BRIEF HISTORY OF PROCESS METALLURGY RESEARCH since 1960s

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During 1960s, 1970s and 1980s University based Fundamental research on Process Metallurgy concentrated primarily on

Thermodynamics

Phase Equilibria

and

Kinetics

of relevant high temperature systems to understand the underlying principles of the processes.

This type of fundamental research still continues **today** way beyond 1980s at even a higher rate in the solid and liquid states along with solution modelling on

less common not yet examined systems

and also on

older pre-studied systems where data variability is rather high

The approach here is two-fold

To generate lacking data and

To confirm/or correct previous data

1. To be used in thermodynamic data banks for advanced packages such as FACTSAGE, HSC,THERMOCALC, MDATA, PYROSIM, METSIM etc.
2. To be directly used in modelling, simulation and process control procedures

During the 1970s under the leadership of late Professor J Szekely

Research into Transport Properties and Transport Phenomena in process metallurgy started to gain momentum.

This type of research involved heat, mass and momentum transfer (Fluid Flow)in complex multiphase-multicomponent metallurgical process to understand their dynamic behaviour.

During 1980s and 1990s Transport Phenomena Research Intensified

And started to dominate fundamental process metallurgy research both experimental and later computational especially at Universities and some research centres with close links to Universities (CSIRO-University of Melbourne; Australia, Mintek- Wits University; South Africa, SINTEF-NTNU; Norway, Max Plank Ins- Aachen University; Germany).

The increases in computational power lead to development (especially during 1990s) of several; now commercially available computer packages (Phoenix, Fluent etc.) with appropriate model algorithms that permitted numerical solutions to very complex high order partial differential equations such as the Bernoulli, Navier Stokes' and others. Thus the **CFD** (Computational Fluid Dynamics) started to emerge as a powerful dynamic tool in simulating metallurgical processes/reactors.

On the experimental side new techniques, procedures, equipment, sensors and set-ups were developed to cope with ever more demanding observations/measurements of any type-thermodynamic, kinetic, transport and even in-situ cases.

Due to the difficulty in reactor size experimental measurements at high temperatures a new and novel technique was developed primarily under the leadership of Professor Rod Guthrie (McGill University-Canada):

The Cold (Water) Model

For example for metallurgical converters the cold water model makes use of water, oil (usually kerosene) and air to simulate metal/matte, slag and gas phases respectively.

The **geometric similarity** is achieved by reducing the size of the actual reactor and all its ancillaries by a certain factor, $1/7^{th}$ for example.

Dynamic and kinematic similarities are achieved by dimensionless transport numbers such as the **modified Froude, Reynolds and Morton numbers**.

Additionally for **top lance blowing** dimensionless **Momentum number** and for **tuyere blowing** dimensionless **Blowing number** are also used.

These numbers are adjusted in such a way that their values are the same for both the actual converter and the cold water model making their dynamic behaviour the same.

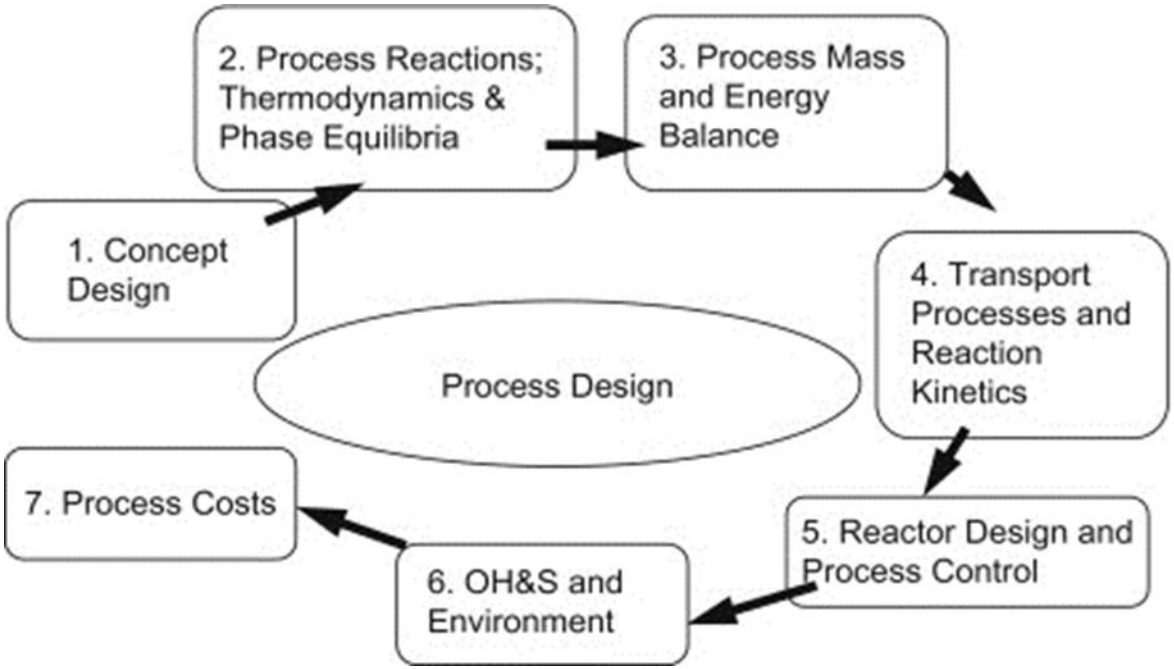
Since the beginning of the 21st Century

The advances made in Transport Phenomena research along with tremendous increases in computing power led to the emergence of a new comprehensive field:

Metallurgical Process Dynamics

Utilizing advanced CFD procedures and algorithms

The ultimate aim of this new approach is to integrate all the available information on thermodynamics, phase equilibria, kinetics and transport phenomena related to a particular metallurgical process/reactor/or a new one being developed in a holistic and comprehensive way which would lead **to simulation and mathematical modelling of the process and/or the reactor**.


