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SHIPMENT OF DIRECT REDUCED IRON MADE FROM NIGERIAN ITAKPE IRON ORE

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ABSTRACT
The utilization of the Nigerian local Itakpe iron ore for the production of iron and steel at the Delta Steel Company was in addition to being a guarantee of raw material availability to sustain the Nigerian steel industry, also an opportunity to make Nigeria a major market for Direct Reduced Iron feedstock to meet this worldwide demand. A total of 50,152.465 tonnes of Direct Reduced Iron produced from the Itakpe ore with average Degree of Metallization of 92 % and Carbon 2 % was successfully shipped from the Delta Steel quays to Bulgaria and India in 2007. The direct reduced iron was stable throughout the voyages. The one aborted shipment out of a total ten, was as a result of re-oxidation which occurred due to the failure of the sealing materials around the ship hold and with no bearing to the intrinsic properties of the iron ore from which the direct reduced iron was produced.

KEYWORDS: Itakpe Iron Ore, Oxide Pellets, Direct Reduced Iron, Shipping.

1. INTRODUCTION

Iron and Steel Industry in Nigeria
Considering the large tonnage of iron and steel products used annually and the need to harness the available iron and steel mineral raw material resources of this country, the Federal Government since 1970s embarked on the establishment of iron and steel industries, and mineral raw materials sourcing and development agencies. The whole idea, as envisaged by the Government, was to reduce the large foreign exchange expenditure on iron and steel products. The mandate included the detailed exploration for iron ore and steel raw materials, iron-ore beneficiation and processing to produce steel. The success of the detailed exploration for iron culminated in the discovery of the Itakpe hills iron ore deposit, and many other iron ore deposits in the same geological environment of North Central Nigeria. (Raw Materials Research and Development Council, 2010). The Itakpe iron ore deposit, with an estimated reserve of about 200 million tons was found in 1977. The deposit is embedded in the Itakpe hill, near Okene, in the north central Kogi state of Nigeria. The deposit contains a mixture of magnetite and hematite whose ratio varies throughout the deposit with an average content of 35% iron in the ore. (Umunakwe, 1985)**.** Table 1 shows the iron ore deposits in Nigeria.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Table 1: Iron ore Deposits in Nigeria

STATE	LOCATION	ESTIMATED RESERVE (tonnes)	Wt % Fe
Kogi	Agbaja Itakpe Ajabanoko Koton-Karfe Choko-choko Agbado-Okudu Kakun Bassa Nge Fatti	1 billion 200-300 million 60 million 2 million 10 million 70 million - 40million 37	45-54 38-45 40 43-53 35 37-43 40-55 43-49 46
Enugu	Nsude Hills	60 million	37.43
Nasarawa	Muro Hills	Not available	35
Kebbi	Dakingari	Not available	27-30
Bauchi	Rishi Gamawa	Not available Not available	14-19 40-45
Borno	Karfa	Not available	34-45
Kaduna	Tajimi, Ayaba	Not available Not available	22-52 27.5
Benue	Egenerja	Not available	34-45
Anambra	Nsude	43-50 million	43-45
Zamfara	Maraba Hill	Not available	-

Sources: Raw Materials Sourcing for Manufacturing in Nigeria,
Inventory of Nigeria Minerals and Mines.
Journals of Minerals and Metallurgical Processing.
NIOMCO

The Nigerian National Iron Mining Company Ltd. (NIOMCO), Itakpe, was established to upgrade Itakpe iron ore to sinter grade of 63% to 64% Fe for the blast furnace based Ajaokuta integrated steel plant, Ajaokuta, Kogi state (Ola et al, 2009). As a result, contract for the establishment in Ajaokuta in Kogi State of Nigeria, of the conventional Blast Furnace – Basic Oxygen Furnace route to steel production, was signed in 1979. However, global recession, poor funding and the installation of massive infrastructural facilities had stood on the way of the completion and full commissioning of Africa's largest steel making Plant at the time. The Nigerian government as a way to boost industrialization and bridge the gap in steel production adopted the direct reduction process route to steel production. This was also hinged on the abundant natural gas in the Niger Delta thereby making the import of coal which was an essential ingredient for the conventional blast furnace process unnecessary. The most important import substitution was the successful utilization of the Itakpe iron ore concentrate in the Direct Reduction Plant and the Steel Melt Shop for the production of truly indigenized steel. (Madagua, 2013)

Use of Itakpe Iron Ore

Upon commissioning of the Delta Steel Company (DSC), and subsequent commercial production of Steel, the Liberian/Guinean Ore mines from where the Lamco iron ore based on which the Direct Reduction Plant at DSC was designed, was depleted within 3 years of commissioning.

This led to the necessity to seek other sources of raw materials. The next alternatives were the Brazilian Companhia Vale do Rio Doce (CVRD) and Feijaio ores which apart from the peculiarity in their operational

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

characteristics were not readily available due to scarce foreign exchange and which were used sparingly between 1989 and 1993. It therefore became imperative to seek other sources of iron ore. This resulted in the need to investigate the possibility of utilizing at DSC, the locally available iron ore in Itakpe in Kogi state of Nigeria, which was originally conceived for use at the Blast Furnace plant in Ajaokuta and was to produce sinter grade of 63% to 64% Fe Total with a silica content in excess of 4% and which was not suitable for the Direct Reduction process based Delta Steel Company (Ola et al., 2009).

