DRI UPDATE

SIMA

Sponge Iron Manufacturers Association

Indian voice for the ore based metallic & steel industry

October-2024

Editorial

Dear Readers,

Presently, Indian DRI and steel industry are passing through the difficult time. Demand for the DRI and steel have come down, price of the major raw materials has increased and there is an all-around concern about the dumping of the steel impacting further steel prices. Several countries have imposed artificial barriers to safeguard the interest of their steel producers. We hope our government will also take similar actions. I am confident that steel demand will soon pick up after the monsoon period.

As we all know, sponge iron is going to be the main driver to mitigate the CO2 emissions. It is common knowledge that gas based DRI + EAF is the most eco-friendly route of steel making. However, there are certain known stumbling blocks due to which no natural gas based DRI plant has come up in India for last 30 years. Further there is uncertainty about the availability of syn gas and GH2 and their prices.

We have limited availability of recycled steel from internal and external sources. This situation is likely to persist at least some more time.

So, what are the options before the steel producers. Naturally they are using more a more coal based DRI as we do not have any merchant gas based DRI plant. Ministry of Steel has recently come out with a report entitled "**Greening the Steel Sector in India Roadmap and Action Plan"**. As per this report, CO2 emissions per ton of coal based DRI varies from 2.15 to 2.45. If we add 0.55 ton of t-CO2/tcs emissions through the electric steel making route, the t-CO2/tcs emission through the CDRI route would be around 2.70 – 3.00 ton which is much higher to the current national emission of 2.54 ton of t-CO2/tcs emission. It may also be mentioned here that the Ministry of Steel has set up a target of 2.2 ton of t-CO2/tcs emission by 2030. In the light of this scenario, CDRI industry has to make double efforts to achieve the targeted level of emissions.

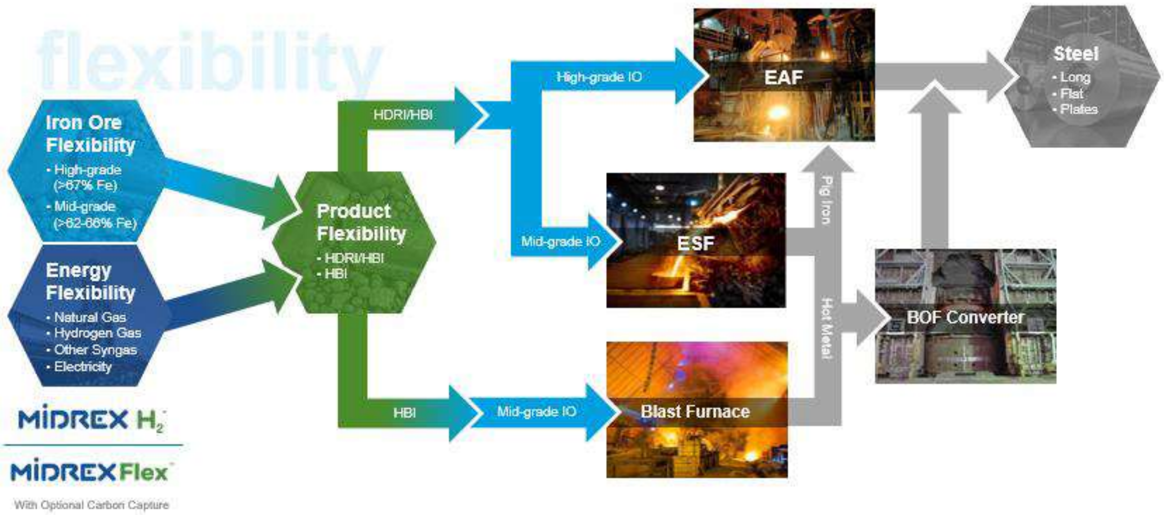
Recently, Tata Steel and SIMA have organized 2 days seminar on "**Sustainability Facets of DRI Industry"** involving DRI plant heads, experts and IIT Bhubaneshwar, IIT Roorkee and IISc. This was very successful, and many workable solutions came out. Some of the presentations have been included in this issue. I am sure you will find them interesting.

Deependra Kashiva
Director General

MIDREX

Direct Reduction: A Building Block for Decarbonization

Wherever your decarbonization journey begins, Midrex has **flexible solutions** for decarbonizing iron and steel production.



MIDREX

What is Midrex doing to reduce CO2 emissions?

MIDREX H_2™ — The Future Today

MIDREX

01

Optimized for 100% H_2

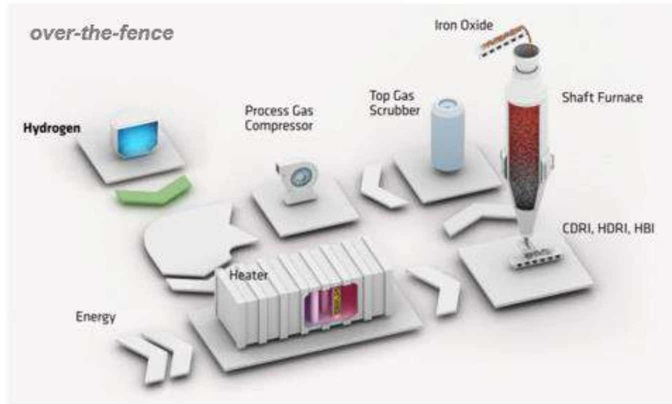
The MIDREX H_2 plant can operate without any fossil fuel input. Hydrogen recovery in the Top Gas Fuel maximizes the process efficiency

02

Electrical Heater

Strong collaboration with Midrex's partner, TUTCO SureHeat, allows for the application of direct electric heating to the Process Gas.

TUTCO SureHeat



03

Product Quality

Ready to deliver maximum CO_2 reduction with 0% carbon DRI, or deliver carbon-containing DRI for the downstream user. Special attention to the electric heater design and Top Gas Fuel hydrogen recovery allows for this flexible operation while avoiding undesirable side reactions.

MIDREX

MIDREX Flex®

01

Hydrogen Ready

Use up to 100% H2 as the reductant. Midrex has solutions ready to accommodate the entire range of input gas compositions at new and existing facilities.

02

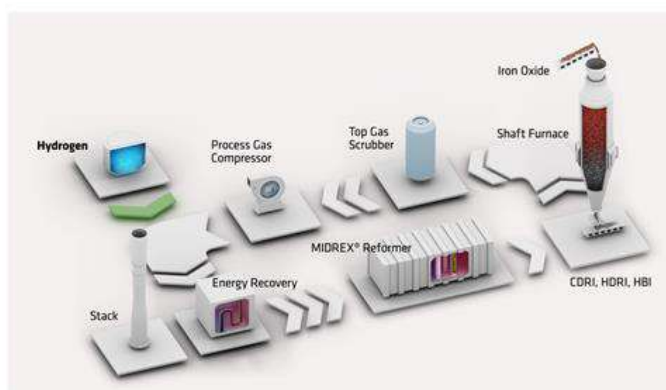
MIDREX® Reformer

The MIDREX Reformer ensures optimum reducing gas conditions throughout the entire range of the transition.

03

MIDREX® Shaft Furnace

Delivers consistent product quality throughout the transition. The influence of endothermic hydrogen reduction is mitigated by the MIDREX Reformer and uniform burden movement.



04

Carbon Capture & Storage

Carbon capture and storage can be applied to several different process streams. CO2 capture of 50% to nearly 100%. Available for addition to existing faculties or new installations.

A Pioneering Venture in Boden

Midrex and Paul Wurth, an SMS Group company, will supply the world's first commercial 100 percent hydrogen direct reduced iron (DRI) plant.

Stegra

LOCATION: Boden, northern Sweden
SCHEDULE: Production begins in 2025 and ramp up during 2026

01 MIDREX H_2 Plant will produce 2.1 million tons per year of hot DRI/hot briquetted iron.

02 The configuration includes the latest innovation from Midrex including an electric heater for the recirculating hydrogen gas.

03 Stegra's purpose is to decarbonize hard-to-abate industries, starting with steel, removing up to 95 percent of carbon emissions compared to traditional steelmaking.

MIDREX

"This unique DR Plant is a "lighthouse" to our industry and sets the standard for large-scale green steel production."

CO2 Emissions Reduction in Duisburg

Midrex and Paul Wurth will engineer, supply, and construct a direct reduction plant for thyssenkrupp Steel Europe AG.

thyssenkrupp

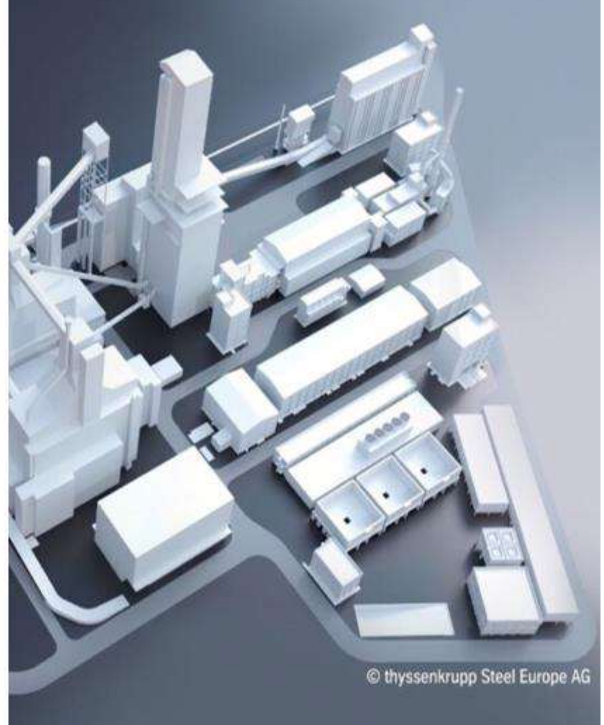
LOCATION: Duisburg, Germany
SCHEDULE: Plant start-up is planned for the end of 2026

01 MIDREX Flex Plant 2.5 million t/y of HDRI will be used in new electric smelters provided by SMS

02 The configuration includes the flexibility to operate at different ratios of natural gas and H2, up to 100% H2

03 The hydrogen-based DRI plant is a major step in thyssenkrupp's conversion of its integrated steelworks to a climate-neutral production site

MIDREX



© thyssenkrupp Steel Europe AG

Tosyali Algérie Expands Steel Complex

Midrex and Paul Wurth partner for the Phase 4 expansion of this integrated direct reduced iron-electric arc furnace (DRI-EAF) steel complex in Algeria.

LOCATION: Oran, Algeria

01 MIDREX Flex Plant 2.5 million t/y of HDRI and CDRI with plans to operate with increased percentages of hydrogen in the future.

02 DRI will be fed via a hot transport conveyor to the new 2.4 Mt/y EAF melt shop, providing greater EAF productivity and energy savings.

03 The upcoming third plant will utilize the MIDREX Flex concept for hydrogen transition.

TOSYALI ALGERIE PHASE 1 & 2


TOSYALI ALGERIE PHASE 3

Midrex and Primetals selected by Blastr

Midrex Technologies, Inc. and Primetals have been selected to supply a hydrogen direct reduced iron (DRI) plant for Blastr Green Steel (Blastr), one of the largest industry start-ups in the Nordic region.

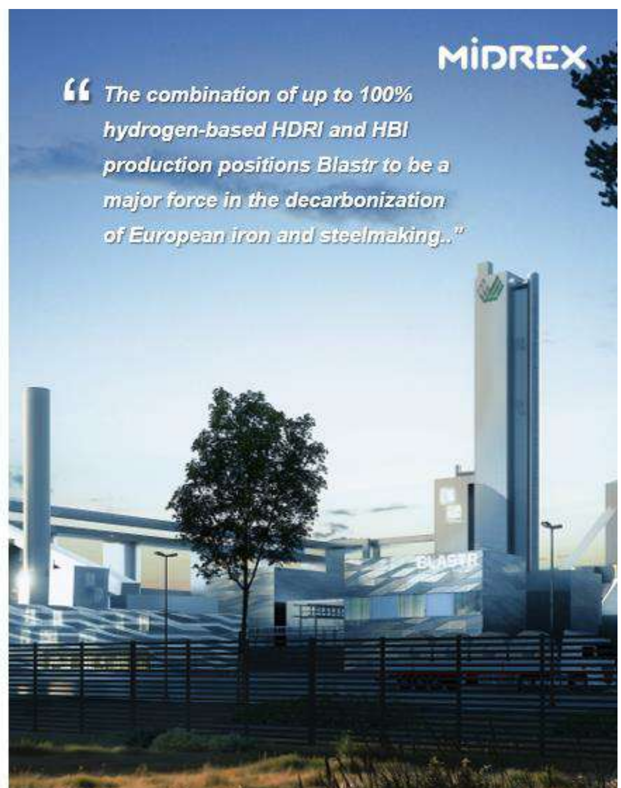
BLASTR Green Steel

LOCATION: Inkoo, Finland

01 MIDREX H_2 Plant will produce 2.0 million tons per year of hot DRI/hot briquetted iron.

02 Blastr Green Steel's unique, integrated value chain will produce high-grade ultra-low CO_2 steel for segments like automotive and construction industries, with ~90% lower scope 1-3 emissions than conventional steel production.

03 The Blastr value chain represents a yearly reduction of close to 6 million tonnes of CO_2, which is 25% more than the yearly CO_2 emissions from all passenger vehicles in Finland.



Vale and Midrex to Cooperate for Use of Iron Ore Briquettes in Direct Reduction Plants

Vale and Midrex Technologies, Inc. have agreed to cooperate in advancing a technical solution for the use of iron ore briquettes in direct reduction plants. Executives of the two companies met at the Midrex Research & Technology Development Center and signed a Technical Cooperation Agreement, united by a common vision for steelmaking decarbonization.

VALE

"More than a technical cooperation agreement, it is the start of a partnership that will play a crucial role in scaling briquette technology to several markets." - Eduardo Bartolomeo - Vale CEO

01 Vale's briquette production process represents an alternative to the pelletizing process with lower production costs, lower investment intensity, and approximately 80% less CO_2 emission.

02 The collaboration aims to demonstrate the viability of using iron ore briquettes in MIDREX® Plants, which could lead to significant advancements in sustainable steel production.