2. Process Reactions; Thermodynamics & Phase Equilibria
3. Process Mass and Energy Balance
1. Concept Design
4. Transport Processes and Reaction Kinetics
Process Design
7. Process Costs
5. Reactor Design and Process Control
6. OH&S and Environment

Future

New and novel processes and/or reactors can be designed from scratch (and experimentally checked/verified by cold models and once developed controlled)based on **Metallurgical Process Dynamics** principles. Here an evolved version of CFD (under continuous development) which can be called **Computational Process Dynamics (CPD)** incorporating all the fundamental principles of thermodynamics, phase equilibria, kinetics and transport will be a major tool supported by continuing research in all the fields mentioned.

Education

At the Universities offering process metallurgy, (which is on an increasing trend especially related to sustainability and Carbon footprint) curriculum and related educational tools follow the research trends summarized above quite closely.

Education

Since late 1990s a new emphasis started to emerge in Metallurgical Engineering Curriculums especially offering Process Metallurgy:

Design

At my department at Wits:

Third year level

- Process and Materials Design I(2-0-1)(9)
- Process and Materials Design II(1-0-3)(9)

Education

Fourth year level:

- Simulation and Computational Approach to Process Design (2-0-2)(12)
- Design Project (0-0-8)(18)

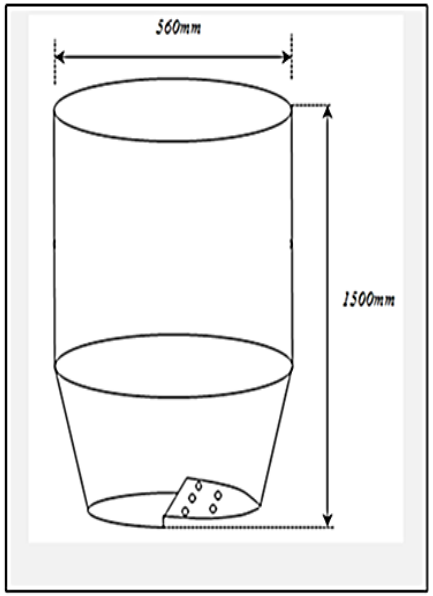
COMPUTATIONAL PROCESS DYNAMICS (CPD) MODELLING OF CREUSOT LOIRE (CLU) UDDEHOLM CONVERTER

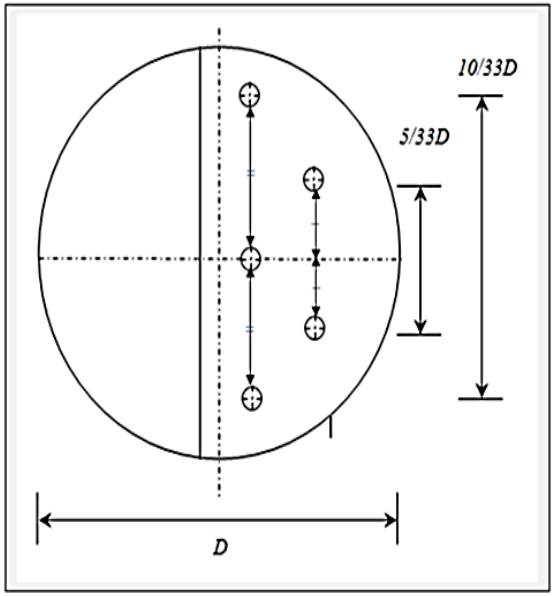
R Hurman Eric
Pyrometallurgy Research Group
University of the Witwatersrand

The Creusot Loire Uddeholm (CLU) convertor for ferroalloy refining is a large cylindrical vessel tapered at the bottom, with a capacity of 100 tonnes and operates at high temperatures between 1650^{o}C and 1800^{o}C.

Computational Domain (2D&3D): Water Model: One-fifth of a tapered industrial scale CLU with a capacity of 100 tons and a step. Experimental: Mixing time, Kinetic Energy input and Mass transfer measurements