The beneficiated Itakpe Iron ore (Fe^{tot} – 65.74%, SiO_2 + Al_2O_3 = 8.10%) and re-beneficiated iron ore (super concentrate) with Fe^{tot} of 67.4%, SiO_2 + Al_2O_3 of 2.45% derived from the former using facilities available at the Nigerian Metallurgical Development Council (NMDC). The significant aspect of the latter job carried out in Jos was the reduction of the acid gangue from about 8% to less than 3%. Table 2 shows the chemical composition of the raw and beneficiated Itakpe iron ore, while Table 3 shows the chemical characteristics of the oxide pellets used for pilot tests. Table 4 shows the physical properties of the oxide pellets used for the pilot tests.

Table 2: Chemical Composition of Beneficiated Itakpe Ore (Olayebi, 2014)

PARAMETERS	AS-RECEIVED ORE (CONCENTRATE)	BENEFICIATED ORE	RE-BENEFICIATED ORE (SUPER CONCENTRATE)	DSC SPECIFICATION
Fe^{total} (%)	62.28	65.74	67.4	66-67
Fe_2O_3 (%)	89.00	93.90	96.31	94-96
$SiO_2 + Al_2O_3$	11.10	8.10	2.45	3.5 max
CaO (%)	0.17	0.001	0.17	0.1
MgO (%)		Trace	0.03	0.1
S		0.004 max	0.001	0.04 max
P	0.011	0.06 max	0.04	0.05
LOI	0.21	0.18	0.24	1.2 max
SSA			2056	1850 – 2500

Table 3: Chemical Characteristics of Itakpe Ore used for Pilot Tests (Olayebi, 2014)

PARAMETERS	AS-RECEIVED ORE (CONCENTRATE)	BENEFICIATED ORE	RE-BENEFICIATED ORE (SUPER CONCENTRATE)	DSC SPECIFICATION
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P	0.011	0.06 max	0.04	0.05
LOI	0.21	0.18	0.24	1.2 max
SSA			2056	1850 – 2500

Table 4: Properties of Oxide Pellets derived from Itakpe Ore used for Pilot Tests (Olayebi, 2014)

PARAMETER	BENEFICIATED ORE	RE-BENEFICIATED ORE	DSC SPECIFICATION
Compression Strength (N/P)	4955	5000	3450
Pellet Size (6.3 – 19mm) (%)	98.47	97.00	92-97
Tumble Index (%)	96.92	95.00	93.00 min
Abrasion Index	2.31	3.50	5.0 max
Basicity (CaO + MgO / $SiO_2 + Al_2O_3$)	0.51	0.75	0.6 min
Firing Temp (max) ^{0}C	1200	1200	1300

Basket Tests on Itakpe Pellets

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The reduction behavior of the Itakpe oxide pellets in the shaft furnace confirmed the results from the earlier pilot test that indicated good reducibility of pellets from Itakpe iron ore as shown in Table 5. The Fe_{Met} which gives the level of metallic iron was however below the DSC specification by virtue of the chemistry of the ore, which is characterized by high silica. The high level of gangue was accommodated in the steel making shop by careful choice of production strategy.

Table 5: via Shaft Furnace Reductibility Basket Test using 67.4% Fe^{tot} Ore (Olayebi, 2014)

Parameter	Dri Quality	DSC Specification
Fe^{met} (%)	92	90 min
Degree met	96	80 min
C	1.27	1.1 – 2.0
S	0.003	0.04 max
P	0.04	0.04 max
Reduction Temp	800	760 – 850

Since it was not likely that a super concentrated plant (re-beneficiation plant) will be in place soon at Itakpe sustenance of production in DSC depended on the availability of iron ore locally. The possibility of blending high grade imported Feijao and CVRD ores, separately with the Itakpe ore (62.68% Fe^{tot}) was explored. Although the blend of 1:2 of Itakpe/imported ores produced the desired results, this route was laden with the problem of having to rely on the importation of Iron ore for DSC operations. This made the blending scheme less attractive. Additional laboratory work in DSC based on grain size gradation, ore with 62% Fe^{tot} yielded an iron ore with 65 Fe^{total} and gangue level not more than 5% in the grain size range of + 500µm.

Table 6: Typical Chemistry of Commercial Quantity of Ore delivered to DSC (Olayebi, 2014)

PARAMETER	%
Fe^{tot}	65.77 (mfs)
Fe_2O_3	94.05
SiO_2	3.93
Al_2O_3	0.80
CaO	0.13
LOI	0.11
H_2O	2.36

* mfs = moisture free state.