03 Initial test results have shown promising results in using iron ore briquettes in the direct reduction process. Once the technology has been successfully demonstrated in MIDREX® Plants, both partners plan to evaluate the creation of a joint venture to exclusively provide briquette technology and facilities to the market.

Dillinger and ROGESA selects Midrex and Primetals for Major Decarbonization Project

German steel producer Dillinger and ROGESA signed a contract with Midrex Technologies, Inc. and Primetals Technologies for the supply of a new production complex, including a direct reduced iron (DRI) plant and an EAF Ultimate electric arc furnace plant. The solutions from Midrex and Primetals will support Dillinger's goal of reducing CO_2 emissions by 4.8 million tons per year within six years.

"This partnership with Midrex and Primetals represents an important building block on the way to climate-friendly steel production here in Germany. We are convinced that we can successfully launch our Power4Steel decarbonization project on schedule with such an experienced and reliable partner." - Dr. Peter Maagh, Chief Technical Officer - Dillinger

01 Dillinger and ROGESA will deploy MIDREX Flex technology to create a DRI plant with an annual production capacity of 2 million tons.

02 The new production complex will include an electric arc furnace (EAF) and advanced systems for material handling, water treatment, and process automation. The design allows for tailored solutions that facilitate integration with existing facilities, optimizing operational efficiency while maintaining high-quality DRI output through the DRIPAX expert system.

03 This project is part of Dillinger Group's broader Pure Steel + program, aiming for carbon neutrality by 2045. The initiative is supported by funding from the German state and the European Union, highlighting a strategic investment in sustainable steel production and a significant step toward long-term environmental goals.

MIDREX Plant Anniversaries in the 3rd Quarter:

Midrex is known for designing, engineering, and servicing reliable direct reduction plants, as well as ensuring that these plants have long and successful operating lives. The below plants have third quarter anniversaries:

Antara Steel Mills HBI

40 YEARS

Location: Labuan Island, FT, Sabah, Malaysia

- **Start-up:** August 1984
- Product: HBI
- **Rated Capacity:** 0.65 million tons/year

The first MIDREX HBI Module was started up in August 1984 for Sabah Gas Industries, which later became part of the Lion Group as Antara Steel Mills HBI. Esteel Enterprise of Singapore completed acquisition of the HBI plant in 2022.

Antara Steel Mills HBI operated 9% over its annual rated capacity in 2023, following a record-setting year in 2022 of 20% over rated capacity. Total iron content averaged 92.63% for the year. All production was shipped by water to third parties. Cumulative HBI production through 2022 is more than 23.3 million tons.

Libyan Iron and Steel Company (LISCO) Module 1

35 YEARS

Location: Misurata, Libya

- **Start-up:** July 1989
- **Product:** CDRI
- **Capacities:** 0.55 million tons/year

Production by LISCO's three modules increased significantly in 2023 compared to previous years. Modules 1 & 2 produce CDRI for the LISCO steel mill, while Module 3 produces HBI for export.

The three modules combined to set a multimodule production record that was last set in 2005 and eclipsed the 35 million tons milestone for cumulative production. Read more about Libya Iron and Steel Company (LISCO) at: https://libyansteel.com

JSW Steel (Dolvi)

30 YEARS

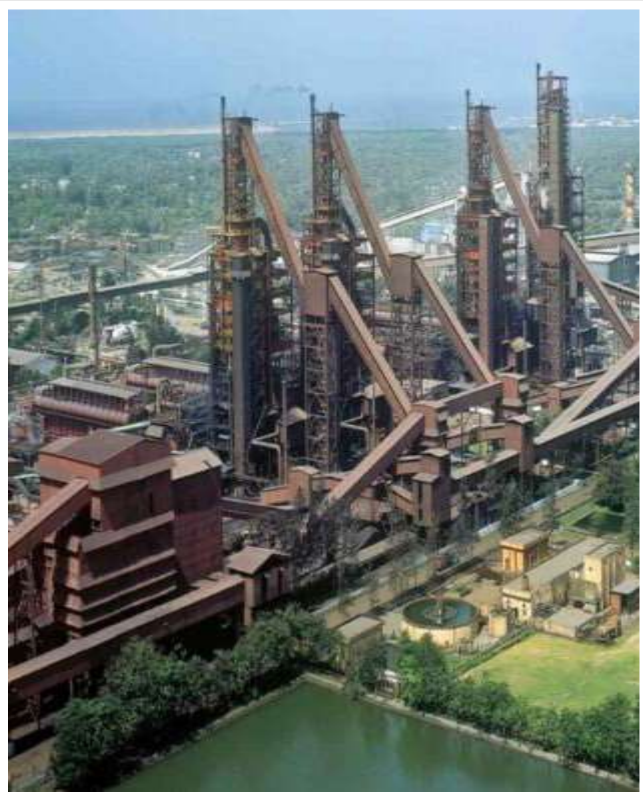
Location: Raigad, Maharashtra, India

- **Start-up:** September 1994
- **Product:** CDRI
- **Rated Capacity:** 1.0 million tons/year

JSW Steel's MIDREX Module easily exceeded its rated capacity in 2023 and operated 8198 hours. Approximately 10% of the module's energy input is COG injected to the shaft furnace to reduce natural gas consumption.

JSW Steel (Dolvi) has averaged 8044 hours of oper-Ation per year since its initial start-up in 1994, and 8149 hours per year in the last 8 years. Its cumulative production through 2022 is almost 33.2 million tons. Read more about JSW Steel and its Dolvi Works at: https://www.jswsteel.in

ArcelorMittal/Nippon Steel India IV



20 YEARS

Location: Hazira, Gujurat, India

- **Start-up:** July 2004
- **Product:** HBI/HDRI
- **Capacity:** 1.0 million tons/year

Module IV established new annual productivity & electricity consumption records in 2023, as well as a new monthly production record in May.

All six modules combined have produced over 91 Mt of HDRI, HBI, and CDRI since start-up of the first two modules in 1990. Approximately 96% of the output from the four HDRI/HBI modules was in the form of HDRI, while Modules I and VI produce CDRI exclusively. Read more about ArcelorMittal/Nippon Steel India at: https://www.amns.in

JSPL (Angul)

10 YEARS

Location: Angul, Odisha, India

- **Start-up:** July 2014
- **Product:** HDRI/CDRI
- **Capacity:** 1.8 million tons/year

This is the first MxCol Plant using synthesis gas from coal gasifiers to produce both HDRI and CDRI for the adjacent steel shop. Through 2022, the plant had produced more than 5.3 million tons of DRI.
A hot DRI conveying system is installed from the MIDREX Plant to the melt shop. HDRI production was 54% of total production in 2023. COG was used in the DR plant throughout the year, averaging ~15% of the plant's energy requirements.
Read more about JSPL and its Angul Works at: https://jindalshadeed.com/odisha

JSW Steel (Toranagallu)

10 YEARS

Location: Toranagallu, Karnataka, India

- **Start-up:** August 2014
- **Product:** HDRI/CDRI
- **Capacity:** 1.2 million tons/year

JSW Steel (Toranagallu) using COREX export gas as energy input, operated over 8000 hours in 2023. Through 2022, the plant had produced almost 6.9 million tons of DRI.
A hot DRI conveying system is installed from the MIDREX Plant to the melt shop. 55% of production went to the steel shop as HDRI.
Read more about JSPL and its Toranagallu Works at: https://www.jswsteel.in

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Sustainability of DRI process

D.P. Deshpande, Consultants & Former Chairman, SIMA

1. Sustainability is the ability to continue over a long period of time

2. The sustainability of Direct Reduced Iron (DRI) in India is a complex issue, shaped by the country's energy resources, environmental concerns, and the demand for steel. Here's an overview of key factors affecting its sustainability:

A) Energy dependency , why coal, integration of renewable energy
B) Carbon emissions ; challenge of reduction , going to net zero
C) Iron ore quality ; need to beneficiated/pelletise
D) Circular economy; reuse char
E) Govt regulations ; beyond NDp, PAT, incentivizing renewables, CCUS
F) Use of green hydrogen

3. 1.86 t of CO2/t steel. 2.6 billion t of CO2 7 -9% of global CO2.

4. Let us look at the rotary kiln process and it's ability to sustain

Rotary kilns as a solid - gas reactor

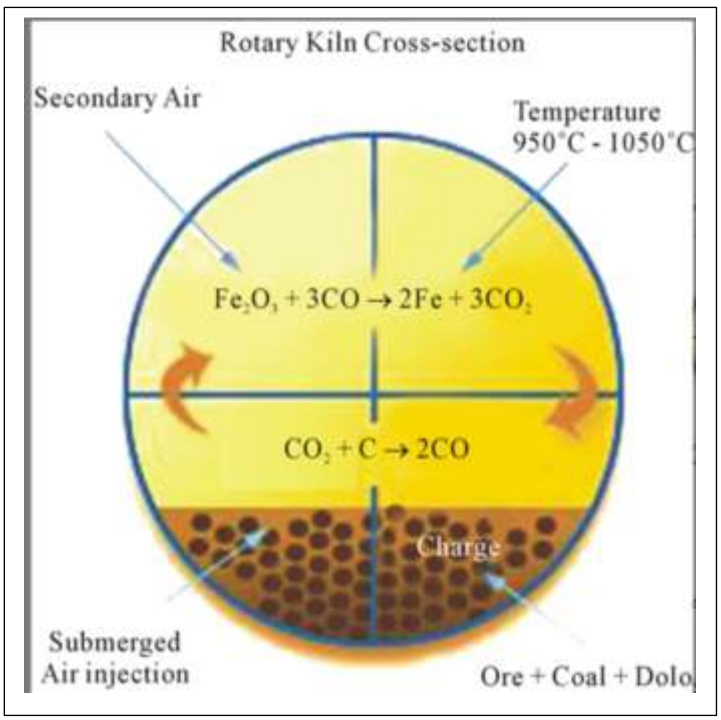
1. Better heat and mass transfer rates compared to fixed bed reactors

2. 25 GJ/tdri

3. Heat losses from shell, from exhaust gases,from product, incomplete combustion of fuel, Low heat efficiency

4. ~100 t/hr capacity, 85-90% metalisation ;

5. Char as solid waste



Rotary kilns …… Contd.

1. 1.6-2.4 t CO2/t DRI;
2. Preheating of feed material, WHB, air pre heaters, will partially offset.
3. CCUS to ethanol. Just right capacity?

7.3. Theoretical Heat Balance, Ideal Case (Table 4)

Negative sign indicates exothermic reaction or heat release and positive sign indicates requirement or absorption of heat.

Iron Ore	1.43 Kg	Heat Supplied = 2058 Kcal	Sponge Iron	1 Kg (Basis)
Coal	0.64 Kg	→	Char	0.064 Kg
Air	5.20 Kg	− 251 Kcal (Excess Heat)	Flue Gas	6.20 Kg
Total Input	7.270 Kg		Total Output	7.264 Kg

Table 3. Mass balance of reactants & products to produce 1 Kg of pure sponge iron.

Component	Heat Value (Kcal)
Sponge iron sensible heat; assuming Δt = 1045˚C	+124
Char sensible heat; assuming Δt = 1045˚C	+13
Flue gas sensible heat; assuming Δt = 1045˚C	+1555
Heat loss due to moisture present in the coal	+66
Heat loss due to vapor formed from hydrogen of coal	+49
Heat of iron reduction reaction (exothermic)	−758
Heat gain from burning of VM of coal	−1300
Net heat surplus in overall Kiln reaction	−251
Total additional heat/coal requirement to produce 1 Kg sponge iron	nil

To calculate the enthalpy change (ΔH) for the reaction:

$$3C + 2Fe_2O_3 \rightarrow 4Fe + 3CO_2$$

we need the standard enthalpies of formation (ΔH_f°) of the reactants and products. The formula for calculating ΔH is:

$$\Delta H = \sum \Delta H_f^\circ(\text{products}) - \sum \Delta H_f^\circ(\text{reactants})$$

The standard enthalpies of formation for the relevant substances are approximately:

- $\Delta H_f^\circ(Fe_2O_3) = -824.2\,\text{kJ/mol}$
- $\Delta H_f^\circ(C) = 0\,\text{kJ/mol}$ (for elemental carbon in its standard state, graphite)
- $\Delta H_f^\circ(Fe) = 0\,\text{kJ/mol}$ (for elemental iron)
- $\Delta H_f^\circ(CO_2) = -393.5\,\text{kJ/mol}$

Now, using the equation:

$$\Delta H = [4(0) + 3(-393.5)] - [2(-824.2) + 3(0)]$$

$$\Delta H = [0 - 1180.5] - [-1648.4 + 0]$$

$$\Delta H = -1180.5 + 1648.4$$

$$\Delta H = 467.9\,\text{kJ}$$

So, the enthalpy change for the reaction is $\Delta H = +467.9\,\text{kJ}$. This means the reaction is endothermic.

3 + 1.189 = 4.189 mol
For four moles of Fe
⇒ 225 kg C / t DRI
≈ 410 kg Coal / t DRI @ 55% C

1 T DRI ≈ 500 kwh
≈ 275 kg Coal @ 55% C

Total Coal Reqt ≈ 700 kg Coal/t DRI + Power

For the reaction:

$$C + O_2 \rightarrow CO_2$$

The enthalpy change (ΔH) can be directly obtained from the standard enthalpies of formation. The relevant enthalpy values are:

- $\Delta H_f^\circ(C) = 0\,\text{kJ/mol}$ (for elemental carbon, graphite)
- $\Delta H_f^\circ(O_2) = 0\,\text{kJ/mol}$ (for elemental oxygen in its standard state)
- $\Delta H_f^\circ(CO_2) = -393.5\,\text{kJ/mol}$

Using the formula for ΔH:

$$\Delta H = \sum \Delta H_f^\circ(\text{products}) - \sum \Delta H_f^\circ(\text{reactants})$$

$$\Delta H = [-393.5] - [0 + 0] = -393.5\,\text{kJ/mol}$$

So, the enthalpy change for the reaction is $\Delta H = -393.5\,\text{kJ/mol}$, meaning the reaction is exothermic.