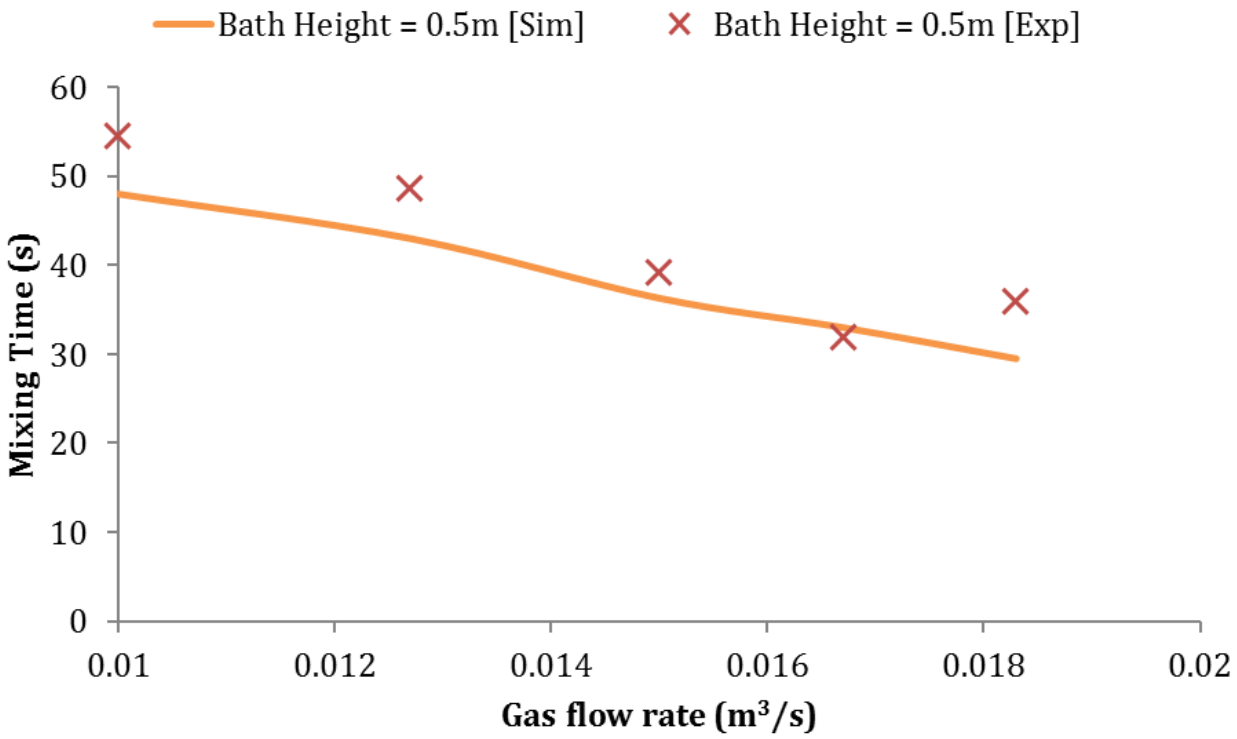
Parameter	Industrial	Model
Liquid	Steel	Water
Nozzle D	30mm	6mm
Bath H	2.9m	0.5-0.7m
Froude No.	242	242
Purging gas	Steam/Argon/ Nitrogen	Air
Gas rate (m^3/s)	0.93 – 1.69 (m^3/s)	0.01-0.0183 (m^3/s)
Nozzles No.	5	5





VALIDATION

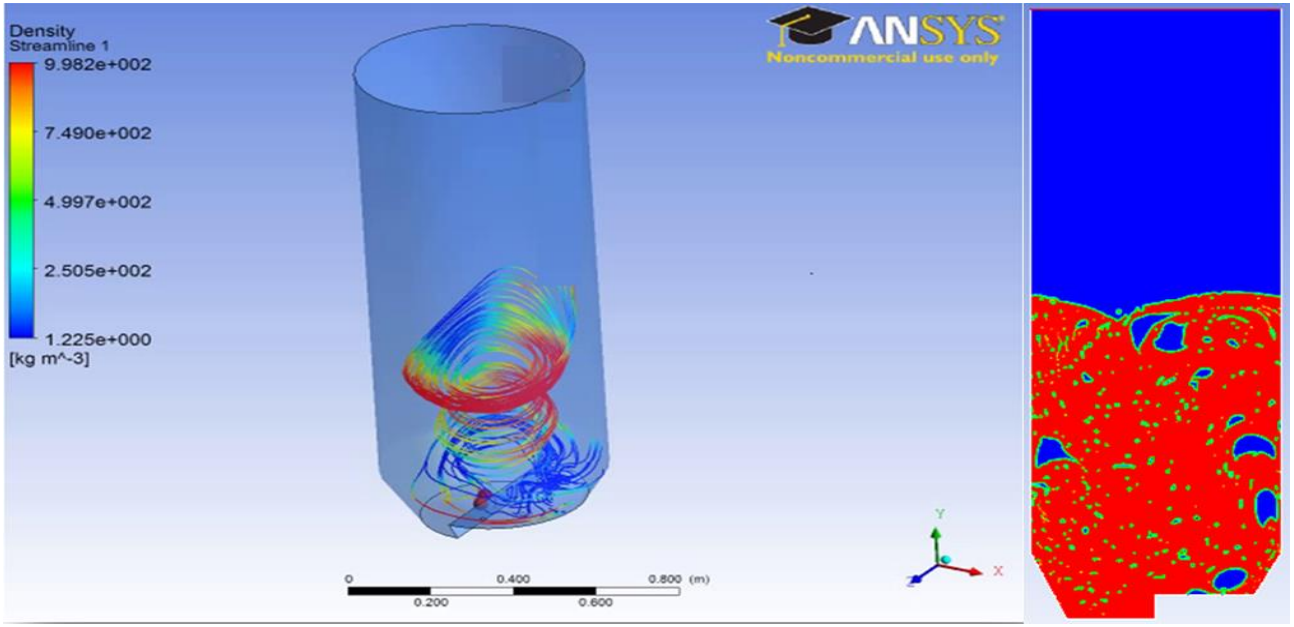
The numerical mixing results for a two-phase, 3-D model were validated against water model experimental results.