Table 7: Physico-Chemical Properties of Pellets derived from Itakpe Iron Ore (Olayebi, 2014)

PARAMETER	PRIME ORE	DSC SPECIFICATION
A. GREEN PELLETS		
MOISTURE (%)	8.10	7 – 8.0
DROP NO (D/P)	5.7	4.8 min
CCS (N/P)	11.22	9.0 min
B. FIRED PELLETS		
i. PHYSICAL PROPERTIES		
CCS (N/P)	4560	3450
+ 16mm (%)	21.41	5.0 max
6.3 – 19m (%)	95.05	92.0 min
Tumble Index (%)	94.51	93.0 min
Abrasion Index (%)	3.93	05.0 max
Firing Temp (^{0}C)	1300	1300
Ii. CHEMICAL PROPERTIES		
Fe^{tot} (%)	65.10	66.00 min
Fe_2O_3 (%)	93.21	94.00 min

ISSN: 2277-9655
Impact Factor: 5.164
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$SiO_2 + Al_2O_3$ (%)	04.57	03.50 max
CaO (%)	02.13	01.50 – 01.70
MgO	Trace	02.00 max
S	0.001	0.001 max
P.	N.D	0.03 max
Basicity	0.51	0.60 min

Table 8: Physico – Chemical Properties of DRI from Itakpe Iron Ore (Olayebi, 2014)

PARAMETER	PRIME ORE	DSC SPECIFICATION
CHEMICAL PROPERTIES		
Fe^{total}	88.30	90 min
Fe^{met}	81.20	82 min
Deg. Met	92.00	88 min
FeO	09.10	2.0 – 9.4
CaO	01.22	2.5 max
$SiO_2 + Al_2O_3$	05.42	3.6 max
C	02.08	1.1 – 2.0
MgO	Trace	0.04 max
P	N.D	0.03 max
S	0.006	0.03 max
PHYSICAL PROPERTIES	970	700
CCS (N/DRI)	970	700
Grain Size (%) (9.5 – 16mm)	89.50	90 min
Tumble Index (%)	83.33	80 min
Abrasion Index (%)	6.67	6.0 max
Fines Level (%)	6.27	6.0 max
Reduction Temp (^0C)	760	760-860

2. DIRECT REDUCTION PLANT AT DELTA STEEL

The direct reduction iron making plant at the Delta Steel Company are two MIDREX Process based 600 series 5.5m diameter modules each with an annual production capacity of 510,000 Tonnes of direct reduced iron (DRI). The Midrex process flow sheet is shown in Figure 1.

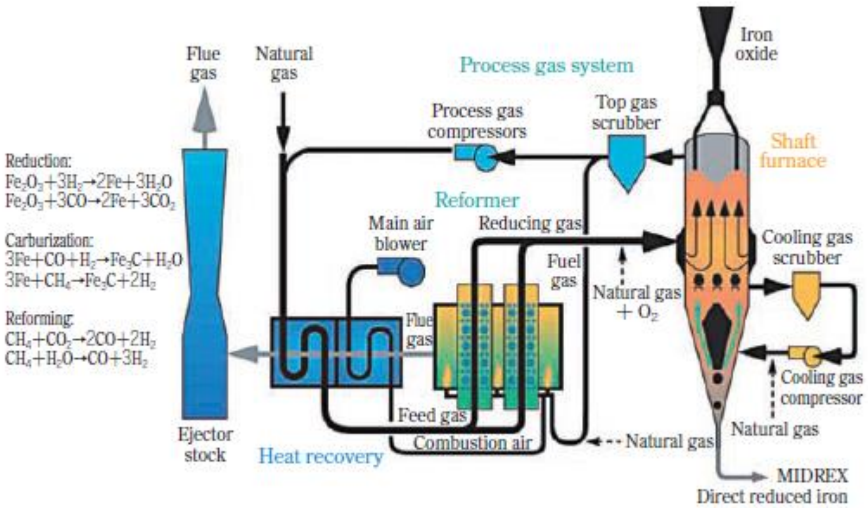

FIG 1: Midrex Direct Reduction flow sheet. (Atsushi et. al, 2010)

The increase in the global demand for steel, led to higher demand for steel manufactured via the electric arc furnace (EAF) route as against the more traditional production methods. In addition, DRI has increasingly emerged as a cheaper, low-residual iron feedstock for EAFs, which have traditionally relied almost entirely on ferrous scrap feed. This has led to an increase in the demand for DRI worldwide.

Dri Properties and Dangers

DRI in either form is similar to other steel structures in its susceptibility to rust (re-oxidize) in the presence of oxygen. The rate of oxidization is dependent, to a greater or lesser degree, on the moisture content of the DRI and the atmosphere in which the DRI is carried. The oxidization process generates heat, which in bulk cargoes of DRI can be significant. The process of oxidation is accelerated in the presence of moisture and is substantially increased if the water contains dissolved chlorides, as is the case with seawater. The sponge-like structure of DRI also inhibits the dissipation of heat and DRI in bulk can therefore heat rapidly in isolated pockets.

Hot iron when in contact with water can cause a chemical reaction resulting in the production of hydrogen, which is highly explosive in the correct quantities. The generation of hydrogen is the most dangerous property of DRI and has led to several fatal explosions.

In some manufacturing processes, the DRI undergoes one of two processes called either ‘passivation’, whereby the briquettes are coated with sodium silicate or ‘ageing’ in which the briquettes are allowed to form an iron oxide coating. These processes are intended to reduce or inhibit the oxidation process during transit.

Storage of Dri

DRI as it is produced is very reactive to free water and oxygen. Pellets and briquettes are always passivated and cooled before being shipped on the seas, rails or highways. DRI pellets can be subject to a high degree of re-oxidation. Self-ignition can occur if there is a natural air draft through the pile, the pellets buried inside are wet and the volume of material is large enough to insulate against heat losses.

Fires result when dry DRI pellets are placed on top of wet material. The best way to stop a DRI fire is to spread out the hot material with a bulldozer to a height of ½ meter. A second method is to bury the pile under sand or slag.