To determine how many moles of carbon are required to meet a heat requirement of 467.9 kJ, we use the enthalpy change of the reaction:

$$C + O_2 \rightarrow CO_2 \quad (\Delta H = -393.5\,\text{kJ/mol})$$

Since 1 mole of carbon produces 393.5 kJ of heat (in an exothermic reaction), we can set up a proportion to find how many moles of carbon are required to release 467.9 kJ of heat.

$$\text{Moles of C} = \frac{467.9\,\text{kJ}}{393.5\,\text{kJ/mol}}$$

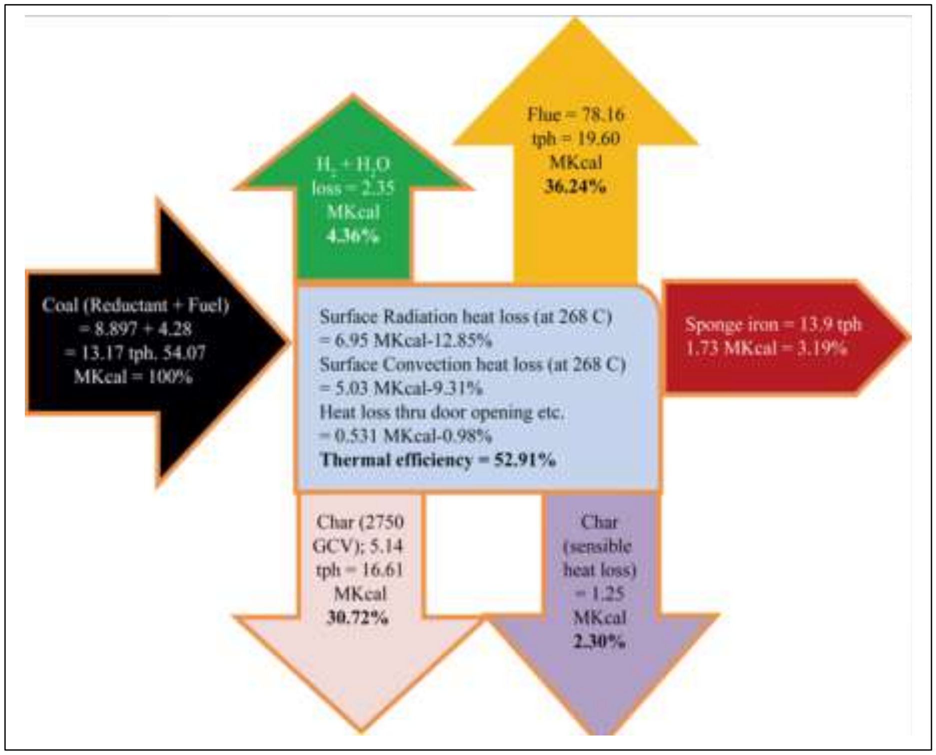
$$\text{Moles of C} \approx 1.189\,\text{mol}$$

Therefore, approximately 1.19 moles of carbon are required to meet the 467.9 kJ heat requirement.

Energy consumption in rotary kilns

1. Heat losses to be recovered/prevented … preheating of RM and air, WHB, use high quality coal,

2. Needed better heat utilisation, Better waste management for CO2 reduction.



Rotary kilns, Breakup of 2.5-3 GJ/t-DRI.

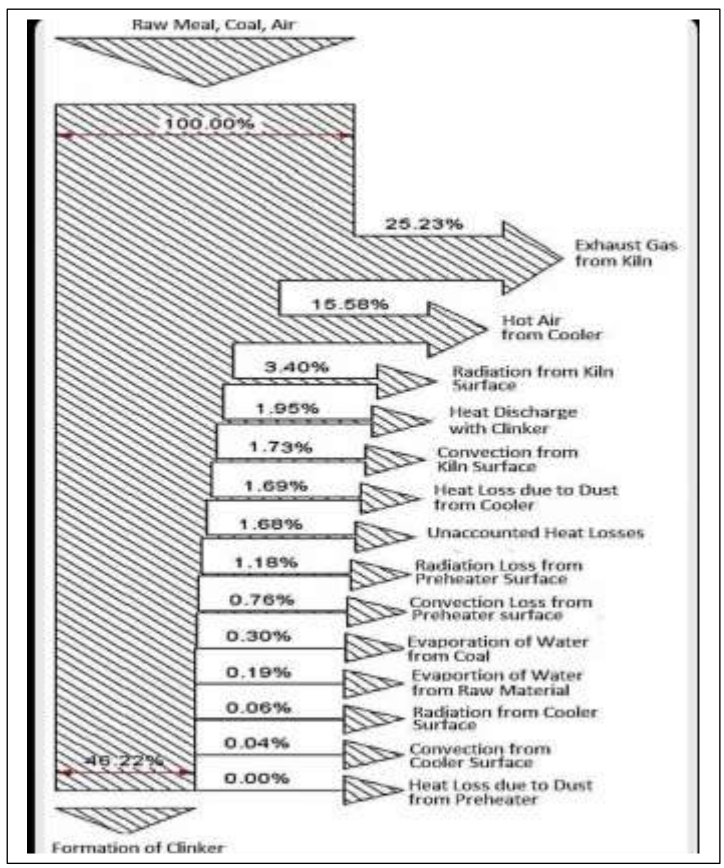
1.Energy consumption ~60% of total energy is consumed by the reduction reactions.

2. 20-30% energy in raising the temperatures, heating.

3. 10-15% recovered in WHB

4. 5-10% as electrical energy

5. 5-15% as heat losses; radiation, hot gases, hot product, unburnt fuel.



Energy consumption in rotary kilns

Conclusion

The rotary kiln process for DRI production is less competitive in terms of energy consumption compared to modern gas-based DRI processes. However, it remains viable in regions where coal is the primary energy source, and natural gas is either expensive or unavailable. The future competitiveness of rotary kiln processes will likely depend on their ability to reduce energy consumption, improve efficiency, and address environmental concerns, particularly CO_2 emissions.

Iron ore	1.55 Kg	Heat input = 3889.84 Kcal	Sponge Iron	1 Kg (Basis)
Coal	0.947 Kg	→	Char	0.43 Kg (calculated from mass balance)
Air	3.28 Kg		Flue gas	4.41 Kg (calculated from mass balance)
Dolomite	0.068 Kg			

Table 5. Actual mass balance based on plant data.

MIDREX PROCESS FLOW SHEET

1. Equally simple process

2. Cleaner fuel

3. Better heat utilisation

4. Little to no waste

5. So, better control on

CO2

6. 5000 tpd capacity

possible

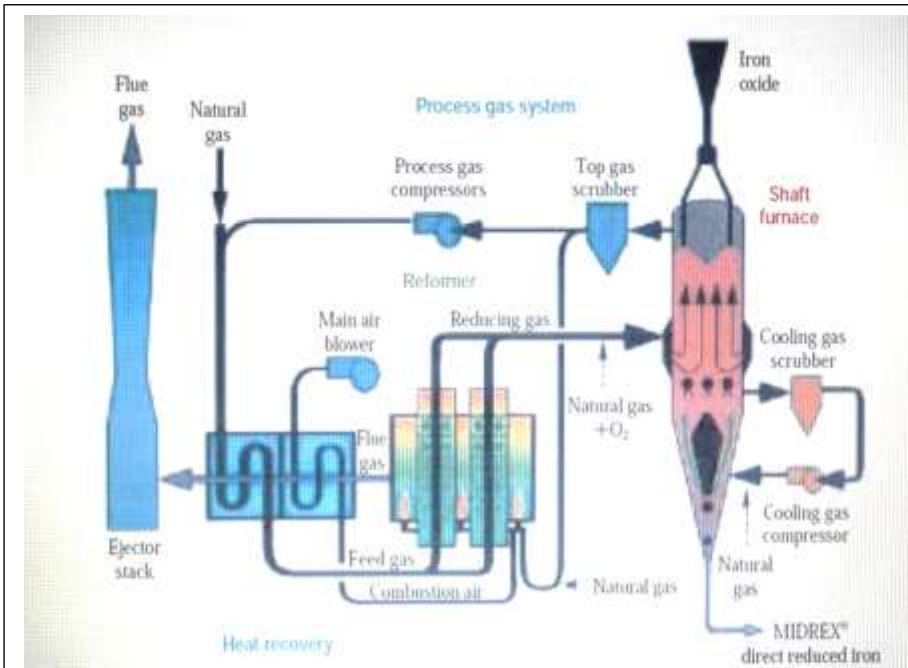


Fig. 4 Standard MIDREX process flowsheet

Comparison of options for producing iron/steel.

Parameter	DRI coal	DRI - gas based	BF	EAF with scrap	EAF DRI
Energy consumption	25-30 GJ/ t DRI	10-12 GJ/t dri	14-18 GJ/ t HM	3-5 GJ/ t steel	10-12 GJ/ t steel
CO_2 emissions	1.6t-2.4 t CO_2/ tdri	1.2-1.5 t CO_2/ t DRI	1.8-2.5 t CO_2/ tdri	0.3-0.4 t CO_2/ Rs	1.2-1.5 t CO_2/ t gas DRI

Limitations of coal based DRI under Paris agreement

1. High CO_2 emissions; the potential to reduce emission is limited by the chemistry of the process.
2. Stricter regulatory norms will follow; will make coal based DRI potentially unviable; carbon pricing mechanism such as carbon taxes, or cap and trade systems will hurt coal based DRI.
3. High cost of CCUS, and uncertain feasibility to implement.
Using alternative fuels can be capital intensive.
4. Customers wanting low CO_2 steel will favour gas based DRI.

Options for coal based DRI under Paris agreement

1. Raise energy efficiency; optimise kiln design, improver thermal insulation, enhance heat recovery.
2. Partial substitution of coal , biomass, biogas,
3. CCUS; CCUS integrative options, Use CO2 as a feedstock for chemicals
4. Hybrid processes;coal gasification + NG;use of hydrogen,
5. Carbon offsetting investments;e.g reforestation or renewable energy, buying carbon credits.

Industries that failed to sustain

1. Whaling industry in late 19 th and early 20 th century… cost increase & failure of developing alternative fuel.
2. Asbestos industry…failure to transit into safer alternatives
3. CFC based refrigeration industry… companies failed to transit in non CFC based refrigerants.
4. Coal mines in Europe..
5. Real Estate 2008 and Lehman brothers and now China ?

Industries that survived and sustained by definitive actions

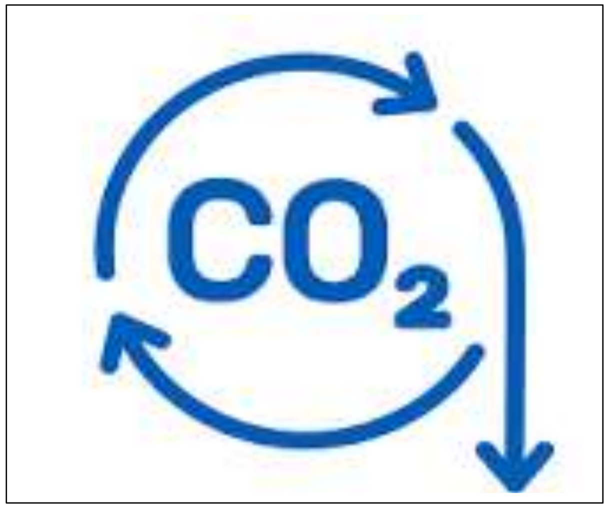
1.Paper and pulp industry…adopted sustainable forestry, FSC, invested in recycling of paper
2. Automotive industry shifting to hybrid and EVs…
3. Agriculture ….sustainable farming, crop rotation, agroforestry, integrated pest management, drip irrigation
4. Textile industry…use of sustainable materials like organic cotton, recycled polyester, reducing water wastage, promoting circular economy.

What does a billion T steel producing nation think….

1. Shift from BF to EAFs/ DRI/EAFs, several pilot projects
2. Improve energy efficiency.. when you reach limits, look at the upstream and downstream processes and optimise.
3. Ultra low emission standards
4. Circular economy… RRR
5. Policy measures…carbon pricing and emission trading; industry consolidation
6. Investment in green technology…public private partnerships
7. International cooperation

On CO_2 usage applications

1. Enhanced oil recovery
2. Carbonated beverages
3. Chemical manufacturing like urea
4. Building materials like carbonate aggregates; to cure concrete,
5. Synthetic fuels like Methanol
6. Plastics and polymers like poly carbonates and polyurethanes
7. Algae cultivation for biofuels and bio products



Tata Sponge set up in 80's for…

1. Pioneering in sponge iron as an upcoming technology.
2. Meet demand for scrap substitutes in secondary steel making
3. Social objectives of employment and industrialization of rural India.

Mission forward ……

Summary - sustainability of coal based DRI

1. 30% steel from DRI, India would want DRI industry to sustain ….strategic interventions, laws will follow
2. Match fuel consumption rates of the next class of competing iron making processes.
3. Non- carbon or biomass based supplementary fuels /reductants
4. Unburnt char must be reused; but it is not CO2
5. A fit case for 1000-2000 tpd CO2 usage application ?. … consultants/ technology providers to see.

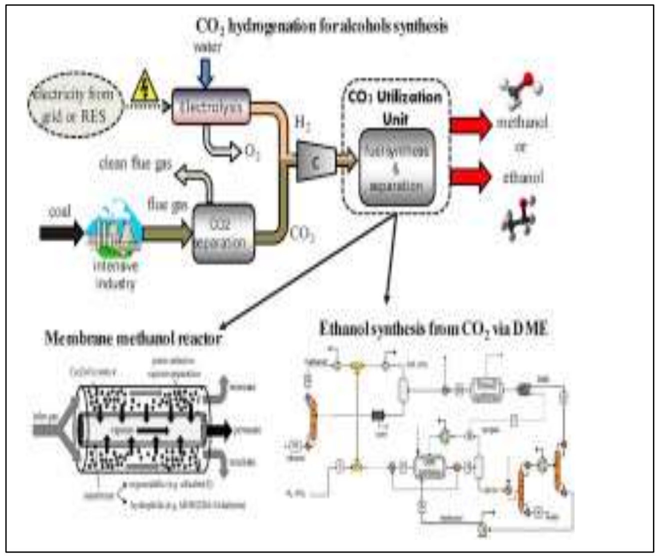


Table 1
Coal-based DR Processes

Process	Raw material	Product	Largest single module ($x10^6$ t/y)	Status
ACCAR/Grate Car	fines	solid	0.35	operating
AISI/Cyclone	fines	molten	0.50	pilot plant
AISI/Pellet	pellets	molten	0.35	development
Circofer	fines	solid	0.50	lab scale
Corex	pellet/lump	molten	1.20	operating
DIOS	fines	molten	1.00	pilot plant
DRC	pellet/lump	solid	0.15	operating
Fastmet	fines	solid	0.45	pilot plant
Finex	fines	solid	0.25	development
HIsmelt	fines	molten	0.50	pilot plant
INMETCO	fines	solid	0.30	pilot plant
Romelt	fines/lump	molten	0.40	pilot plant
SL/RN	pellet/lump/fines	solid	0.25	operating
Tecnored	fines	molten	0.30	pilot plant

Most of the processes available are of limited capacity, have high investment requirements or are commercially unproven.

