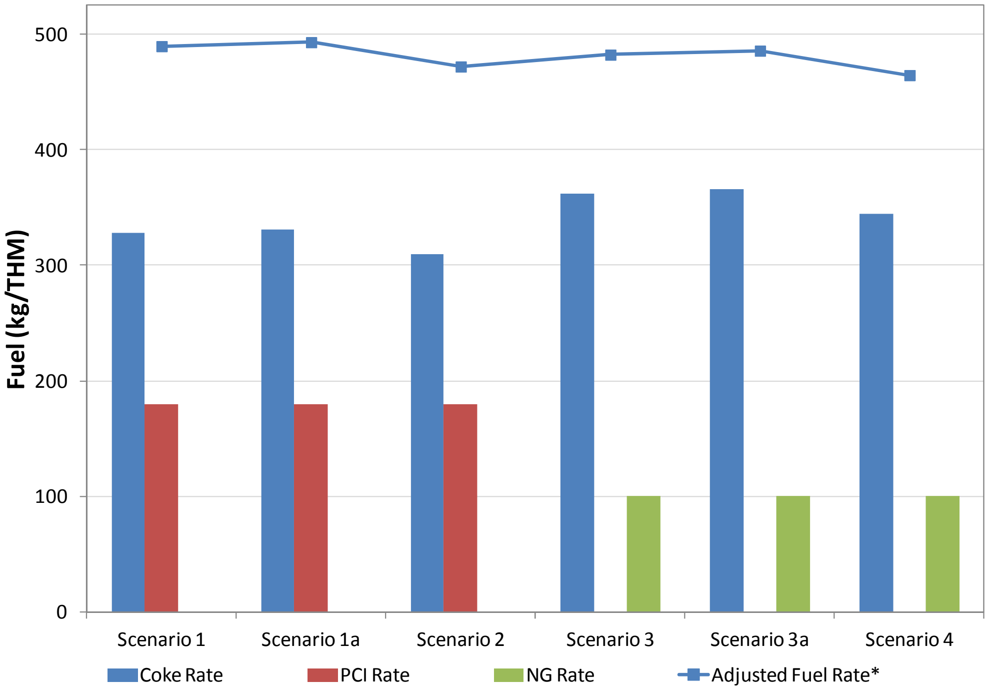
Table 7. Comparison of Key Performance Indices (KPIs)

KPI	**Units**	**Scenario 1**	**Scenario 1a**	**Scenario 2**	**Scenario 3**	**Scenario 3a**	**Scenario 4**
Slag rate	kg/THM	259	273	188	254	253	168
Coke rate	kg/THM	328	331	310	362	366	345
Burden to hot metal yield	t Fe charged/t burden charged	0.61	0.61	0.66	0.61	0.61	0.66

Hatch's calculations confirm higher slag rates in Scenarios 1, 1a, 3 and 3a as a result of sinter use in the burden. As expected, coke rate and overall fuel rate are also higher for those scenarios compared to Scenarios 2 and 4. The higher fuel rate in the sinter scenarios also results in increased blast furnace carbon emissions, as shown in Section 5.2.

The above analysis indicates that significant benefits in blast furnace operation can be achieved by using pellets instead of sinter as the main BF burden constituent. Specifically, the use of pellets results in a higher production of hot metal per ton of burden charged, lower slag rate, lower coke rate and lower overall fuel consumption. The lower fuel consumption benefits, which can bring important operational savings to the steel producer, are illustrated in Figure 4.

There are also important environmental benefits of using pellets in the BF, which will be discussed in the next section.



*Adjusted fuel rate (kg/THM) = Coke rate + 0.9xPCI rate + 1.2xNG rate

Figure 4. Comparison of fuel consumption between scenarios.

4 ENVIRONMENTAL IMPACTS

This section compares the environmental impact of blast furnace operations using pellets and sinter as the main burden constituents. The environmental impact comparison focuses on four items; atmospheric emissions at the agglomeration processes, blast furnace equivalent carbon emissions, transportation/materials handling emissions and ability to recycle solid wastes.

4.1 Agglomeration Process Atmospheric Emissions

Table 8 below compares the typical emissions for the two agglomeration processes relevant to this paper; sintering and pelletizing. The figures are for existing sintering and pelletizing plants in the European Union some of which are considered as world benchmarks.

Table 8. Averaged maximum and minimum air emissions of sintering and pelletizing plants in the EU(3)

Air Emissions	Unit	Sintering Process	Pelletizing Process
Waste gas flow	Nm^3/t	1,500 - 2,500	1,940 - 2,400
Dust	g/t	41 - 559	14 - 150
SO_x	g/t	220 - 973	11 - 213
NO_x	g/t	302 - 1031	150 - 550
CO	g/t	8,783 - 37,000	<10 - 410
CO_2	kg/t	162 - 368	17 - 193
VOC	g/t	37 - 673	5 - 40
PAH	mg/t	0.2 - 592	0.7 - 1.1

A quick inspection of Table 8 reveals that the environmental performance of the pelletizing process is significantly better than the sintering process, as the typical emissions of all the pollutants shown in Table 8 are lower. When the entire production chain starting at the agglomeration process is considered, there is a clear environmental benefit of using pellets instead of sinter as the main blast furnace burden constituent.