In the situation of a fire inside a storage silo, the pile of DRI can be flooded with extremely large amounts of water (Hunter, 1997).

Storage of Direct Reduced Iron at Delta Steel Company

The DRI is discharged from each furnace at a temperature of about 50 – 70^{0}C on to a conveyor by the product discharge mechanism known as the wiper onto a single product belt conveyor which transports it to four product bins of 5,000 tonnes capacity each. The flue gas from the reformer combustion chamber, cooled, conditioned, and compressed is used as seal gas. The composition of the flue gas leaving the reformer is approximately 65% nitrogen, 20 % water vapour, and 15 % carbon dioxide. After cooling, the gas composition is approximately 75% nitrogen, 5% water vapour, and 20% carbon dioxide. Normally the flue gas contains one percent or less oxygen: the maximum allowable concentration of oxygen for seal gas is 3%. Final seal gas conditioning is accomplished in the seal gas dryers, where the dew point of the gas is lowered to 6^{0}C. This seal gas is used in the product bins where the DRI is stored prior to shipment (Direct Reduction Plant Operating Manual, 1981).

3. DRI SHIPMENT

According to Grobler and Minnitt (1999**), t**he future for merchant DRI shipments depends largely on the ferrous scrap market situation, in terms of availability, price and quality. In the past, the ample supply and low price of scrap has been a dampening factor on the growth of merchant DRI shipments. Therefore, in the past, it was seldom economically viable to give preference to DRI. The situation changed when there was scarcity of good quality scrap, leading to increase in scrap prices

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Classification of Direct Reduced Iron for Shipping

DRI – Direct reduced iron

Direct reduced iron, normally in the form of sponge pellets or lumps vary between 6 and 25mm nominal diameter, but often 8 to 12mm diameter. The IMO BC Code classifies this product as **"a material that is hazardous only when in bulk"** (MHB). It can be found under the BC Code as BC015. If this product becomes wet it can significantly overheat and emit hydrogen gas. Thus it must be carried under inert conditions. Nitrogen gas is normally used and is applied to the holds by way of a temporary manifold fitted to the tank top prior to loading. Thermocouples must also be positioned in the cargo on the tank top and elsewhere throughout the stow at different heights to monitor the temperature. Gas monitoring of the holds, normally for hydrogen and oxygen, must also be undertaken throughout the voyage. The product must be kept dry at all times prior to and during carriage. The product should be treated as DRI, BC 015.

HBI – Hot briquetted iron

This material is manufactured from DRI product, which is compressed at temperatures exceeding 650° C to form briquettes between about 90 and 130mm long, 80 to 100mm wide and 20 to 50mm thick. This product is a much safer form of DRI than DRI pellets. It is far more resistant to overheating if it becomes wet. During a voyage it can still generate small amounts of hydrogen. Inerting is not required by the BC Code but adequate surface ventilation is required. It should be treated as HBI BC 016, provided there is no additional qualification to the HBI (www.shipownersclub.com)**.**

In order to ensure safe carriage of DRI, the IMO through the IMO Maritime Safety Committee (MSC), adopted recommendations and Codes named the International Maritime Solid Bulk Cargo Code (IMSBC Code) which categorized DRI and the conditions for carriage as follows:

DRI (A), Briquettes, hot-molded

- A maximum limit on the moisture content of 1%
- Cargo is to comprise essentially whole briquettes. Fines of less than 6.35mm and dust are limited to 5%
- Concentration of hydrogen to be measured throughout the voyage. If it exceeds 25% LEL appropriate precautions to be taken
- Surface ventilation only shall be conducted as necessary. When mechanical ventilation is used, the fans shall be certified as explosion-proof and shall prevent spark generation
- Wire mesh guards shall be fitted over inlet and outlet ventilation openings

DRI (B), Lumps, pellets, cold-molded briquettes

- Average particle size is limited to 6.35mm to 25mm. Fines of less than 6.35mm and dust are limited to 5%
- Loading conveyors are to be dry
- Prior to loading, an ultrasonic test or another equivalent method with a suitable instrument shall be conducted to ensure weather tightness of the hatch covers and closing arrangements
- Moisture content must be less than 0.3% and must be monitored during loading
- Any cargo that has already been loaded into a cargo space and which subsequently becomes wetted, or in which reactions have started, shall be discharged without delay
- Carriage is only permitted under an inert gas blanket
- The ship shall be provided with the means of reliably measuring the temperature at several points within the stow, and determining the concentrations of hydrogen and oxygen in the cargo space atmosphere on voyage whilst minimizing the loss of the inert atmosphere
- The ship shall be provided with the means to ensure that the requirement to maintain the oxygen concentration below 5% can be achieved throughout the voyage. The ship's fixed CO_2 fire-fighting system shall not be used for this purpose
- Consideration should therefore be given to providing vessels with the means to top up the cargoes spaces with additional supplies of inert gas having regard to the duration of the voyage – the ship shall not sail until the master and a competent person are satisfied that:
  - all loaded cargo spaces are correctly sealed and inerted,

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

- the cargo temperatures have stabilised at all measuring points and are less than 65°C.
- concentration of hydrogen in the free space has stabilised and is less than 0.2% by volume
- oxygen concentration shall be maintained at less than 5% throughout duration of voyage

DRI (C), By Products, Fines

- Average particle size is less than 6.35mm, and there are to be no particles greater than 12mm in size
- The reactivity of this cargo is extremely difficult to assess due to the nature of the material that can be included in the category. A worst-case scenario should therefore be assumed at all times
- Carriage requirements are largely identical to those for DRI (B), including the 0.3% limit on moisture and carriage under an inert gas blanket.