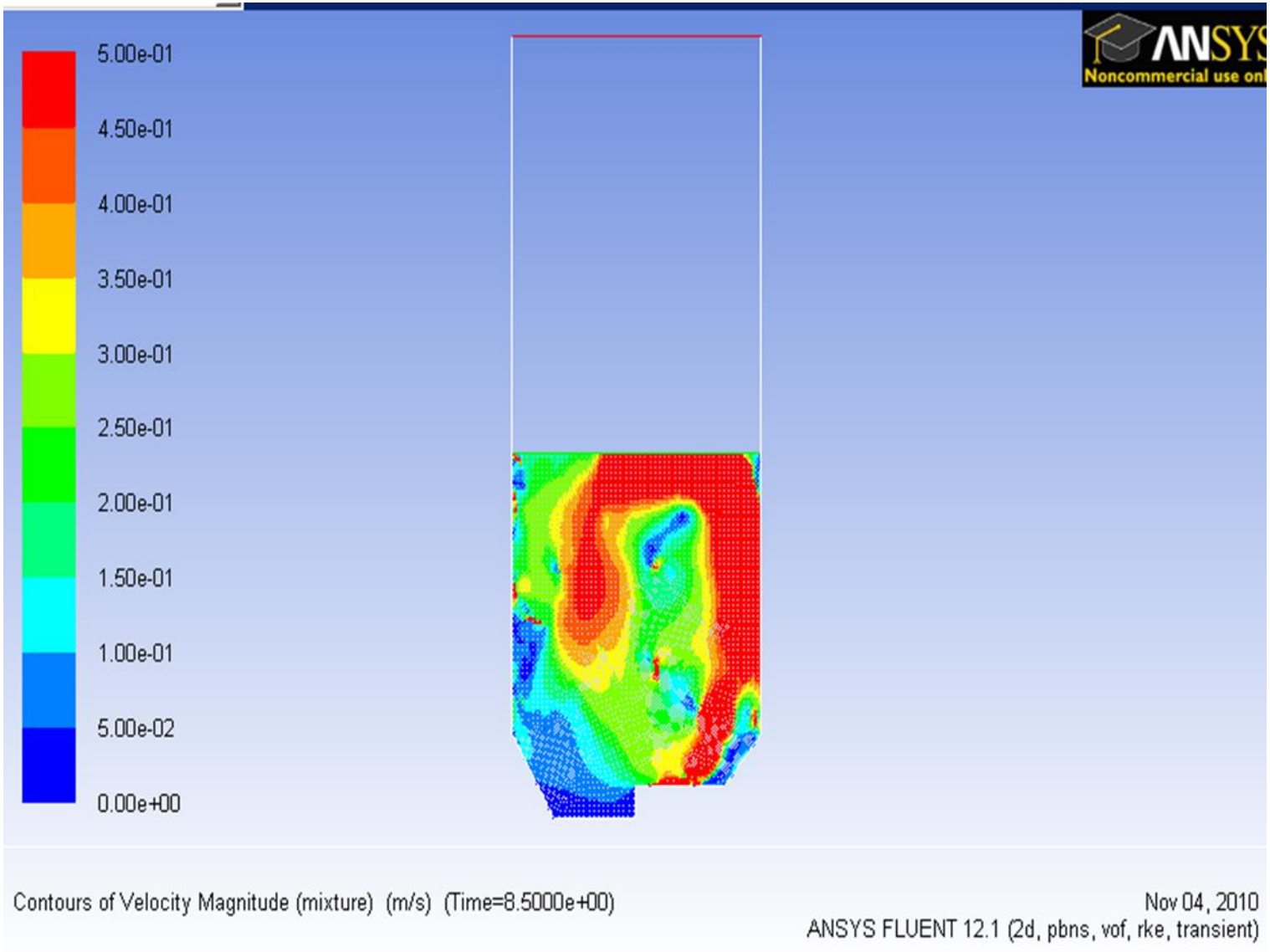


Testing different gas flow rates and bath heights revealed the following:

A turbulent re-circulatory flow of the bath

The exiting gas forms a plume zone

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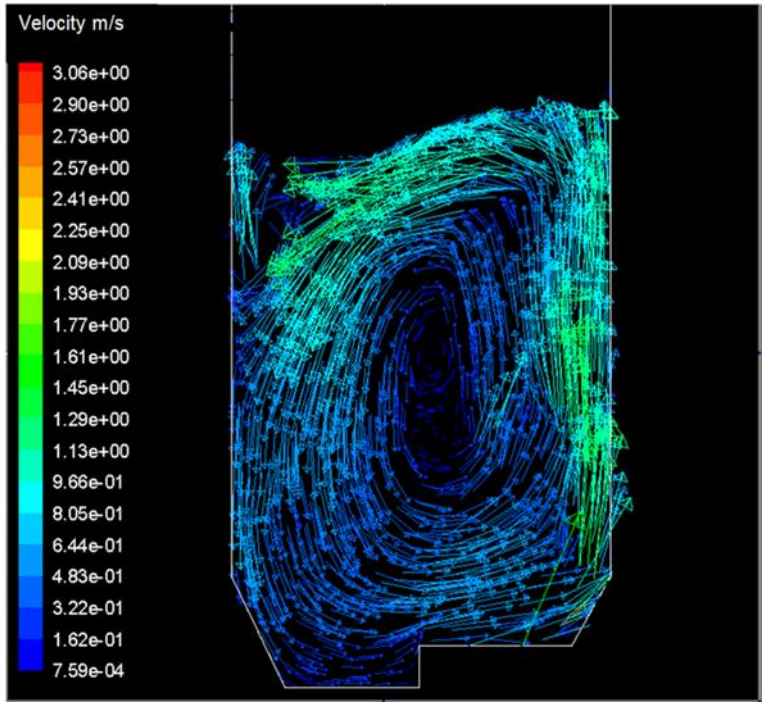
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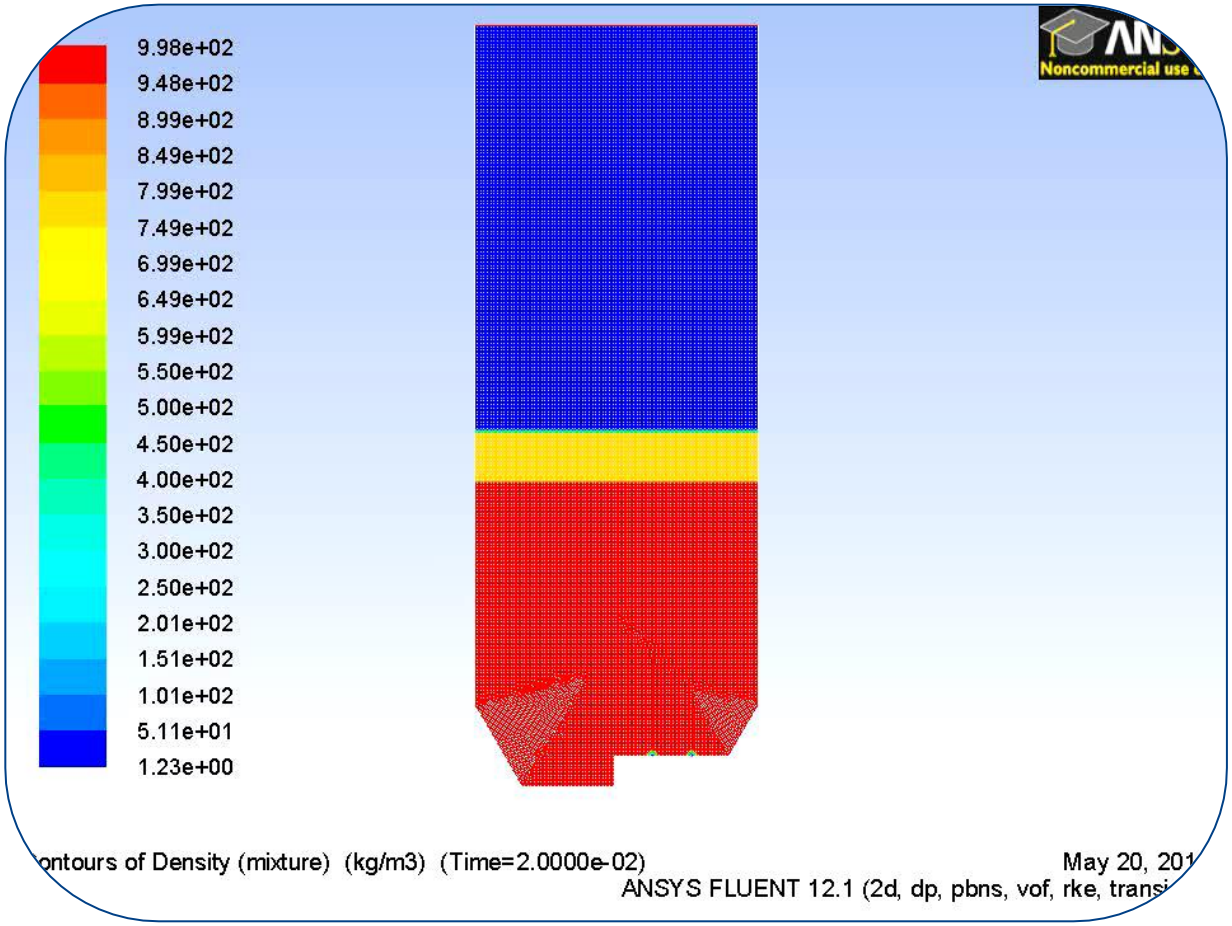
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Milestones in Industrial Research and Process Developments

1960s

- Adaptation of Circulating Fluidized Bed Reactors to some metallurgical processes such as roasting of sulphides and solid state reduction of iron
- Solvent Extraction of Uranium (South Africa)

1970s

- The Argon Oxygen Decarburization (AOD) Process for Stainless Steel Making/Refining
- The Queneau Schuhmann Lurgi (QSL) Counter Current Process for Direct Sulphide Lead Smelting

  (The first Metallurgical Reactor Designed using first hand fundamental principles by Professors Queneau and Schuhmann)
- Quenching and Dig-Out of Blast Furnaces (Japan)

  Late 1970s
- Carbon In Pulp (CIP)Process for Gold Recovery using regeneratable activated carbon derived from coconut shells (Johannesburg-South Africa)

1980s

- DC Plasma Arc Furnaces for Ferrochromium Smelting (First DC furnace in the world: 33 MW Single Electrode Furnace commissioned in Krugersdorp-South Africa)
- Quenching and Dig-Out of Submerged Arc Ferromanganese Smelting Furnace (Mayerton-South Africa)

1990s

- Direct Iron Smelting Processes:

  Corex (First Large Commercial Plant in ISCOR Saldanha Iron and Steel Works (South Africa)

  HiSmelt (500 000t/y demonstration plant (Western Australia)

  DIOS Pilot plant (USA)

  Kawasaki Pilot Plant (Japan)

1990s

- Ausmelt Submerged Lance Reactor/Converter

  Developed in Australia-First Large Scale Plant in South Africa for converting Cu-Ni-Fe-S matte containing Platinum Group Metals)

2000s

Carbothermic Reduction of Aluminium:

The Elkem-Alcoa Hex Process

Pilot plant located in Kristiansand-Norway (Elkem) until 2010 and then in Pittsburgh-USA(Alcoa)

designed, supervised and operated based on Computational Process Dynamics by the following consultant/advisor team (in alphabetical order):

2000s

Professor R Hurman Eric (South Africa)

Professor James Evans (USA)

Professor Richard J Fruehan (USA)