Newly constructed sintering plants include modern pollution control equipment designed to achieve lower emissions. Hatch currently does not have data of the most modern operations, but expects a superior performance compared to those European sinter plants reported in Table 8. Sinter producers and pollution control equipment manufacturers must continue to push the limits of innovation in order to comply with ever tightening environmental legislation worldwide.

4.2 Blast Furnace Carbon Emissions

For the blast furnace, carbon is principally introduced to the process via coke, PCI and NG injection and any raw carbonate containing fluxes added to the furnace. The hot metal tapped out of the furnace typically contains 4.5% carbon, with the balance of carbon leaving the furnace in the top gas as a combination of CO and CO_2. Figures 5 and 6 show a comparison of the BF carbon footprint for the six scenarios studied in this paper.

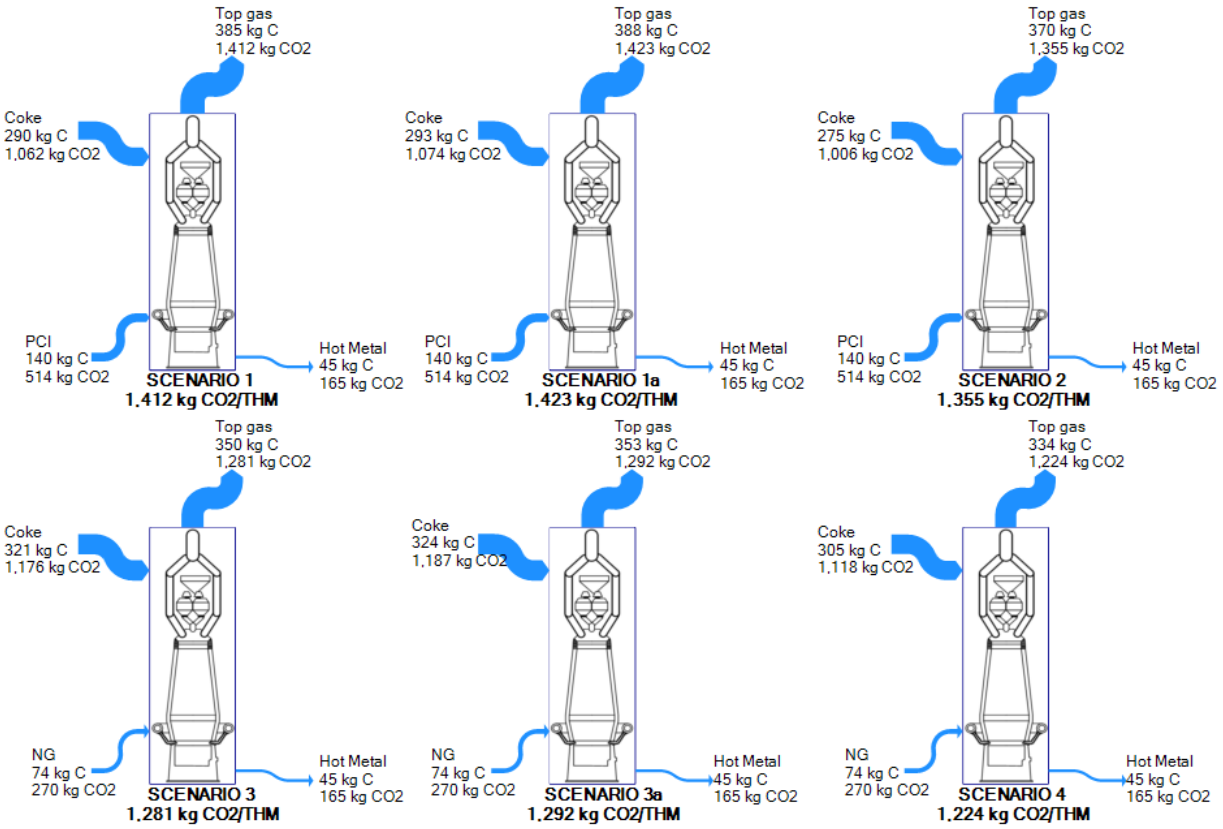


Figure 5. Comparison of BF carbon flows for the six scenarios.