Shipping Requirements

The requirements for the loading and shipping of DRI (B) produced in Delta Steel Company include:
i. The shippers' certificate shall state the date of manufacture for each lot of cargo.
ii. The certificate issued after loading shall confirm that the moisture content has not exceeded the permitted value.
iii. The cargo shall be certified as having been aged for at least 3 days, or treated so as to achieve the same reduction in activity (www.shipownersclub.com).

For all types of DRI, the following conditions apply:

1. Fines are defined as particles up to 6.35mm (¼") in size.
2. Cargo spaces shall be clean, dry and free from salt and residues of previous cargoes.
3. Wooden fixtures and combustible materials shall be removed.
4. The carrier's representative is to have reasonable access to stockpiles and loading installations for inspection.
5. Prior to loading, the shipper shall provide the Master with a certificate issued by a competent person stating the cargo is suitable for shipment and that it conforms with the requirements of the Code in terms of particle size, moisture content and temperature.
6. A similar certificate shall be provided after loading relating to the whole consignment.
7. The shipper shall provide comprehensive information on the cargo and safety procedures to be followed in the event of an emergency.
8. No cargo shall be loaded or transferred during precipitation and non-working hatches shall be kept closed.
9. The cargo shall not be accepted when its temperature is in excess of 65^{O}C, or its moisture content exceeds the permitted value, or if the quantity of fines exceeds the permitted value, where appropriate.
10. The cargo temperatures shall be monitored during loading and recorded in a log.
11. The cargo shall be trimmed in accordance with the relevant provisions of the Code.
12. Adjacent tanks other than double bottom tanks shall be kept empty during the voyage.
13. Weather tightness shall be maintained throughout the voyage.
14. The bilge wells shall be clean and dry and protected from ingress of cargo.
15. Precautions shall be taken to protect personnel, equipment etc. from the dust of the cargo.
16. During handling of the cargo, "NO SMOKING" signs shall be posted and no naked lights or other ignition sources permitted.
17. Suitable precautions shall be taken before entering cargo spaces, which be depleted of oxygen and/or contain a flammable atmosphere.
18. The ship shall be provided with a detector suitable for measuring hydrogen in an oxygen depleted atmosphere and for use in a flammable atmosphere.
19. Cargo temperatures and hydrogen concentrations in hold atmospheres shall be measured at regular intervals during the voyage.
20. If the hydrogen concentration exceeds 1% or the cargo temperature exceeds 65^{O}C, appropriate safety precautions shall be taken. If in doubt, expert advice shall be sought.
21. Bilge wells shall be checked regularly for the presence of water.
22. All records of temperature, hydrogen and oxygen measurements, where appropriate, are to be retained on board for 2 years.
23. The hydrogen concentration shall be measured in the holds prior to opening the hatch covers **(**www.shipownersclub.com**).**

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

4. PRE SHIPMENT BRIEFING

The following Pre-shipment briefing was given to participants which included Direct Reduction Plant operations (Super Cargo) and maintenance personnel, , DSC Harbor operatives, Shipping Agents, Maritime Surveyors, Ship Captain, and Ship Chief Officer. This was done prior to the first shipment from Delta Steel Company.

Surveyors Report

Only Government recognized Competent Authority, and/or independent surveyor is qualified to certify by conducting integrity test, that:

(i) A ship is suitable for use in DRI loading for Export.
(ii) The DRI loaded is stable and suitable for shipment.
(iii) All the ship's ventilators are closed and sealed with tape and/or expanding foam before inerting of the vessel begin.
(iv) The tubings for monitoring of oxygen and hydrogen contents are suitable and adequate.
(v) Recommended quantity of Nitrogen gas is available on ship in addition to the carbon dioxide on ship, for inertizing the ship holds to ensure that oxygen concentration is below 5% throughout the voyage.

Duties and Responsibities of Super Cargo

At the Harbour

i. To be equipped with a sketch of the installation pattern of the thermocouple
ii. To assist the Surveyor or competent Authority, hired by DSC in the usage of Nitrogen and in the monitoring and recording of temperature and oxygen content during inertizing of the Ship holds.
iii. Hatches to be checked for leakage.
iv. No wet material is loaded into the hatch.
v. Pipings installed for inertizing and thermocouples should be intact during loading.
vi. After loading, checks for leakage to be made before sealing off hatches.
vii. Sealing foam to be used in addition to flash band.
viii. Covers and other joints are to be properly sealed.

Durig Voyage

i. Readings are to be taken every 6 hours and daily readings relayed to DSC.
ii. "Supercargos" are not to go out alone to take reading especially at night.
iii. At the Atlantic Ocean, Mediterranean
iv. Sea and the Black Sea Supercargo are to be alert because the waves are usually very high in these locations.
v. When waves are high, readings are not to be taken until waves subside.
vi. If for any reason, readings are not taken, the Ship Captain is to be informed and mail to DSC stating the reason(s) why reading could not be taken.
vii. Extra sealing materials are to be taken in case of emergency.
viii. Daily report should be countersigned by the Ship Captain.
ix. Hydrogen concentration during voyage should not be than 1%, and oxygen should be less than 5%.
x. Should a rise in hydrogen level in any hold exceed 1%, the hold is to be ventilated, until the level is reduced to below 1%.
xi. In the event of sustained increase in the hydrogen level above 1%, ventilation is to be stopped and carbon dioxide injected to the hold.