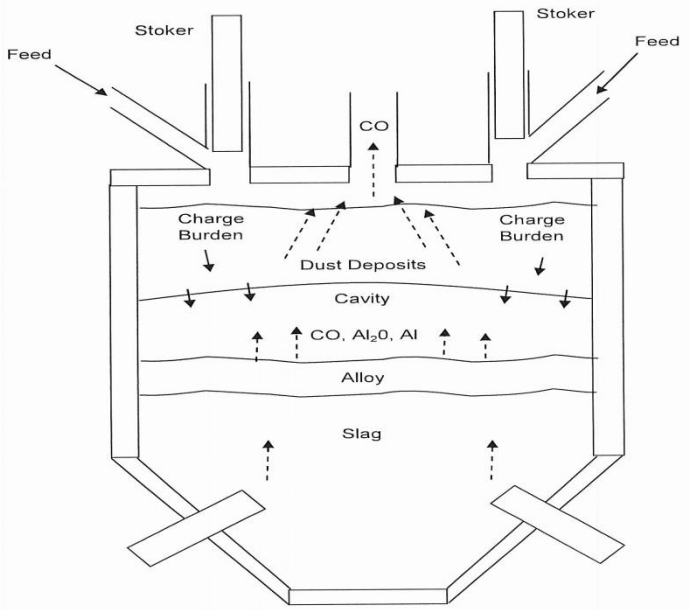
Dr Mark Kennedy (Norway)

Professor David G C Robertson (USA)

Professor Torstein Utigard (Canada)

Professor Heinz Voggenreiter (Germany)

Figure 4: In-Situ VRR Concept



Alternative 2: Rotary Feeder and Dust Collector
This concept is similar to the moving bed concept described previously. The major difference is that the pellets are moved by the rotating action of feed drum. This may keep the particles in motion and prevent dust clogging in the solids bed. It could also be possible to introduce a heat source to drum (rotary kiln) thus significantly increasing pellet temperature (~1000 C) if desired. This concept is shown below in Figure 5.

3D reactor models are shown in Figures 8 and 9.

Figure 8: Top View of Reactor Interior Showing Electrodes and Moving Bed Feeder Positions

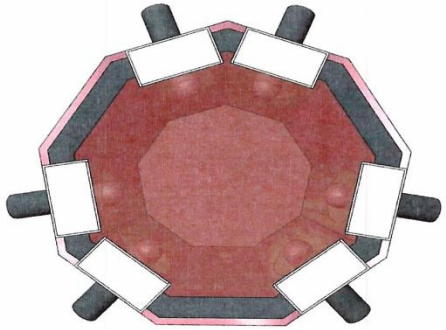
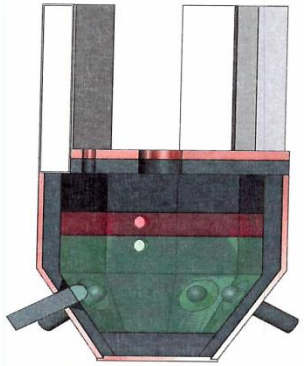
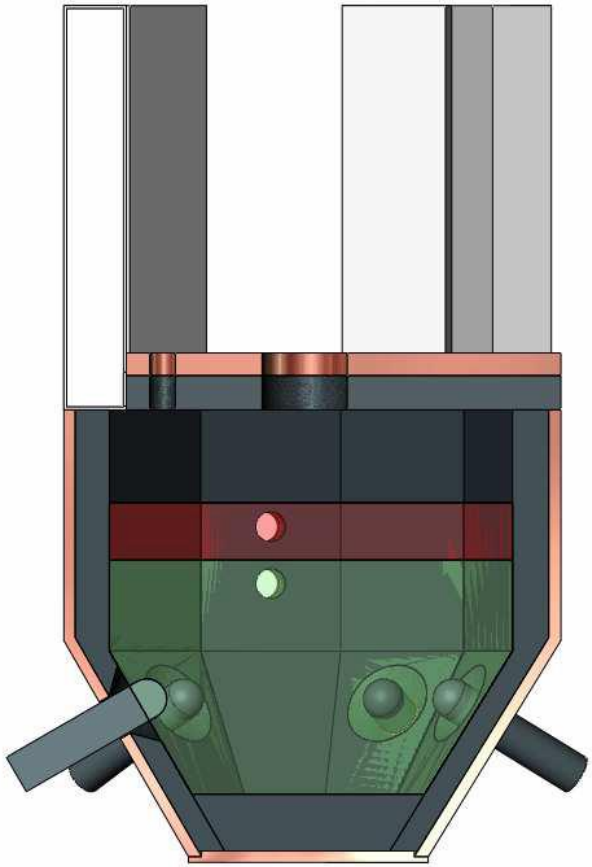


Figure 9: Side View of Reactor Showing Slag (green) Alloy (red) Tap Holes and Moving Bed Feeders