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Maintenance- Online Anomaly or Error Prediction or Detection in a Dynamical System

Dr. Brahma Deo, Professor, IIT Bhubaneshwar

MAINTENANCE
Online anomaly or error prediction or detection in a dynamical system

- What can not be measured, can neither be accurately controlled nor predicted
- Dynamical systems change with time, divergence increases with time
  - A pipe used for coal injection continuously wears and changes its dimension and shape also
  - Eventually it bends or cracks

How to detect the changes: one example

- Coal injection pressure changes, gradually
- Continuous measurement of injection pressure data gives a time series
- This time series of pressure has all the components of forces acting on the system
- Similarly gas temperature close the mouth of the pipe (injection lance) changes
- Vibration pattern of pipe changes

So what we have measured in a mechanical system: **pressure, temperature, vibration, flow**

What changes are measureable:

- In an electrical system: current, voltage, resistance and vibration changes
- In an electro-mechanical (coupled) system: pressure, temperature, flow, vibrations, rpm, current, resistance and voltage changes
- These changes can be due to wearing out of bearing of motor, or of motor housing, lubrication failure, change in combustion efficiency of burner (parameters of burner itself)
- Each measurement gives a data series
- Each data series has time delay and embedding dimension, and state space
- Each data series has characteristic patterns/features related to particular fault(s)
- Most of the times one or two times series are enough!!

What is maintenance then?

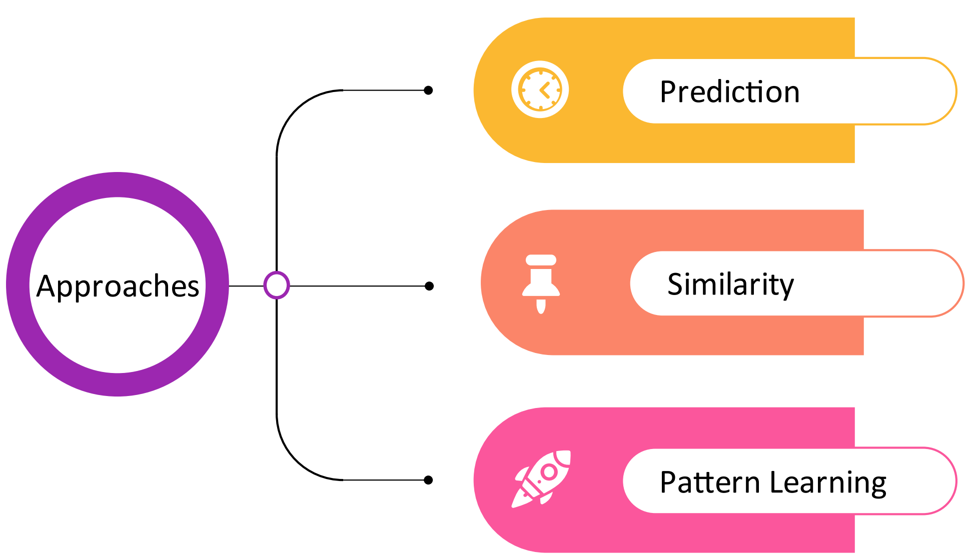
- Identification/prediction of errors and faults: **measurements** are a must
- Models: it is possible to make a **digital twin** of the system
- Need to build a **signal collection** system (signal from measurement tools)
- We need to learn about data analysis tools and techniques for study of signals: **signal analysis**
- **Compare** signal from a digital twin to the signal from a real system
- Doing corresponding plant **repairs** in time

Develop data analysis tools for

- Stationary system: linear or nonlinear system
- Non-stationary system, non -linear system
- Complex system: many variables, travels in different domains
- Chaotic system, single or multiple variables, domains of operation change frequently, divergence with time, return to chaotic attractors from time to time

Not all complex systems are chaotic and chaotic systems need not necessarily be complex

2



The classic approach is to train a model, at each moment, to predict the next point . If the observed point is too far from the prediction, the point is declared an anomaly.

Divide TS into multiple sigments and determine the different similarity measures between the reference series and segment (Self Similarity)

Train an AutoEncoder model to learn the pattern of a curve over normal periods.Thereafter, the network will be able to reproduce the curve. If some anomaly occurs the pattern will change and encoder won't be able to reproduce it and accuracy will decrease.

ANN, RNN, LSTM, CNN…-Development Pipeline

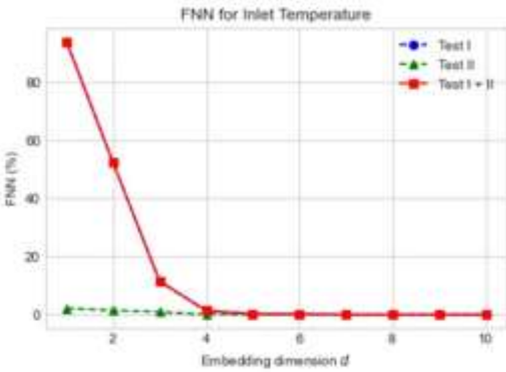
01	Data Preprocessing	Managing missing data, Filters for noise removal, Time delay and embedding dimension, scaling etc .
02	Model Architecture	CNN (3 different architecture with different number of hidden layers) AutoEncoder for third approach .
03	**Training**	• In the case of CNN approach 3-4 months of rotary kiln operation data is used for training . (time delay and embedding was used) • For pattern learning approach,
04	**Validation and Analysis**	• For AutoEncoder we observe digital twin and real system simultaneously

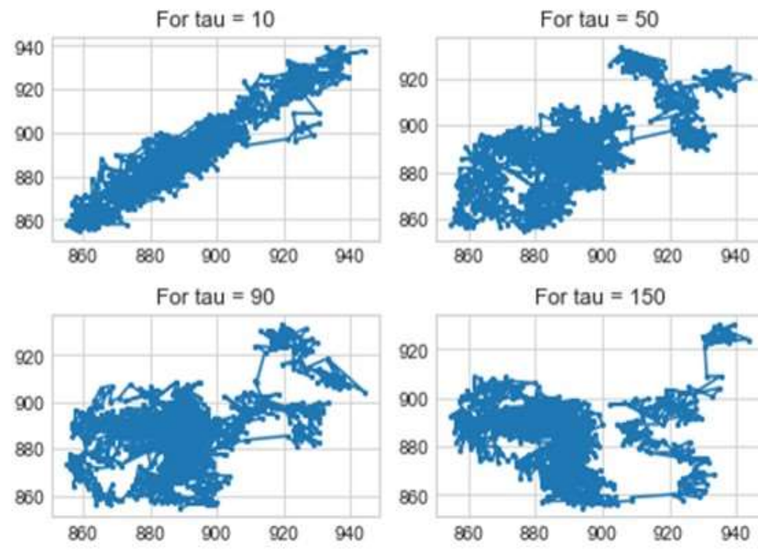
Is it enough to use, MLR, CNN, ANN, RNN, LSTM….

Answer is:NO

Dynamical systems now and then pass through a chaotic regime and then come back to chaotic attractors: regions of success and failure

State space changes of of a 500 tpd rotary kiln





1. Why we are using 3 embedding dimension?

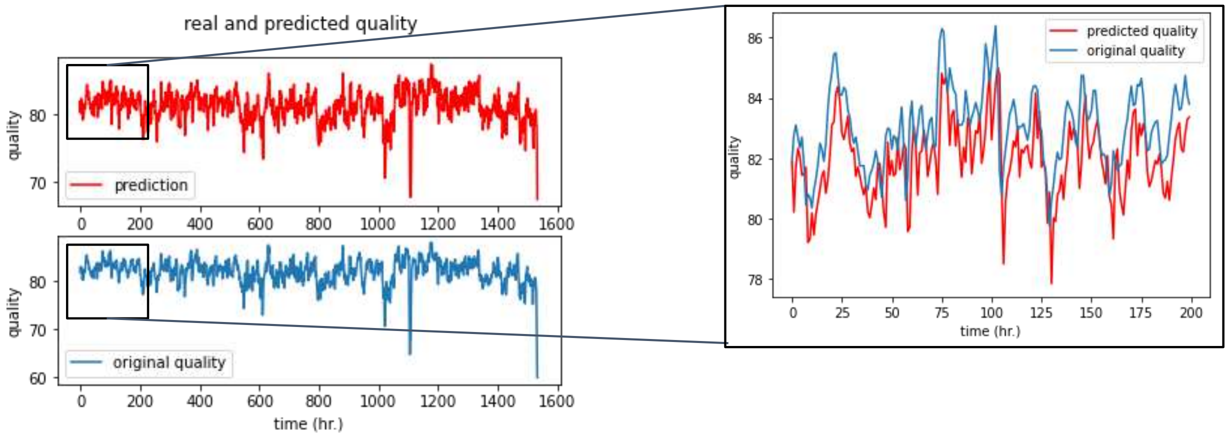
1. What will decide t value?

What is the solution then: track the system and bring it back to the attractor

This is called chaos control

Normal period: predictions are good, use even simple methods like OSAA, Grey(1,1)

8 .



Abnormal period: SIMILARITY ANALYSIS

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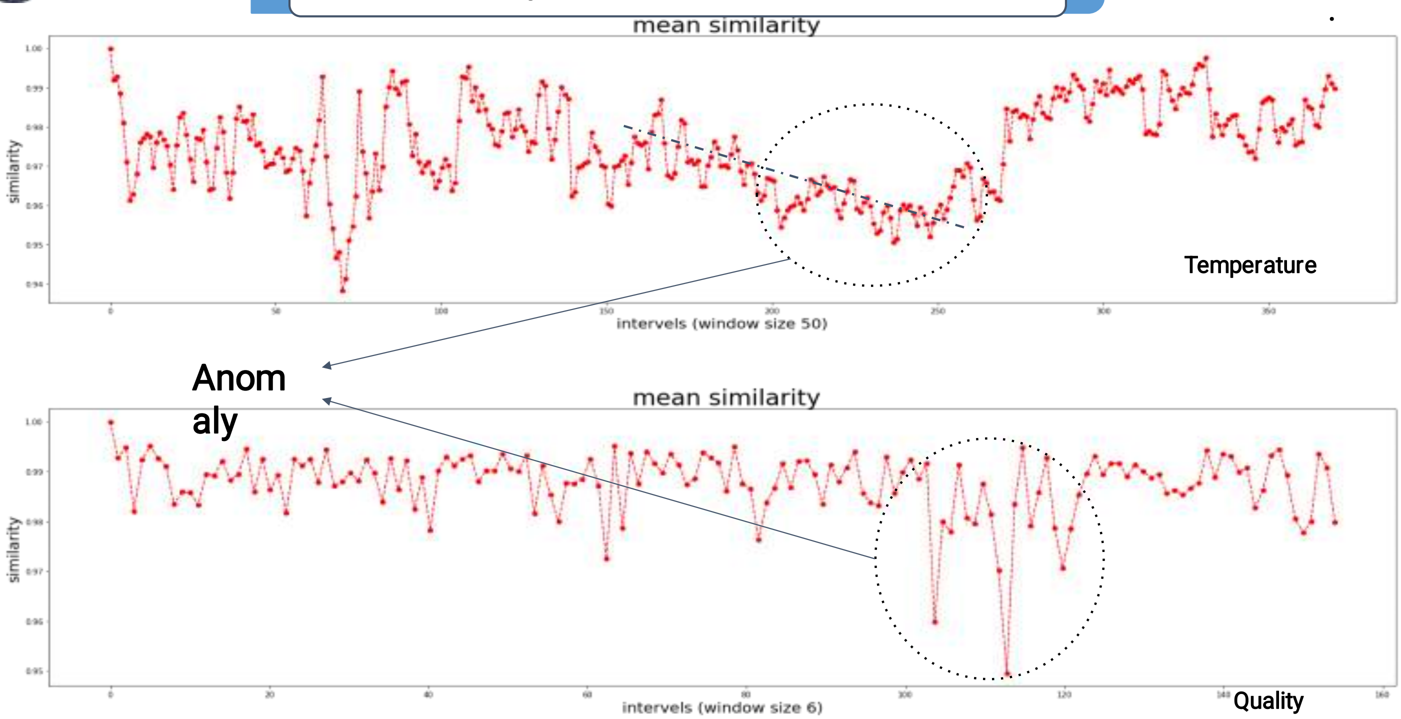


Similarity measures

1
1.