Guidelines for the Ship Captain

It is the responsibility of the Ship Captain to do the following.
i. Transmit to Delta Steel Company on a daily basis the reports of all data given by the Super Cargo.
ii. Electrical power to duct Keel to remain disconnected throughout.
iii. Smoke section is to remain disconnected unless required for Emergency purpose.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

iv. Ensure adequate supply of ram neck tape for his used and as required and necessary.
v. Should the temperature of any thermocouple on the tank top above empty fuel tanks exceed 80^{O}C, double bottom tanks should be flooded by water.
vi. In no case should the hatch covers be opened if the hydrogen level approaches 4% without first purging the hold with carbon dioxide.
vii. There should be no possible source of ignition in holds or on deck during the voyage or during off-loading.
viii. Should the temperature increase to 150^{O}C at any one thermocouple or 100^{o}C at more than thermocouple ventilation is to be closed and carbon dioxide injected into the hold.

NOTE: if temperature continues to increase to 200^{O}C at more than one thermocouple, head for the nearest port.

ix. However if the nearest port cannot be reached, flooding of hold is to be considered at the fastest rate possible on the way to the nearest port.
x. Flooding of hold with water should always be the last resort.
xi. The super Cargo should always be ready to advise the Captain on all the above points if required.
xii. In case a DRI fire results, if hatches are to be opened, expert advice which can be obtained through the Local P&I Correspondents should be sought.

REPORT OF FIRST SHIPMENT OF DRI FROM DSC (NIGERIA) TO BOURGAS (BULGARIA)

1. Ship Particulars:

Ship's Name:	M/V MYSHIP
Type of Vessel:	General Cargo
Register Port:	Bratislava
Registration No:	BRS – 061
Flag:	Slovak Republic
Call Sign:	OMKI
IMO Number:	8121719
Main Engine:	1600 HP/1177 Kw

2. Gross Cargo (DRI) - 3,011.875 MT

3. Vessel Inspection/Preparation for Cargo Loading:
   a. The vessel was inspected and okayed for loading of DRI by the Maritime surveyor.
   b. For the purpose of maintaining inertness in the ship's hold, a network of pipes was welded in the hold for charging nitrogen gas through the DRI into the space above the cargo.
   c. The horizontal pipes on the floor of the hold were perforated for even distribution of nitrogen.
   d. The vertical pipes extending upwards through the access hatch coaming were constructed to serve the purpose of nitrogen gas injection during voyage whenever the inertness in the ship hold is lost.
   e. A second pipe for gas sampling, carrying a (1/4) ball valve was also welded through the access hatch coaming down to the free space above the cargo.

4. Loading of DRI into Ship's Hold:
   a. Loading of DRI into the hold commenced in the evening on 6th January, 2007.
   b. The temperatures of the DRI at the point of storage were monitored to ensure that no DRI above 65^{O}C goes into the ship.
   c. When half of the cargo was loaded, thermocouples were inserted at various positions and thereafter loading continued.
   d. By 9th January, 2007 loading was completed.
   e. The hatch covers were then closed, flash – bands and expanding – foam were applied to seal all joints/openings through which there could be possibility of gas leaks or water ingress.
   f. Thereafter, purging of the hold with nitrogen gas commenced.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

g. The oxygen level in the hold during the purging was regularly measured and recorded.
h. The temperatures of the cargo were also measured and recorded on 6 – hourly basis.

5. Equipment on Board:

a. Five gas cylinders filled with nitrogen (about 53.4 kg each) were provided along with connecting hose and pressure gauges.
b. One digital thermometer.
c. One Gas meter.

6. Activities during Voyage:

Sailing commenced 10:00 hours (Nigeria Time) on 11th January, 2007 (Oxygen level 5.5 %) Table 9 shows daily average 6 – hourly temperatures of the individual thermocouples (TI^S) in the cargo while Table 10 shows the daily average temperatures.

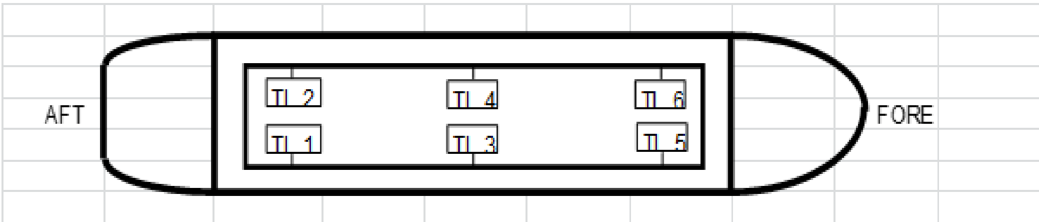

FIG 2: Location of temperature indicators in the cargo

7. Unloading at Bourgas:

The ship arrived Bourgas Port (Bulgaria) at 1:30 hours (local time) on 10th February, 2007 having spent 30 days on the voyage. After berthing, the hatch covers were opened and the cargo (DRI) was found to be in the same good condition as it was in Nigeria. That same evening unloading of the DRI from the ship into train coaches commenced. Unloading was eventually completed on the 19th February, 2007 the delay being as a result of bad weather.