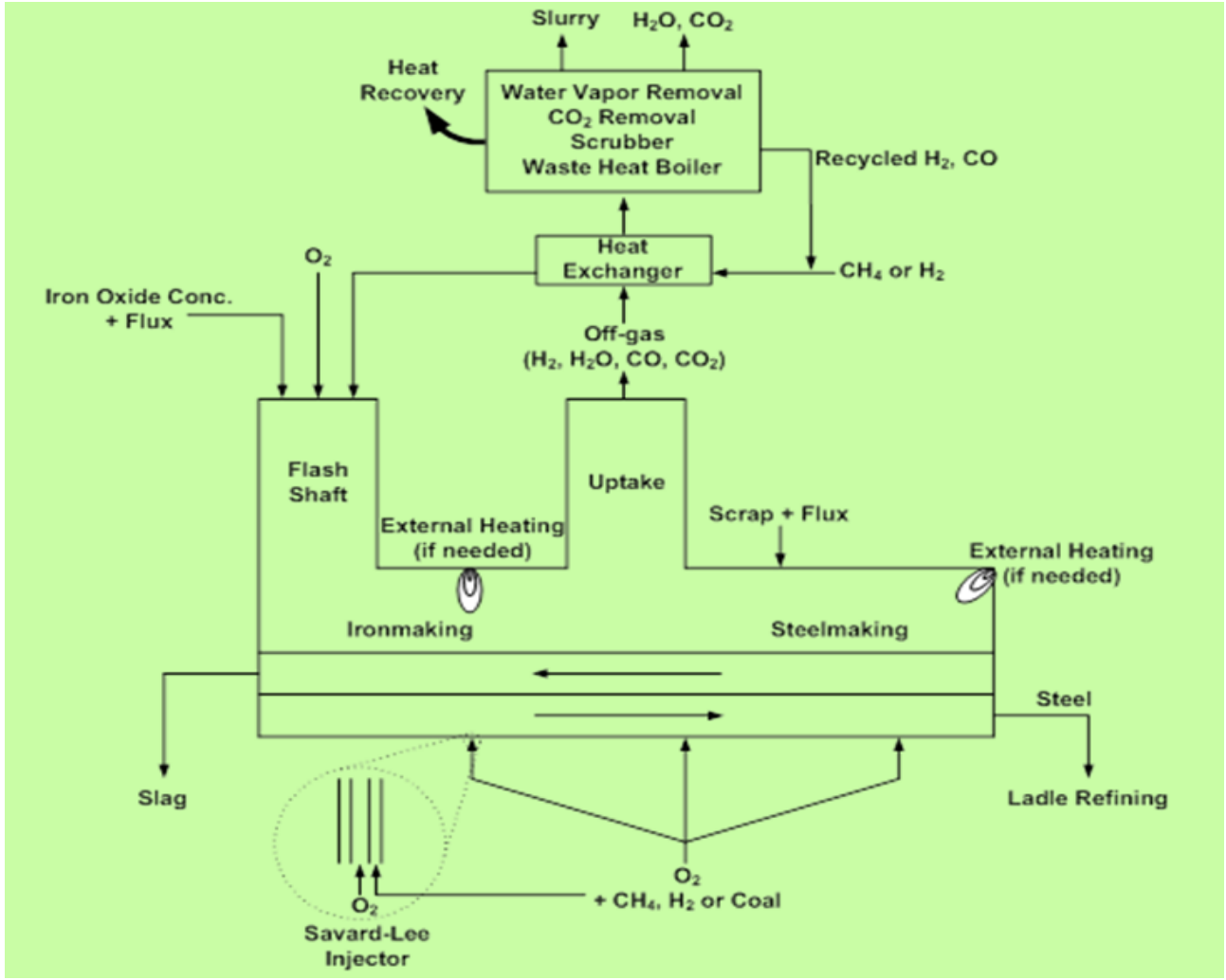
Side View of Reactor Showing Slag (green) Alloy (red) Tap Holes and Moving Bed Feeders