- Mean similarity
- Root mean square similarity
- Peak similarity
- Cross - correlation function
- Cosine similarity
- Euclidean Distance etc.

$$tsim(X,Y)=\frac{1}{n}\sum_{i=1}^{n} numSim(x_i,y_i)$$

$$rtsim(X,Y)=\sqrt{\frac{1}{n}\sum_{i=1}^{n} numSim(x_i,y_i)^2}$$

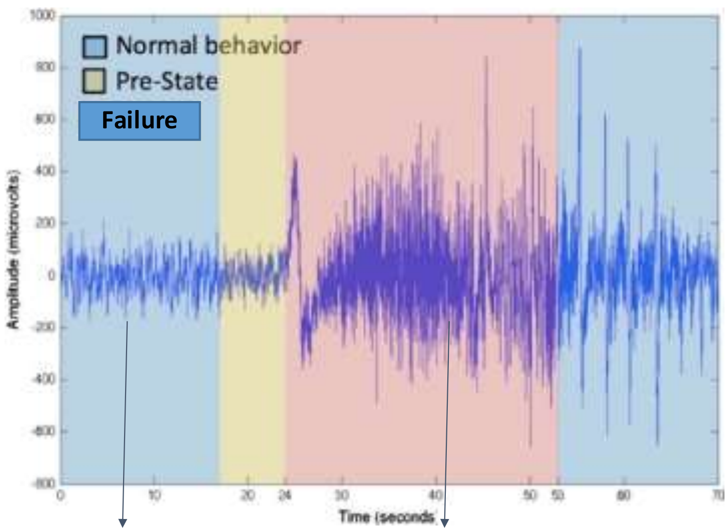
$$psim(X,Y)=\frac{1}{n}\sum_{i=1}^{n}\left[1-\frac{|x_i-y_i|}{2\max(|x_i|,|y_i|)}\right]$$

$$r_{XY}=\frac{\sum_{i=1}^{n}(x_i-\bar{X})(y_{i-l}-\bar{Y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{X})^2}\sqrt{\sum_{i=1}^{n}(y_{i-l}-\bar{Y})^2}}$$

$\bar{X}$ and $\bar{Y}$ are the means of X and Y.

$$\cos(\vartheta)=\frac{X\cdot Y}{\|X\|\|Y\|}=\frac{\sum_{i=1}^{n}x_i y_i}{\sqrt{\sum_{i=1}^{n}x_i^2}\sqrt{\sum_{i=1}^{n}y_i^2}}$$

15.



Training

Difference in reconstructed and original data will be high

Pattern Matching Using AutoEncoder

In the same way very powerful entropy measures: sample entropy, approximate entropy, spectral entropy

Pipe failure

- **Failure: Causes and effects-**

(i) Failure of rotary feeder

(ii) Failure of mild steel pipe

(iii) Failure of Stainless steel pipe/nozzle

All the images (in this page) is taken by the author himself at TSLPL Joda

- **Need of the failure prediction-**
  - **Avoid wastage of resources**
  - **Prevent coal distribution pattern disturbance**

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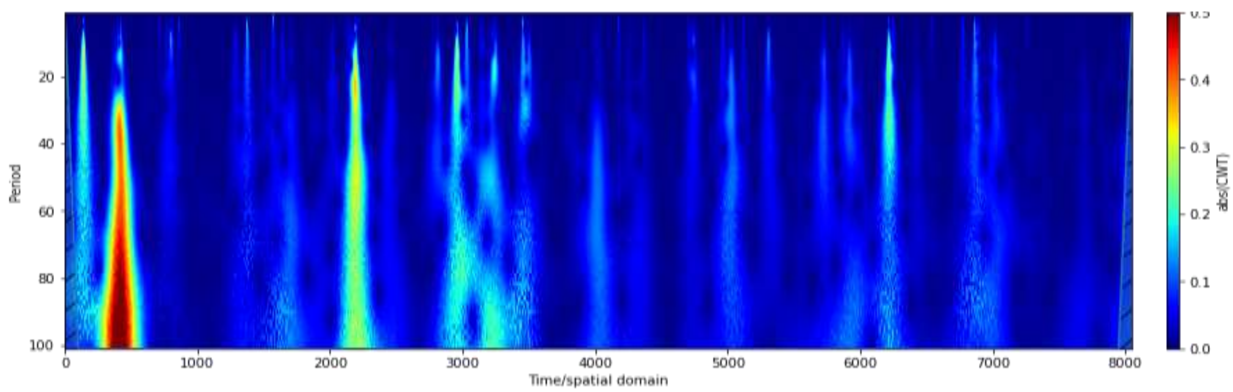
Failureanalysis method

- **Wavelet analysis of signal**



Typical Wavelet Transform of a Pressure data/signal

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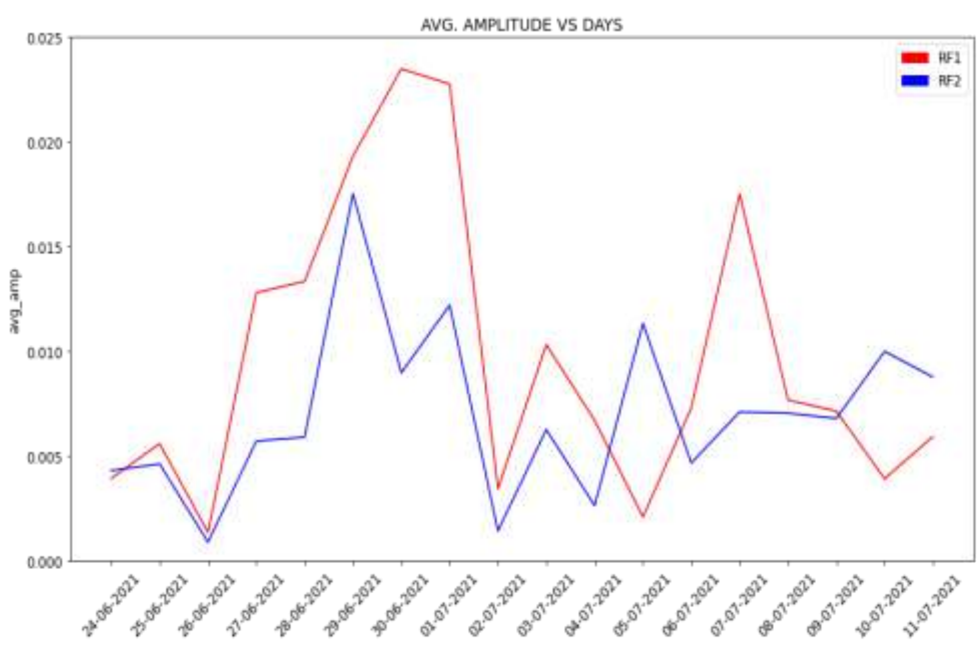
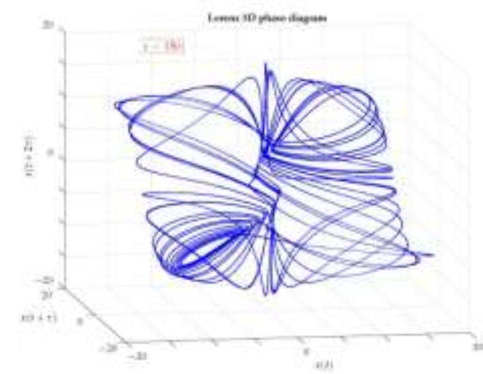


FFT max amplitude on different days

Chaotic dynamical systems analysis



Discrete Dynamical System

State space: Fault identification

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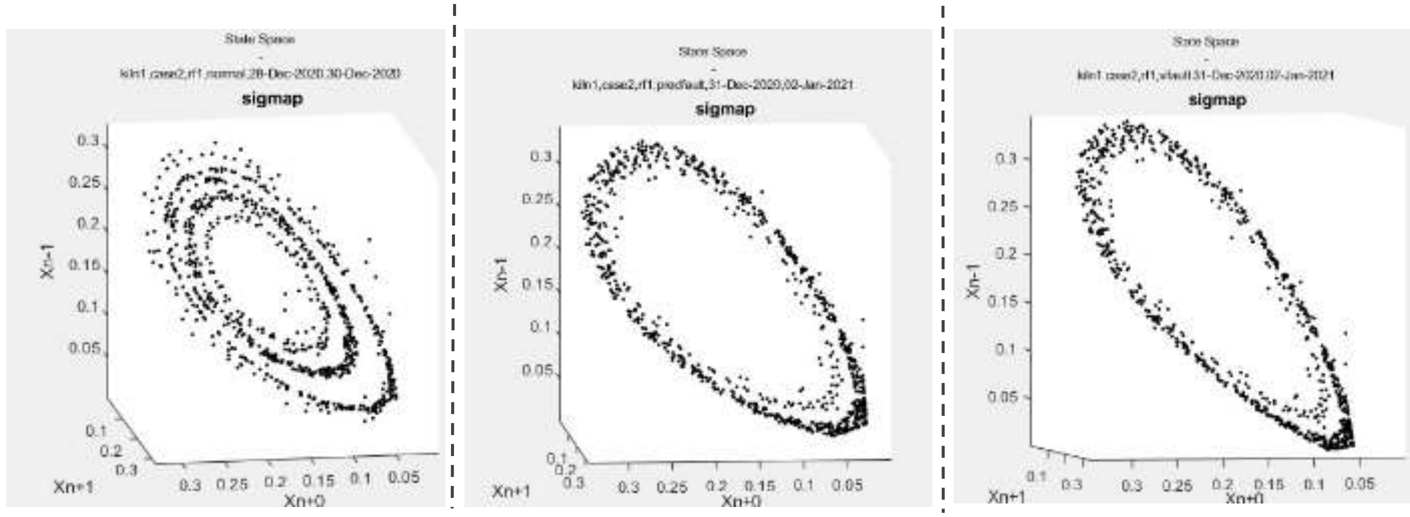
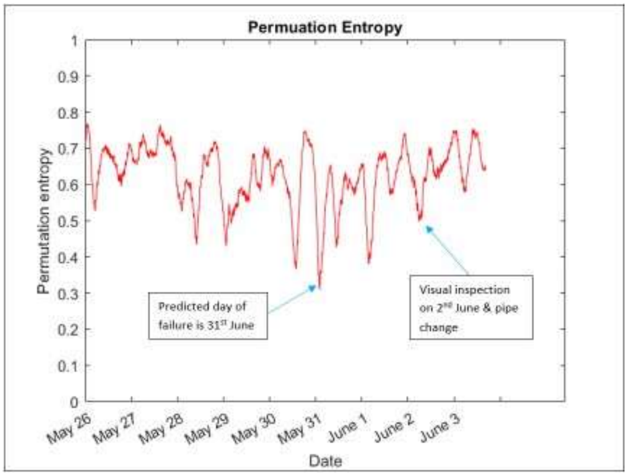
Before Predicted Fault	Fault	when visually seen

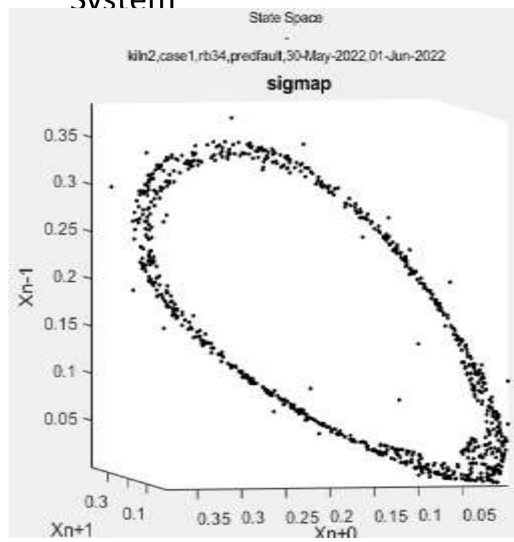


Comparison of permutation entropy and state space:

Ordinal Pattern Analysis

Discrete Dynamical System





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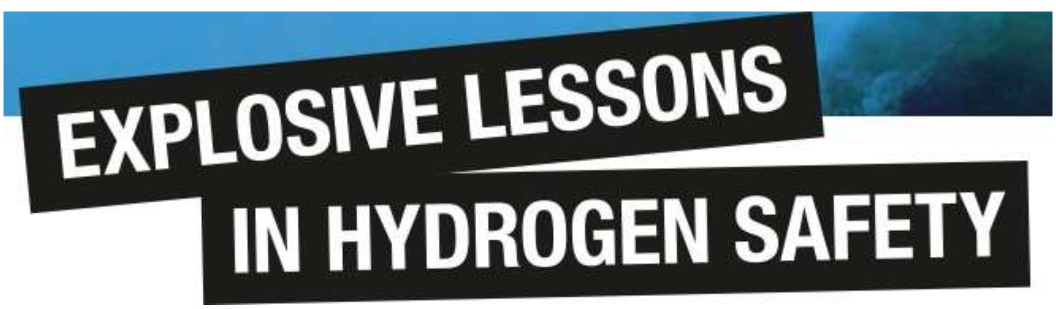

Leaks, or breakage of water seals

Through vessel surface temperature monitoring in critical areas: hot spots

Luro burner failure prediction at PPL through vibration measurement: fully designed system: DAQ, SCADA, model

Four sensor connection ports, DAQ, SCADA model with inbuilt signal analysis capability f engineering and medical (AIIMS) applicatio

ADVANCED MAINTENANCE TECHNOLOGY

Our vision:
To help the plant to maintain a smooth and optimal running system

- A running machine is an asset, and an idle machine in unexpected repair is a
- liability There is a subtle connection between an optimal running system and an optimally maintained system for lowest cost

Contact us

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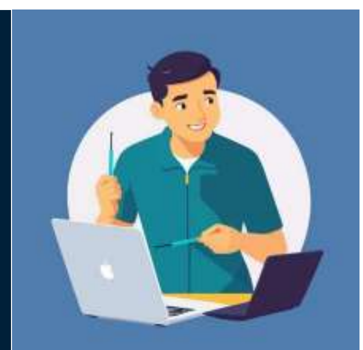

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Newly Designed Refractories for High Capacity DRI Kilns for Energy Optimization and Sustainable Growth

Subhadeep Chatterjee, TRL Krosaki

Newly designed refractories for high capacity DRI Kilns for energy optimization and sustainable growth