Table 9: Daily Average readings of individual Temperature Indicators

		Temperature Indicators in Ship Hold					
DATE	Oxygen LEVEL	TI 1	TI 2	TI 3	TI 4	TI 5	TI 6
11.01.2007	5.5	27.4	27.1	27.8	26.7	26.7	27.5
12.01.2007	6.2	28.1	27.6	27.9	26.2	26.6	27.4
13.01.2007	6.6	25.8	25.5	26.0	24.6	25.2	25.9
14.01.2007	6.9	26.8	26.6	26.9	25.6	26.1	26.6
15.01.2007	7.2	26.9	26.7	27.0	26.2	26.7	27.2
16.01.2007	7.4	26.6	26.6	27.0	26.4	26.9	27.2
17.01.2007	7.6	26.2	26.2	26.4	24.9	26.4	26.9
18.01.2007	7.8	26.4	26.4	26.7	26.1	26.5	26.8
19.01.2007	8.1	26.4	26.4	26.5	25.8	26.4	26.6
20.01.2007	8.5	25.1	25.1	25.1	23.8	25.0	25.1
21.01.2007	8.9	24.6	24.6	24.0	21.5	24.1	24.3
22.01.2007	9.3	22.7	22.5	21.8	19.3	22.0	22.7
23.01.2007	9.5	21.8	21.7	20.0	18.4	20.8	21.9
24.01.2007	Not taken	20.5	20.4	18.3	16.9	19.3	20.6
25.01.2007	10.3	20.3	20.3	18.0	16.9	18.6	20.3
26.01.2007	Not taken	19.7	19.6	17.4	16.4	17.5	19.8
27.01.2007	10.8	15.2	15.2	12.9	12.3	13.1	15.3

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

28.01.2007	11.1	13.0	13.0	10.1	9.2	9.8	12.8
29.01.2007	11.3	16.5	16.5	13.8	13.1	13.6	16.5
30.01.2007	11.3	15.7	15.7	12.8	12.3	12.4	15.7
31.01.2007	11.3	18.0	18.1	14.8	14.5	14.5	18.0
01.02.2007	11.3	16.6	16.7	13.9	13.6	13.2	16.5
02.02.2007	11.3	18.1	18.2	15.7	15.4	14.6	18.2
03.02.2007	11.4	19.3	19.3	17.1	16.9	15.9	19.6
04.02.2007	11.4	12.8	12.8	10.8	11.0	10.0	12.9
05.02.2007	11.7	16.5	16.6	14.8	14.5	13.3	16.6
06.02.2007	11.7	15.5	15.7	13.5	13.6	12.8	15.6
07.02.2007	11.7	16.7	16.9	15.2	15.1	14.6	16.8
08.02.2007	11.7	14.8	14.8	13.1	13.0	12.4	14.7
09.02.2007	11.9	14.0	14.1	12.0	11.4	11.4	14.0
10.02.2007	12.0	15.2	15.1	12.3	11.2	11.7	15.1

Table 10: Daily Average 6 – Hourly Temperatures (in ^{0}C) of DRI

		Temperatures			
Date	O_2 Level	Morning	Afternoon	Evening	Night
11.01.2007	5.5	23.8	27.2	28.5	28.7
12.01.2007	6.2	28.0	27.4	27.4	26.5
13.01.2007	6.6	25.5	25.7	27.0	23.8
14.01.2007	6.9	25.2	27.5	26.1	27.0
15.01.2007	7.2	26.6	27.0	26.0	25.5
16.01.2007	7.4	26.1	27.1	27.6	26.3
17.01.2007	7.6	25.6	26.8	25.8	27.1
18.01.2007	7.8	26.0	26.1	26.8	27.0
19.01.2007	8.1	26.6	26.8	26.4	25.7
20.01.2007	8.5	24.0	23.7	25.9	25.9
21.01.2007	8.9	24.5	23.1	23.6	24.2
22.01.2007	9.3	21.6	22.5	22.4	20.8
23.01.2007	9.5	20.2	21.3	21.2	20.3
24.01.2007	Not taken	18.4	21.1	19.9	18.0
25.01.2007	10.3	18.5	18.4	20.1	19.2
26.01.2007	Not taken	19.2	20.0	17.4	17.1
27.01.2007	10.8	14.5	15.8	14.8	10.9
28.01.2007	11.1	9.9	13.1	15.5	11.5
29.01.2007	11.3	12.4	18.1	15.5	14.1
30.01.2007	11.3	11.1	14.2	14.2	14.8
31.01.2007	11.3	12.1	22.6	16.7	13.9
01.02.2007	11.3	13.3	19.8	14.7	12.5
02.02.2007	11.3	13.2	25.0	15.5	13.1
03.02.2007	11.4	13.9	27.4	16.2	14.5
04.02.2007	11.4	12.7	12.5	10.4	11.2
05.02.2007	11.7	10.5	25.6	12.8	12.7
06.02.2007	11.7	12.6	16.4	14.5	14.2
07.02.2007	11.7	14.9	20.4	14.2	13.9
08.02.2007	11.7	13.6	18.0	13.4	10.1
09.02.2007	11.9	9.2	13.5	12.7	15.7
10.02.2007	12.0	10.9	15.9	Ship Hold opened	

8. Comments:
During the voyage, the sealed joints/openings were inspected daily and damaged flash – bands were

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

replaced and expanding – foam applied. Throughout the voyage the temperature of the cargo and oxygen level in the hold were regularly measured and recorded. Apart from few sunny (hot) days, the temperatures of the cargo were steady downwards; this was an indication of good condition. Due to bad weather encountered during the voyage the journey took more than expected.