2010s

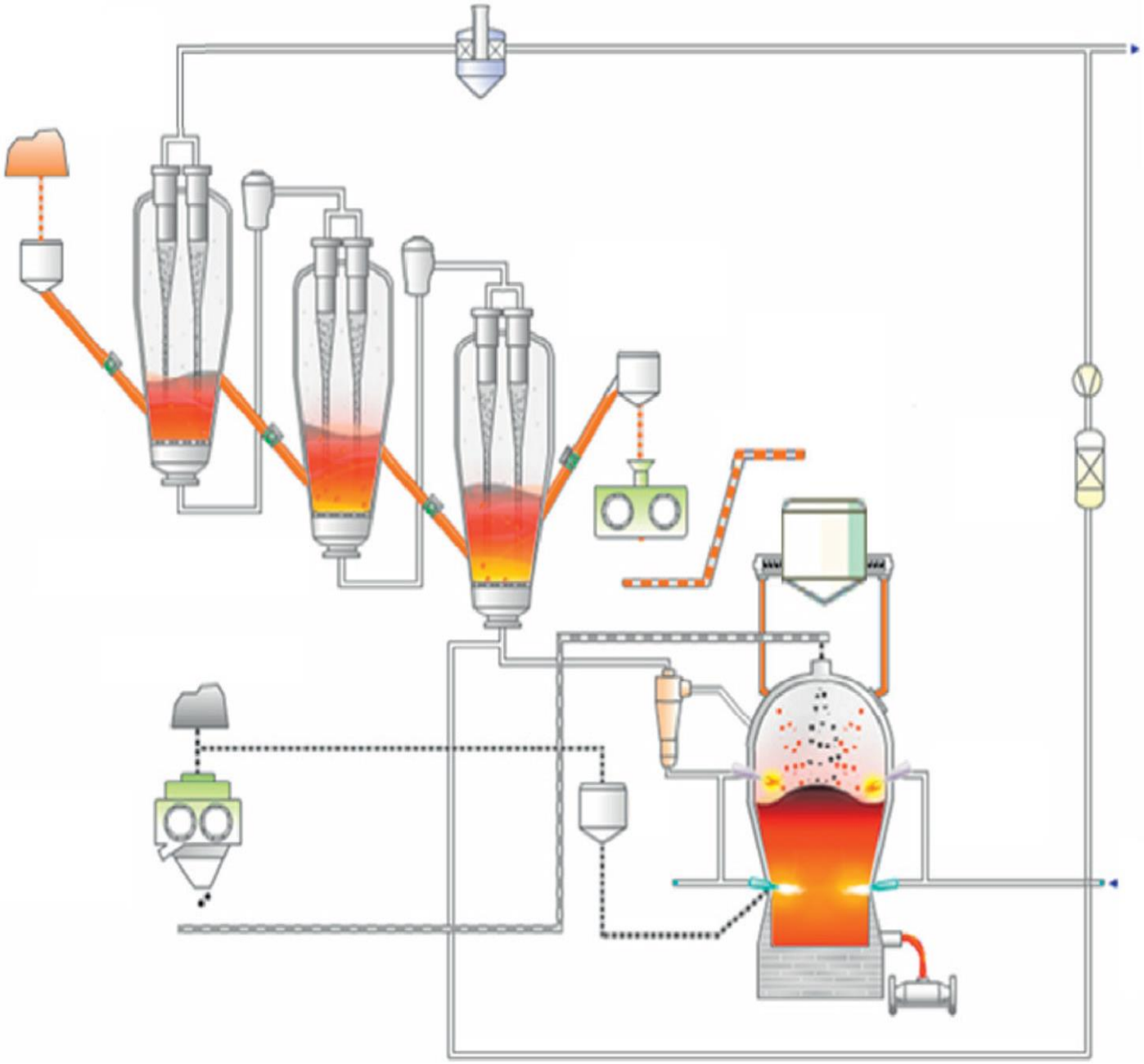
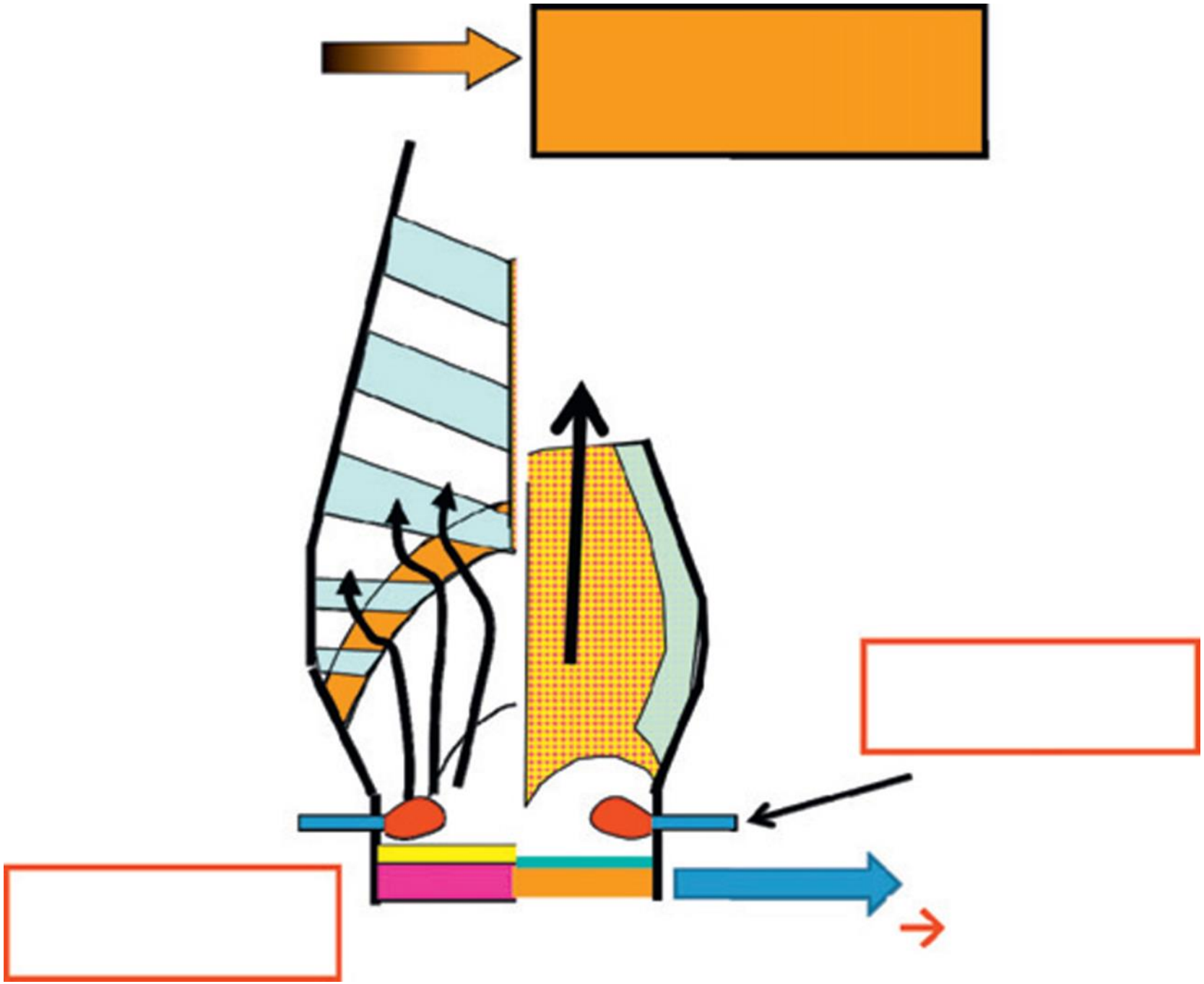
- Emphasis on

1. Circular Economy Concept (Zero Emission Target)
2. Sustainability,
3. Reducing Energy Consumption and Carbon Footprint



Direct steelmaking process

based on Flash Ironmaking

- 36% reduction in **CO_2 emission [using NG]**.
- **Energy savings** up to 30% of BF process **[using NG]**.
- **Eliminating** the use of coke and pelletizing/sintering, with associated generation of **pollutants**.
- Reduction of concentrate: **90-99%** reduction in **2-7 seconds** at 1200-1400^{o}C; sufficiently fast for a flash process.

- There are numerous other initiatives being evaluated and studied, just two examples:
- FINEX Process: Three stage fluidized bed reactor integrated to a COREX type melter gasifier.
- HYDROGEN BLAST FURNACE