From TRL Krosaki Refractories Limited

Points to be discussed

(1) About TRL Krosaki

(2) Pain areas in DRI plants

(3) Addressing the pain areas and provide solutions

(4) Different products available in TRL Krosaki's product basket for DRI

(5) Innovative value-added approach for better performance

(6) Conclusion

(1) About TRL Krosaki

About TRL KROSAKI

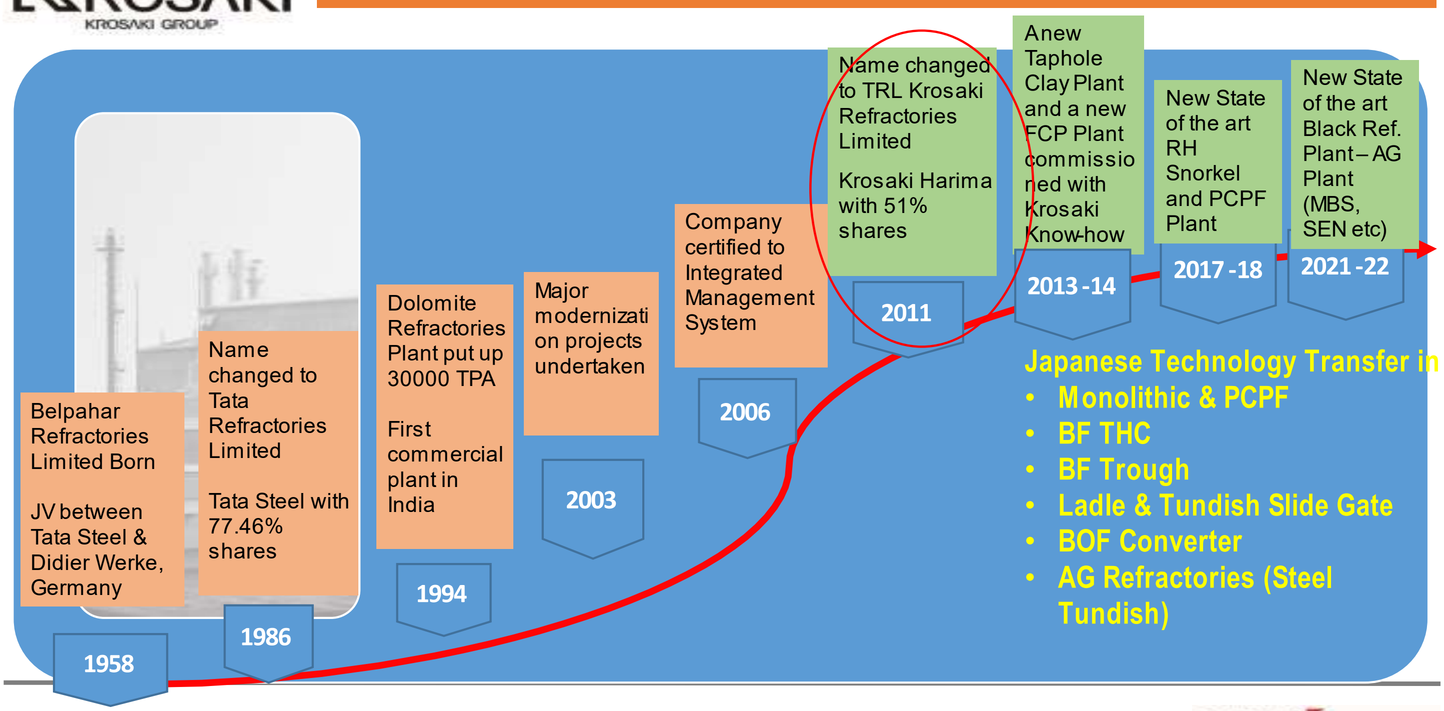
Share holding pattern

- Krosaki Harima Corporation, Japan (77%)
- SAIL (10%)
- Others (12%)

❑ "Krosaki Harima Corporation" (KHC) is an associate of "Nippon Steel & Sumitomo Metal Corporation" Japan – Rank 2nd : steel producer in the world.

- ✓ Revenue (FY 2023-24) – INR 2500 Cr. (approx.)
- ✓ TRLK Belpahar Odisha – Largest one stop refractory manufacturing unit in the world
- ✓ Total Production capacity - More than 3,50,000 MT / Annum
- ✓ Global Sales network
- ✓ Krosaki Harima is in the top 4 refractories manufacturers in the World

Evolution in last 6 decades



Quality Management Policy

TRL Krosaki has adopted Integrated Management System (IMS)

- Quality Management System (QMS) – **ISO 9001:2008**
- Environment Management System (EMS) – **ISO 14001:2004**
- Occupational Health & Safety Management System (OHSMS) – **OHSAS 18001:2007**

TRL Krosaki has recently been certified with

- Information Security Management System - **ISO/IEC 27001:2005**
- **First refractory organization in globe certified by SA 8000 in 2022**

10/10/2024 *** QMS is in line with Krosaki Harima Corporation ,Japan.

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(2) Pain Areas in DRI Pants

Pain Areas in DRI sectors

High shell radiation

(a) This is a common problem for DRI manufacturers. Water spraying is the regular practice to run the kiln till next shut down

(b) However, high shell radiation may cause the buckling of shell and loss of energy

(c) It may be dangerous from safety viewpoint

Severe abrasion from feed material on refractories

(a) Instead of iron ore, DRI manufacturers have started to use pellet which is high abrasive in nature

(b) To achieve good output better quality coals are being introduced which needs higher temperature to get full calorific value

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Pain Areas in DRI sectors

Longer pre-heating time

(a) Since water is added at the time of castable installation and it has to be removed by pre-heating to avoid any steam explosion. The pre-heating schedule is 3 – 4 days causing production loss. Every DRI manufacturers is searching a solution for quick pre-heating schedule to reduce the total shut down time

(b) Sometime adequate facilities are not available for proper maintain the pre-heating schedule

(c) One special castable with quick pre-heating schedule may relief the pain

Fluctuation of Setting time of castable

(a) Refractory cement is a part of castable design and therefore the setting time of castable depends on temperature as well as on humidity. Sometimes it shows delay setting and sometime fast setting.

(3) Addressing the pain areas and provide solutions

Wear Mechanisms in DRI Rotary Kilns

Abrasion	• Significant toward the discharge end, where most of the iron ore is already reduced into DRI
Corrosion	• The iron silicate slags in contact with alumino-silicate refractories leads to low melting phase.
Accretion formation	• Strong reaction occurs in the zone of the highest temperature, this leads to the formation of a thick protective layer of slag on refractory.
CO attack	• Free iron oxide within the refractory material should be minimal to prevent that it could be reduced to metallic iron due to the high CO content

Factors for high shell radiation

- **Factor 1** (Operating temp)

If the Operating temp is higher than normal temperature.

- **Factor 2** (Thickness of castable)

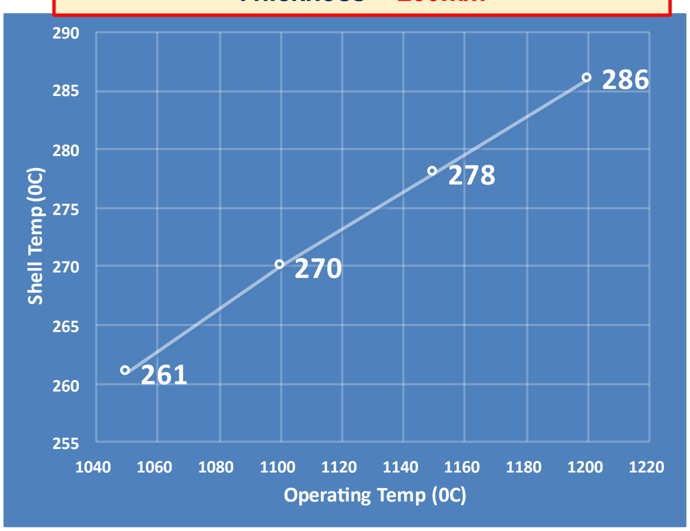
The erosion of castable reduced the thickness.

- **Factor 3** (Thermal conductivity)

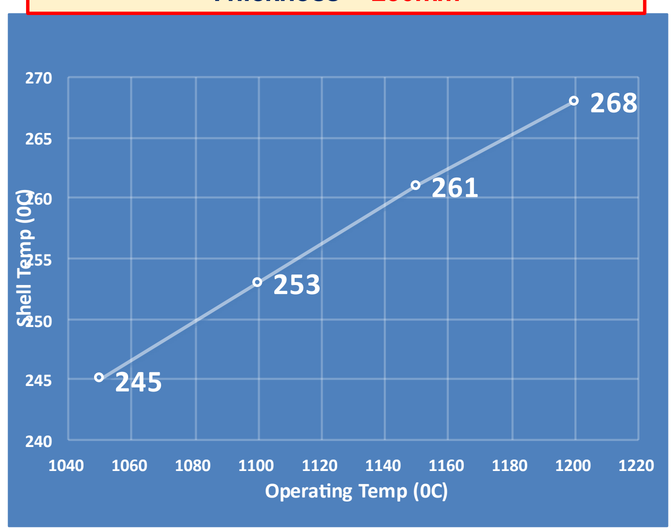
Higher thermal conductivity of castable may results high shell temperature but it should be determined as per Al2O3 content and not varying significantly.

Calculated Shell temperature

Area – Kiln Outlet, Quality: TRL – Mulcast, Thickness = 200mm



Area – Kiln Outlet, Quality: TRL – Mulcast, Thickness = 230mm

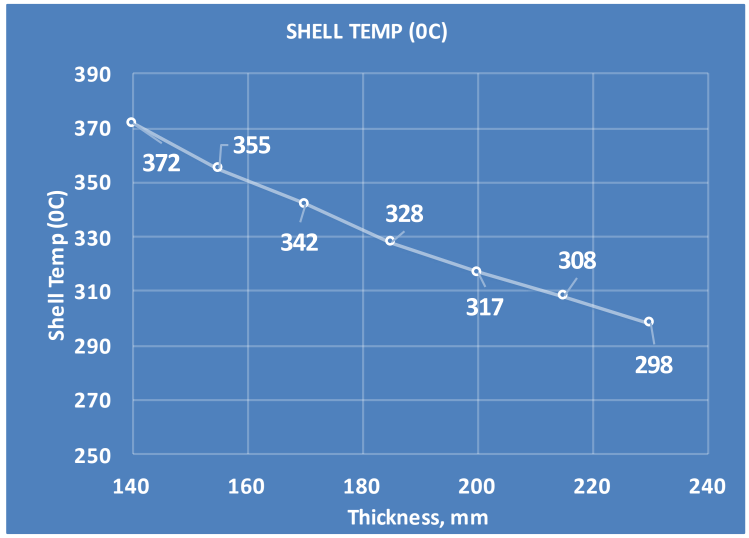


Calculated shell temp. (+/-20^{0}C) on the basis of thermal conductivity

Further Increased of shell temperature due to reduced thickness of refractory lining

- Refractory lining damaged during removal of accretion and reduced the lining thickness
- Refractory skin was removed during accretion removal and results very prone to erosion
- Due to less residual thickness of refractory lining shell temperature may increase.

Operating temperature = 1200 C



Relationship between shell temp. and lining thickness of refractory

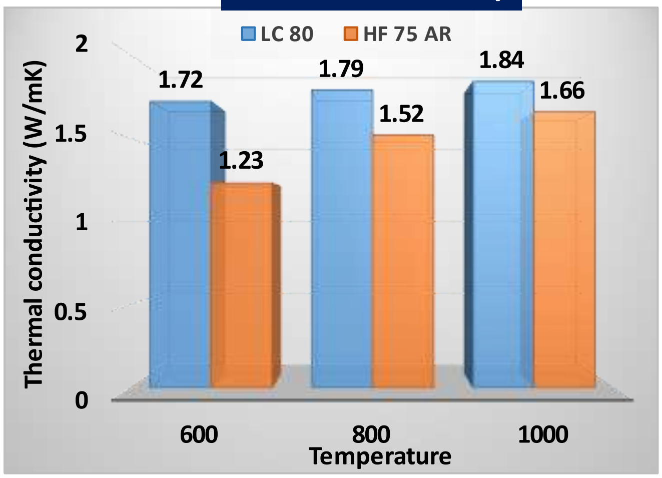
Probable solution to control Wear & High Shell radiation

New generation (HF Series) castables for DRI application

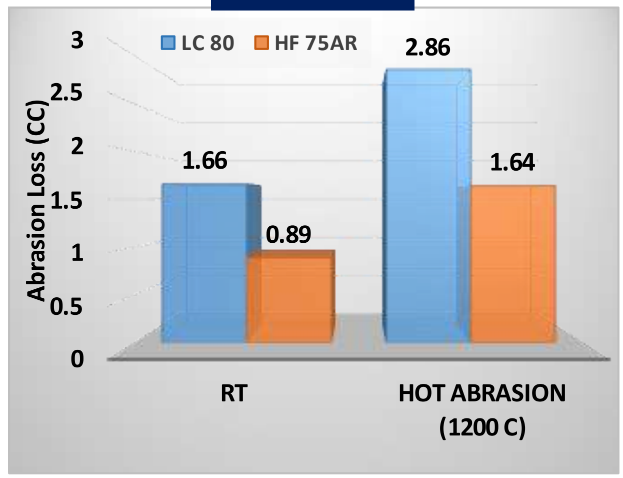
Design special castable having good wear resistance & lower thermal conductivity

Comparison in properties (80% Al2O3 LCC Vs TRL Cast HF – 75AR)

Thermal conductivity



Abrasion Loss



Note : Lower thermal conductivity keep the shell temperature under control

Note : Lower abrasion loss is always better for enhanced performance

Special features for "HF" series castables

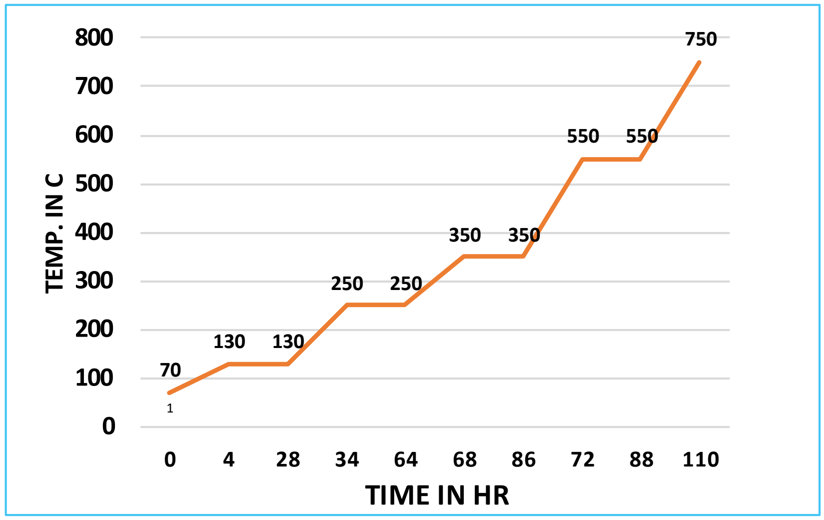
Special features

- Excellent abrasion resistance
- Low thermal conductivity
- Fast strength development
- Good thermal spalling resistance
- Optimum water demand and good flowability
- Easy to remove accretion without damaging the refractory
- Better structural stability