MV TIGER SHIPMENT

The MV Tiger shipment departed DSC Harbour at 11:39 am Nigerian time on the 12th of June, 2007 with a total quantity of 3,723.271 Tonnes of DRI en route to Bourgas (Bulgaria). While en route to destination port Bourgas, the cargo auto-ignited by waters Morocco, resulting in fire. Vessel and crew were in great danger and the vessel berthed at Melilla port in Spain and the DRI was discharged. Table 11 shows the readings taken during the voyage.

Table 11: Report During Voyage of Mv Tiger

Date	O_2 Content (%)	H_2 Content (%)	Temperature ^{O}c	Remarks
14.06.2007	6		24	
15.06.2007	13			
16-18.06.2007				Sailing in progress. Weather conditions reported bad
19.06.2007	17.2	2		Hatch vent opened for inspection
20.06.2007	20		35	
21-28.06.2007				Sailing in progress under adverse weather conditions
29.06.2007		1		Ship vent opened
01.07.2007		2	50	In Algeria waters. Steam observed from hatch vent. Nitrogen introduced into ship hold
03.07.2007			150	Red hot material spotted around one thermocouple. Flooding of hatch with water commenced in Algeria waters.
04.07.2007			> 150	Sailing commenced from Algeria waters with continuous flooding of the hatches.
06.07.2007				In Morocco waters. Flooding continued. Hot DRI shifted from sides to the center of the hatches. Attempts to discharge hot materials overboard failed.
07.07.2007				Flooding of material continued. Sailing

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

				from Morocco waters commenced.
08.07.2007				Ship anchored in Melilla sea port in Spain.
09.07.2007				Discharging of material to shore commenced with continuous flooding.

Figures 3, 4a and 4b show the re-oxidized DRI in the ship hold after berthing at the Mellila sea port in Spain.

FIG 3: Ship at Mellila sea port in Spain

FIG 4a: Re-oxidized 'Burning' DRI inside ship hold

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

FIG 4b: Re-oxidized 'Burning' DRI

Comments

The re-oxidation and auto-ignition that occurred was traceable largely to the ingress of oxygen which occurred few days into the voyage and seepage of water into the holds. This may have resulted from the failure of the seals around the hatch covers. Attempts to discharge the hot portions of the material in Algeria waters in order to prevent a spread proved abortive. The ship eventually anchored at the Mellila sea port in Spain and the re-oxidized DRI was spread on the shore and flooded with water until the temperature dropped to ambient.

5. TOTAL SHIPMENT OF DRI FROM DSC

The total shipments of direct reduced iron made in 2007 from Delta Steel Company is shown in Table 12

Table 12 : Total Shipment of Dri produced from Itakpe Iron Ore

S/ No	NAME OF VESSEL	Qty Carried	Destination	Departure Date	Arrival Date	REMARKS
1.	M/V MYSHIP	3,011.875	Bourgas (Bulgaria)	11/1/2007	10/2/2007	Successful
2.	M/V AYYILDIZ '5'	9,202.392	Bourgas (Bulgaria)	11/1/2007	31/1/2007	Successful
3.	M/V RAINBOW	3,100.853	Bourgas (Bulgaria)	7/2/2007	22/2/2007	Successful
4.	M/V RAINBOW	3,100.853	Bourgas (Bulgaria)	23/2/2007	1/3/2007	Successful
5.	M/V EEC PACIFIC	14,774.68 8	Mumbai(India)	26/2/2007	18/3/2007	Successful
6.	M/V MARIANO LAL	5,050.300	Bourgas (Bulgaria)	28/4/2007	10/5/2007	Successful
7.	M/V YULIA	2,848.163	Bourgas (Bulgaria)	15/5/2007	20/5/2007	Successful

8.	M/V TIGER	3,723.271	Bourgas (Bulgaria)	1/6/2007	12/6/2007	Aborted and diverted to Spain
9.	M/V RAINBOW II	2,956.903	Bourgas (Bulgaria)	25/6/2007	3/7/2007	Successful
10.	M/V LIBERTAS	5,320.195	Bourgas (Bulgaria)	21/8/2007	28/9/2007	Successful

6. CONCLUSION

The shipment of direct reduced iron from the Delta Steel Company in Nigeria was successfully implemented. Nine (9) successful shipments were executed. Efforts were made to ship the products in line with International standards. The MV Tiger shipment which was aborted due to the re-oxidation of the DRI was traceable to the hatch covers of the ship which gave room to sea water sipping into the hatches, egress of nitrogen and ingress of oxygen. The export of DRI made from the Nigerian local ore at Itakpe, in addition to ensuring the utilization of locally available raw materials for production of iron and steel, opened up the potential for foreign exchange earnings for the country. Larger quantities can be exported in single voyages. For safety reasons however, vessels to be used in DRI shipment should have multiple holds for the sake of salvaging some product in the event of re-oxidation in any of the holds.

7. ACKNOWLEDGEMENTS

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