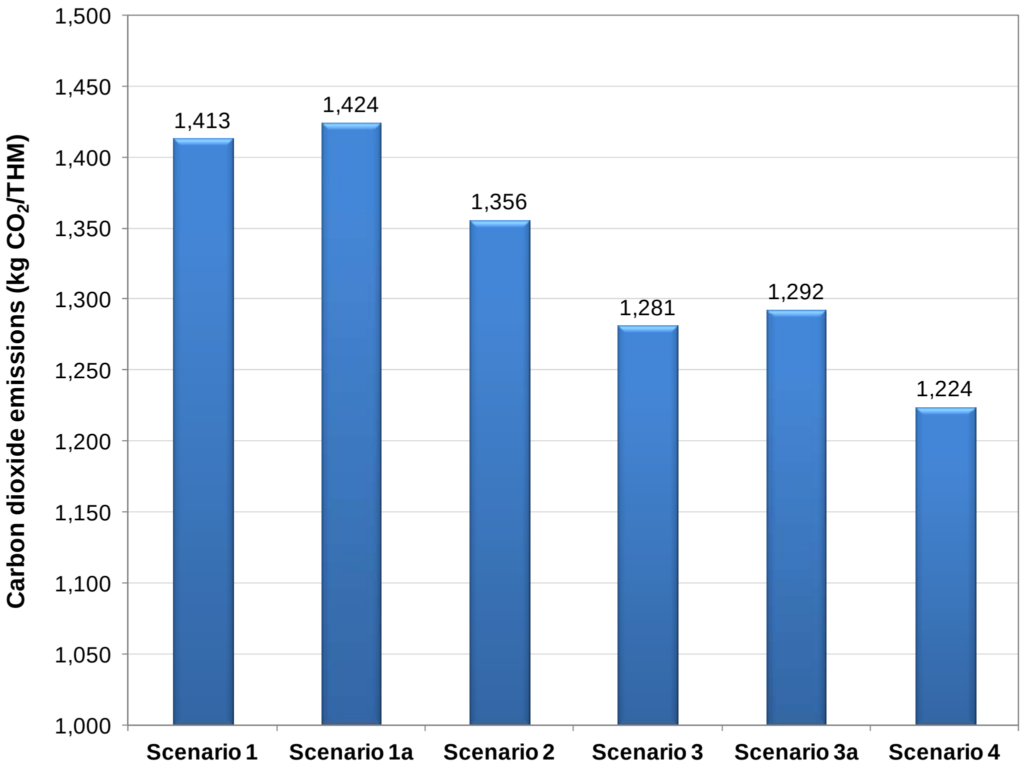


Figure 6. Comparison of BF carbon emissions for the six scenarios.

Figures 5 and 6 above illustrate that the blast furnace carbon emissions are higher in the cases where sinter is used as the main blast furnace burden constituent (Scenarios 1, 1a, 3 and 3a) with respect to those where 100% pellets are used

(Scenarios 2 and 4). This is directly related to the higher coke rate resulting from the sinter operations as described in Section 3. Higher coke consumption directly translates into higher carbon emissions.

The above figures also illustrate that carbon emissions are higher when operating with PCI injection (Scenarios 1, 1a and 2) as opposed to natural gas injection (Scenarios 3, 3a and 4). This is due to the lower carbon content per unit output energy of natural gas compared to injected coal.

The above analysis demonstrates that significant reductions in carbon emissions produced by the blast furnace can be achieved when using pellets as the main ferrous burden constituent.

4.3 Transportation and Materials Handling Emissions

The calculations in Section 3 demonstrated that when using pellets instead of sinter, lower quantities of iron-bearing and carbon-bearing materials are charged to the blast furnace. It follows that using pellets results in freight savings and reduction in carbon emissions as less raw materials require transportation to the blast furnace site. In addition, materials handling operations at the blast furnace site are reduced, resulting in fewer particulate emissions from materials handling activities. Lower slag rates resulting from pellet use also contribute to the overall reduction in materials handling activities and consequently, particulate and carbon emissions.

4.4 Internal Solid Wastes Recycling

An often cited advantage of using sinter instead of pellets is that having a sintering plant within the integrated steelworks allows for the internal recycling of various solid wastes, such as blast furnace dust, BOF dust and mill scale among others. The pelletizing process is also capable of recycling these solid wastes although it is more challenging than for the sintering process as the recycled materials must be finely ground to the same particle size required for balling the iron ore concentrate. In North America, where many steel plants use 100% pellets and do not have a sinter plant, solid wastes are briquetted and added to the blast furnace and steelmaking furnaces to consume these waste materials.

5 CONCLUSIONS

Large quantities of fine iron ore concentrate will enter the seaborne market over the next decade as a result of declining high-quality sinter fines. These concentrates must be pelletized to allow their usage in blast furnace and direct reduction processes. Thus, blast furnace operators that consume seaborne iron ore will gradually increase the use of pellets in the blast furnace burden as the pellet feed supply grows.

Hatch compared the use of sinter and pellets in the blast furnace and demonstrated that using pellets instead of sinter can result in significant technical and environmental benefits. These benefits include lower coke rate, lower slag rate, lower CO_2 emissions at the blast furnace, lower emissions at the agglomeration process and an overall lower fuel requirement to produce hot metal.

Blast furnace operators consuming iron ore from the seaborne market are thus encouraged to consider increasing the use of pellets to improve performance, reduce atmospheric emissions and better adapt to rapidly changing market conditions.

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