Reduction of total pre-heating schedule

Recommended drying schedule for LCC

Hrs	Cumulative Time	Temp in deg.c
0	0	70
4	4	130
24	28	130
6	34	250
30	64	250
4	68	350
18	86	350
4	72	550
16	88	550
4	110	750
Total	110 Hours	



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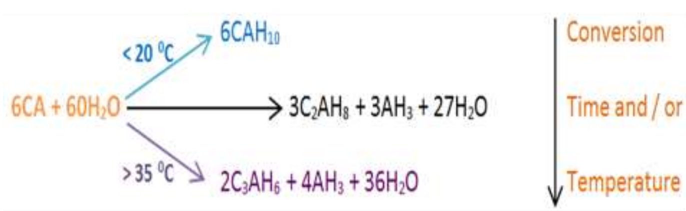
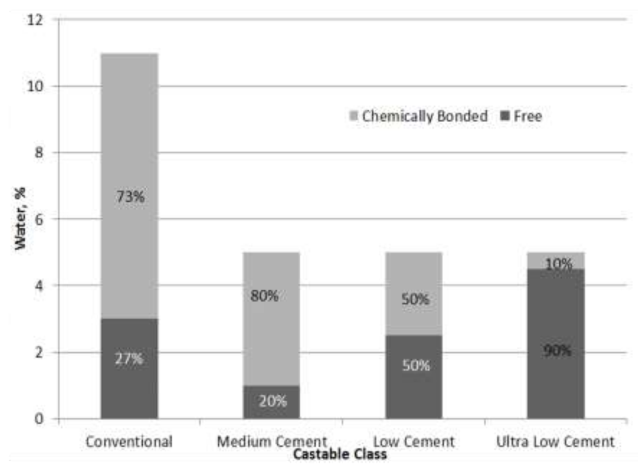
Hydration & Dehydration of CAC

Calcium Aluminate Cement (CAC) is the main reactive phases of hydraulically bonded castable



Compound	Decomposition Peak Temperature, °C	Decomposition Temperature Range, °C
CAH_{10}	-	100 – 130
C_2AH_8	-	175 – 190
AH_3	234	210 – 240
C_3AH_6	315	240 – 370



Dehydration Temperatures of Calcium Aluminate Hydrates

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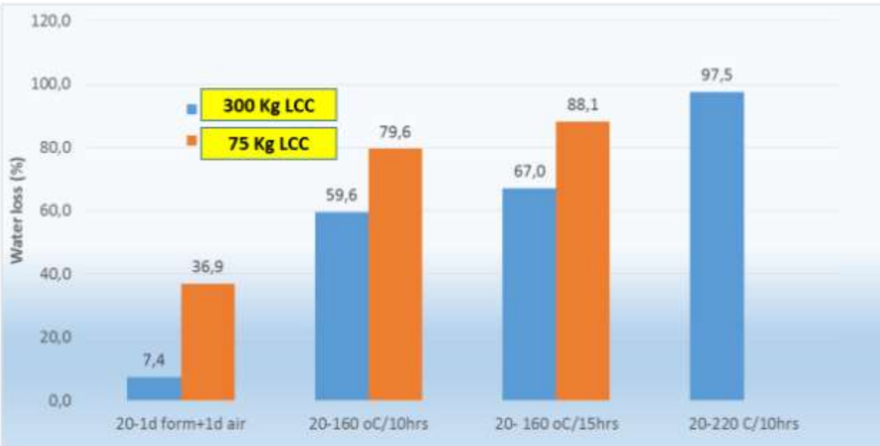
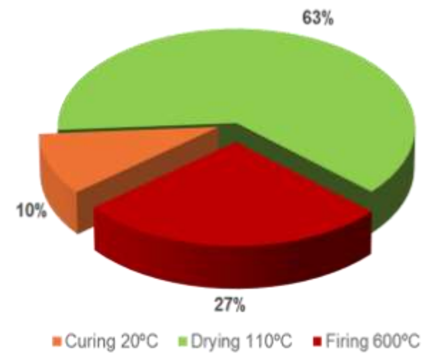
Drying Schedule Vs Water loss





Typical water removal in LCC

The 300kg block lost 97.5% of the water during 10hrs at 220°C, while only 67,0% water was removed after 15hrs at 160°C.

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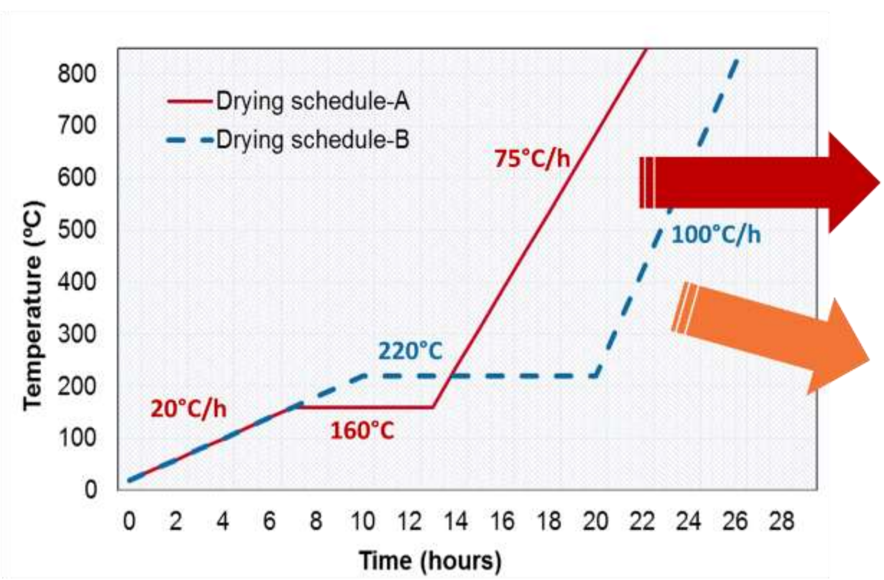
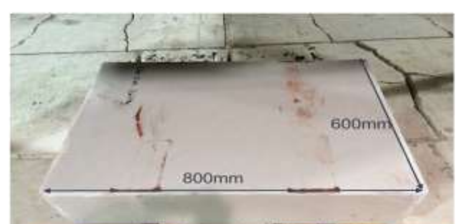
Selection of Proper Soaking temp. & time



After 160°C/6hrs, >40% remaining water



After 220°C/10hrs, 3% remaining water

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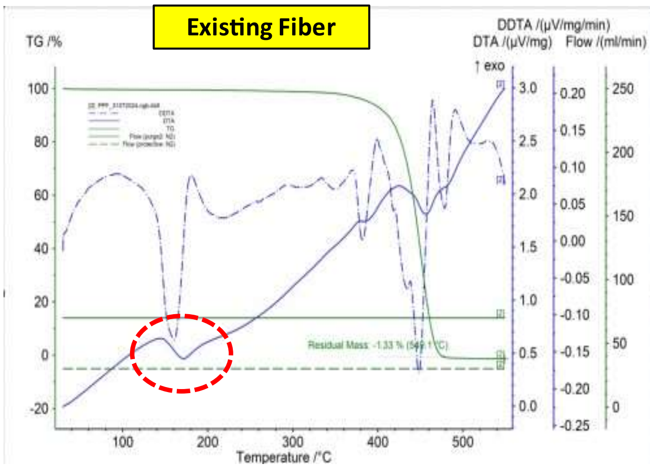
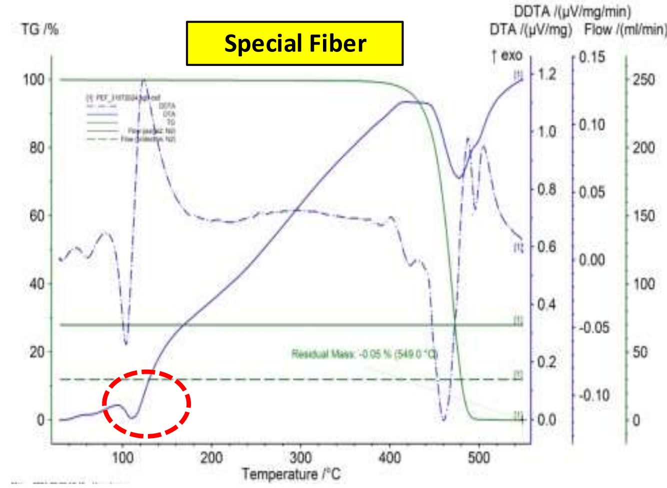
How to reduce the total drying cum heating cycle

One special organic fiber is introduced in castable matrix which help to create more paths to remove the water during heating.

Existing Fiber



Special Fiber



Special fiber melts at lower temperature than existing fiber.

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No steam explosion in presence of special fiber

400 Kg block + 0.1% conventional fiber

400 Kg block + 0.1% special fiber

400 Kg Block + 0.1% special fiber

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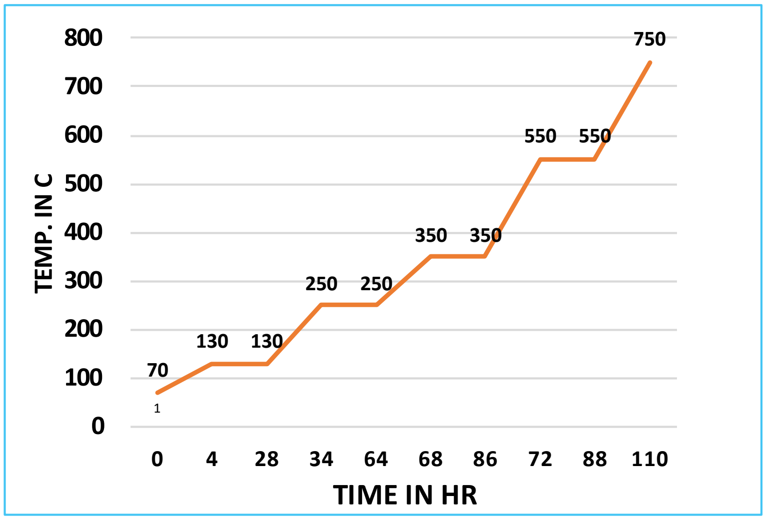
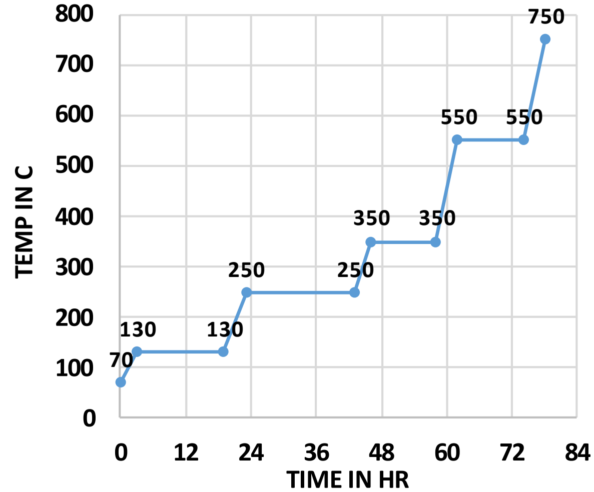
Comparison in pre-heating schedule





Total pre-heating time = 110 hrs. for existing castable

Total pre-heating time = 78 hrs. for modified castable

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Fluctuation in setting behaviour

Ageing of Low Cement Castables (LCC)

- Changes which takes place within a dry mixed castable with passage of time is called "Ageing".
- Effect of Ageing:
  - Loss of flow tendency
  - Increase in water demand
  - Delay in setting time
  - Deterioration of strength and thermo-mechanical properties

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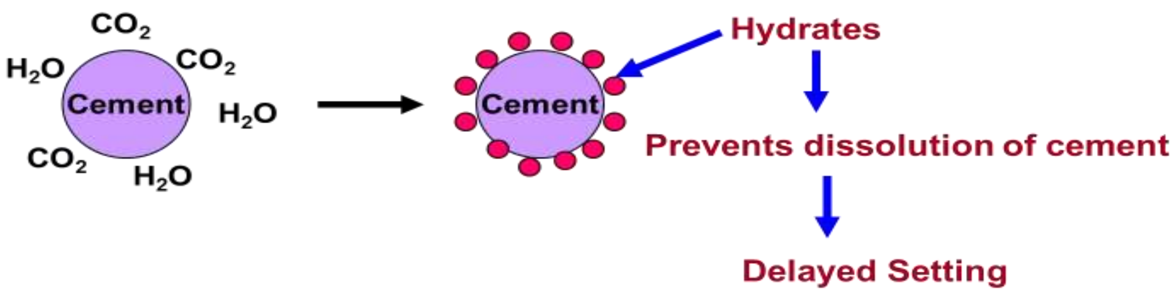
Causes for Ageing of LCC

- **Atmospheric Effect:** Binders reacts with water vapour present in the atmosphere to form Calcium Hydroxide; which in turn, reacts with areal CO_2 to form Carbonate.

$CA + CA_2 + H_2O \quad Ca(OH)_2$

$Ca(OH)_2 + CO_2 \quad CaCO_3 + H_2O$



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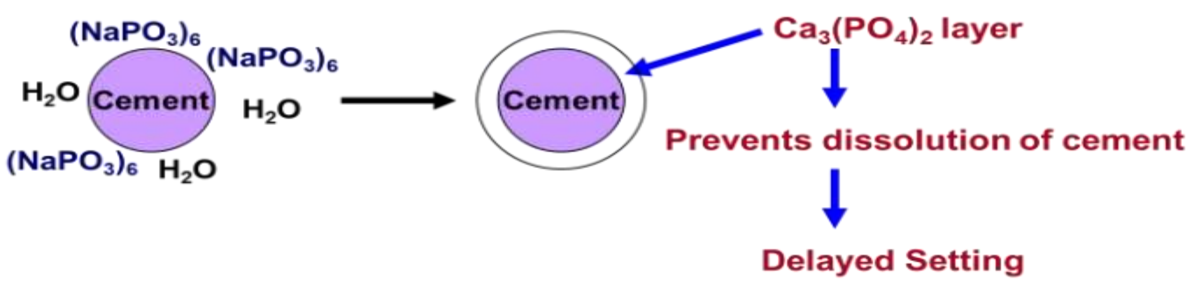
Causes for Ageing of LCC

- **Dispersing Effect:** Binders reacts with water to form Ca-Hydroxide; which, in turn, reacts with SHMP/STPP to form Calcium Phosphate. An impervious layer of Phospate prevents further dissolution of Cement; hence, delay in Setting.

$CA + CA_2 + H_2O \quad Ca(OH)_2$

$Ca(OH)_2 + (NaPO_3)_6 \quad Ca_3(PO_4)_2 + H_2O$



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Action plan to avoid fluctuation in setting time

- Addition of accelerator or retarder at the time of castable manufacturing
- Using Refractory cement having higher shelf life
- Optimum dose of accelerator/Retarder based on the expected setting time
- Provide accelerator or retarder extra along with castable separately

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Design of pumpable castable for DRI application

Advantages

- Reduced installation time
- Avoid large number of application people to transfer castable

  from outside (mixer) to inside the kiln (area of application)
- Better safety at site
- No need to store material and mixer on the platform near the kilns

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Pumpable castable for DRI application

TRL Krosaki Refractories Limited
(Formerly Tata Refractories Limited)
Product Definition Sheet

TRL Pumpcast - Super

Revision No: 00	Date - 10.08.2024
Product Name	TRL Pumpcast – Super
Application	Casting or Pumping
Maximum Service temperature	1600°C
Disposal Recommendation	Must not be disposed together with household garbage. Do not allow products to reach sewage system.

CONTROL PROPERTIES

Chemical Analysis	Unit by wt	Value: Typical	Value: Limit	Test Method
Al_2O_3	%	79.7	≥ 78	EN ISO – 1927 - 3
CaO	%	1.77		EN ISO – 1927 - 3
SiO_2	%	13.8		EN ISO – 1927 - 3
Fe_2O_3	%	1.29	≤ 1.5	EN ISO – 1927 - 3
Physical properties	Unit			
Bulk Density at 110°C/24 hrs	g/cc	2.76	≥ 2.7	EN ISO – 1927 - 6
CCS at 110°C/24 hrs	Kg/cm2	790	≥ 700	EN ISO – 1927 - 6
CCS at 800°C/3 hrs	Kg/cm2	840		EN ISO – 1927 - 6
CCS at 1100°C/3 hrs	Kg/cm2	870	≥ 800	EN ISO – 1927 - 6
CCS at 1400°C/3 hrs	Kg/cm2	1020	≥ 900	EN ISO – 1927 - 6
Thermal conductivity				
At 400°C hot face	W/mk	1.69		BIS 9490
At 600°C hot face	W/mk	1.77		BIS 9490
At 800°C hot face	W/mk	1.83		BIS 9490
PLC at 800°C/3 hrs	%	- 0.09		EN ISO – 1927 - 6
PLC at 1100°C/3 hrs	%	- 0.21		EN ISO – 1927 - 6
Abrasion loss (Pre-fired at 800°C/3 hrs	CC	2.47		ASTM C 704
Maximum Grain size	mm		≤ 6	EN ISO – 1927 - 3
Shelf Life	6 months from the date of manufacture			

Status:
Discussed with Chief (Refractory – TSLM) and we are going to send sample to TSLJ (RTG) for evaluation before taking panel trial

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(4) Different products available in TRL Krosaki's product basket for DRI

Major Castables for DRI Kiln available in basket

(1) TRL Cast LC – 80
(2) TRL Cast LC – 80LI
(3) TRL Cast LC – 80EX
(4) TRL Cast HF – 75AR
(5) TRL Cast HF – 75ARX
(6) TRL Cast HF – 80SFX
(7) TRL – SCUFF(ARSF)

Recommendation:

- For DRI kiln of capacity > 350 TPD, Sl No 1 to 3 are suitable where iron ore and domestic coal are used as feed material
- In case of pellet and South African/Australian coal, Sl No 4, & 5 are suitable
- For DRI kilns of capacity 900 TPD and more, Sl No – 8 & 9 are suggested.

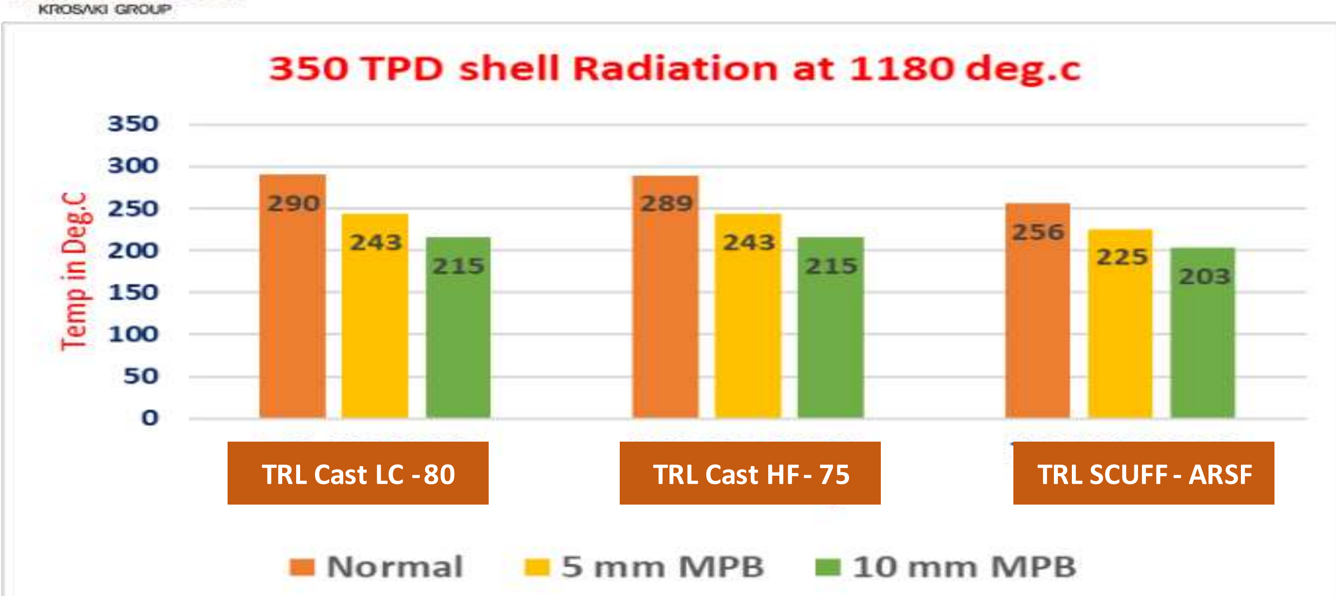
TRL Krosaki

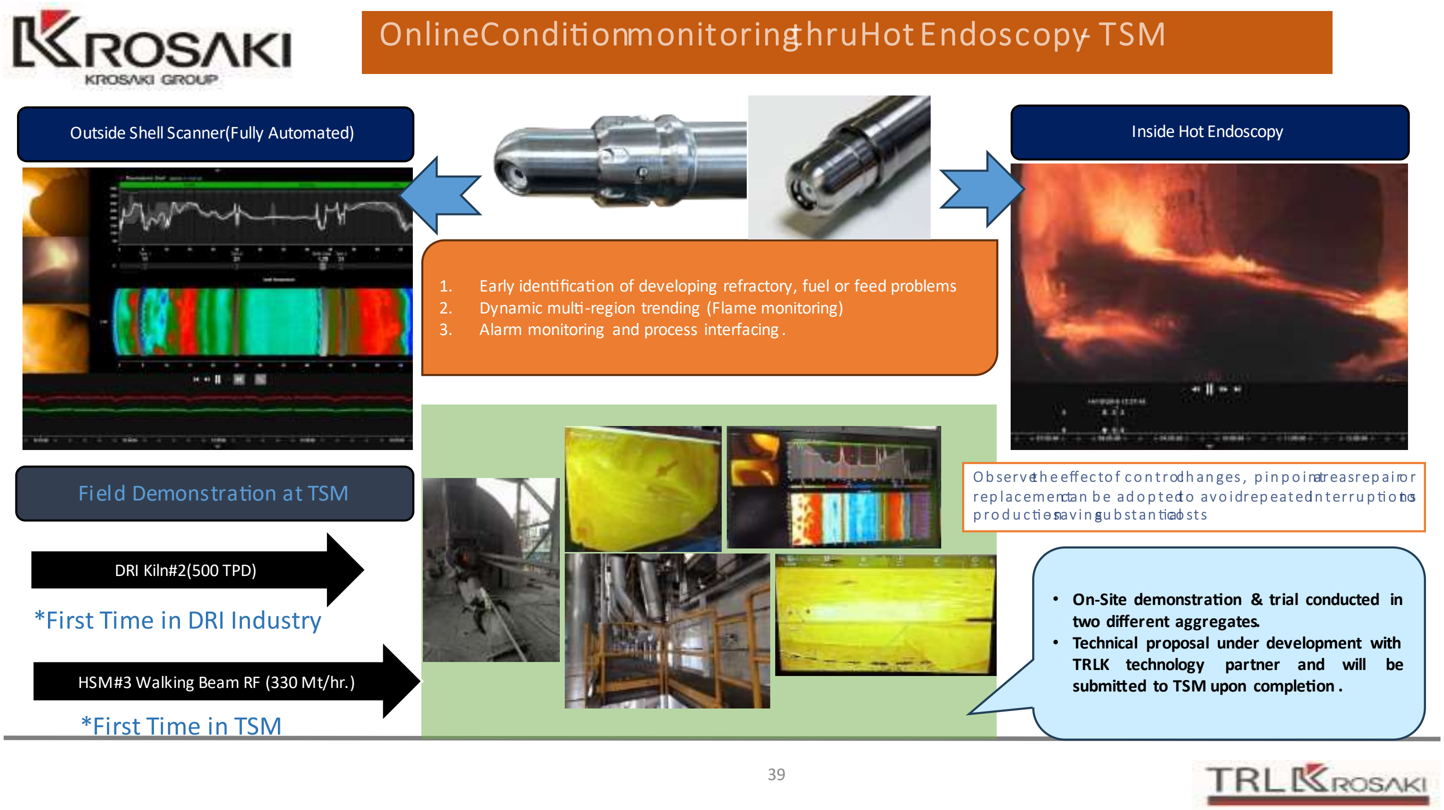
(5) **Innovative value-added approach for better performance**

Product Features of Microporous Board

Colour (without film)		White
Nominal density(Kg/m^3))		300-430
Classification temperature Deg.c		1100
Shrinkage % @1000 Deg.c for 12 hrs		0.4
Linear shrinkage %(24 hrs full soak)	At 950 deg.c	1.6
	At 1000 deg.c	3.7
Compressive strength (Mpa ASTM C 165 @ 600 Deg.C		0.414
Specific heat capacity (kJ/kg.K DIN 51007@700 deg.C		1
Thermal conductivity (W/m.K ASTM C177)		
	At 20 deg.c	0.021
	At 200 deg.c	0.024
	At 400 deg.c	0.028
	At 600 deg.c	0.034
	At 800 deg.c	0.044

Comparison of Radiation Temperature





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Conclusions

- **In DRI kiln, either inlet or outlet, low cement castable is only the choice as it is having several advantages over conventional one.**
- **Due to nature of feed material, there is severe abrasion of refractory which limited the kiln life. Shell radiation is another issue resulting heat loss and safety hazards.**
- **TRL Krosaki has developed special castable having good abrasion resistance and low thermal conductivity to take care the present operational requirements.**
- **Use of microporous board is another solution to restrict the heat loss and keep shell temperature under control**
- **A new pumpable castable is designed for DRI application having several advantages**
- **At TRL Krosaki, state-of-the-art R&D with modern equipment and highly qualified engineers are working on regular basis to develop new products and improvement the existing products.**

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NEWS ITEMS

1. Following R&D projects for financial support are under consideration of Ministry of Steel

Rotary Kiln related R & D Projects:

i. Investigation on coal-biomass blends as reductant and fuel - IIT Hyderabad
ii. Decarbonisation of DRI process in Rotary Kiln using hydrogen as reductant- IIT Roorkee

Vertical Shaft Related R&D Projects:

i. Melting and Refining behaviour of gas based DRI and hydrogen based DRI - IITB
ii. A comparative study on the controlling mechanisms during reduction of iron oxide with CO and hydrogen - IITB
iii. Assessment of design and operation parameters using process simulation for hydrogen based DRI production- IIT Bombay & Bhubaneswar
iv. A laboratory/ Pilot scale set up to optimise the process parameters for producing DRI with varying H2 and CO ratio- IIT Kharagpur

2. Production related data

Item	Performance of Indian steel industry		
	April-September 2024-25*(MnT)	April-September 2023-24(MnT)	% change*
Crude Steel Production	72.755	70.229	3.6
Hot Metal Production	43.624	42.490	2.7
Pig Iron Production	4.068	3.665	11.0
Sponge Iron Production	27.011	24.881	8.6
Finished Steel (alloy/stainless + non-alloy)			
Production	70.621	67.423	4.7
Import	4.735	3.329	42.2
Export	2.311	3.603	-35.9
Consumption	72.697	64.073	13.5
Source: JPC; *provisional; MnT=million tonnes			

It may be noted that sponge iron growth rate for the last two years has been in double digit. However, in the current FY it is hovering in single digit.

3. SIMA has taken another one of the pragmatic steps to resolve the technical problems relating to the DRI production particularly coal based DRI process. In this connection, SIMA has created a new chapter on their website in the name of **SIMA DRI Technical World.**

4. Glimpses of two days seminar on **Sustainability Facets of DRI Industry** at Tata Steel Sponge Iron, Joda.

Mr. Ashish Anupam, Vice President, Long Products, Tata Steel Ltd.

Mr. Deependra Kashiva, Director General, Sponge Iron Manufacturers Association (SIMA)

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