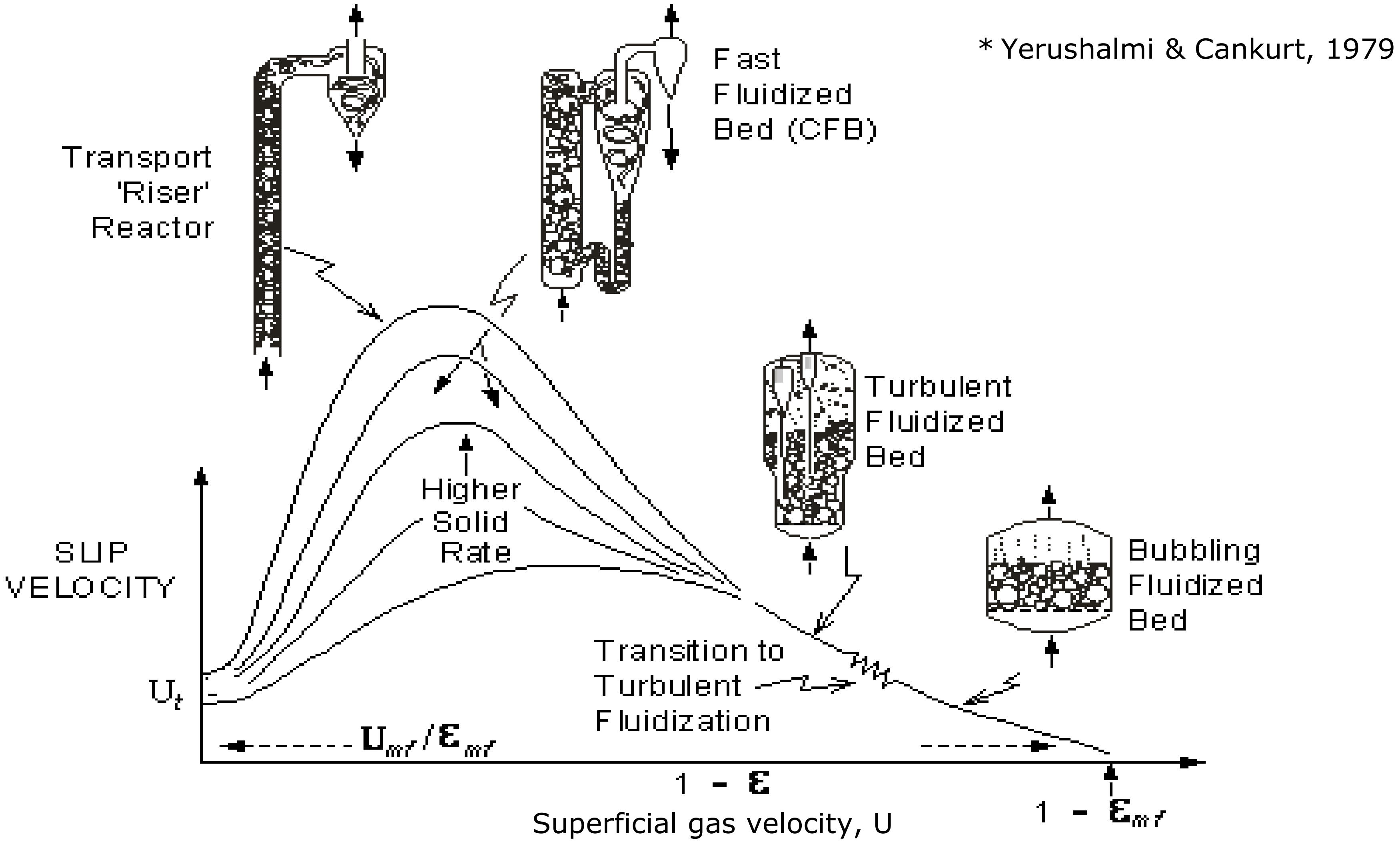
Anglo Research
A division of Anglo Operations Limited

Double, double boil and bubble: Fluidization in reactors and roasters

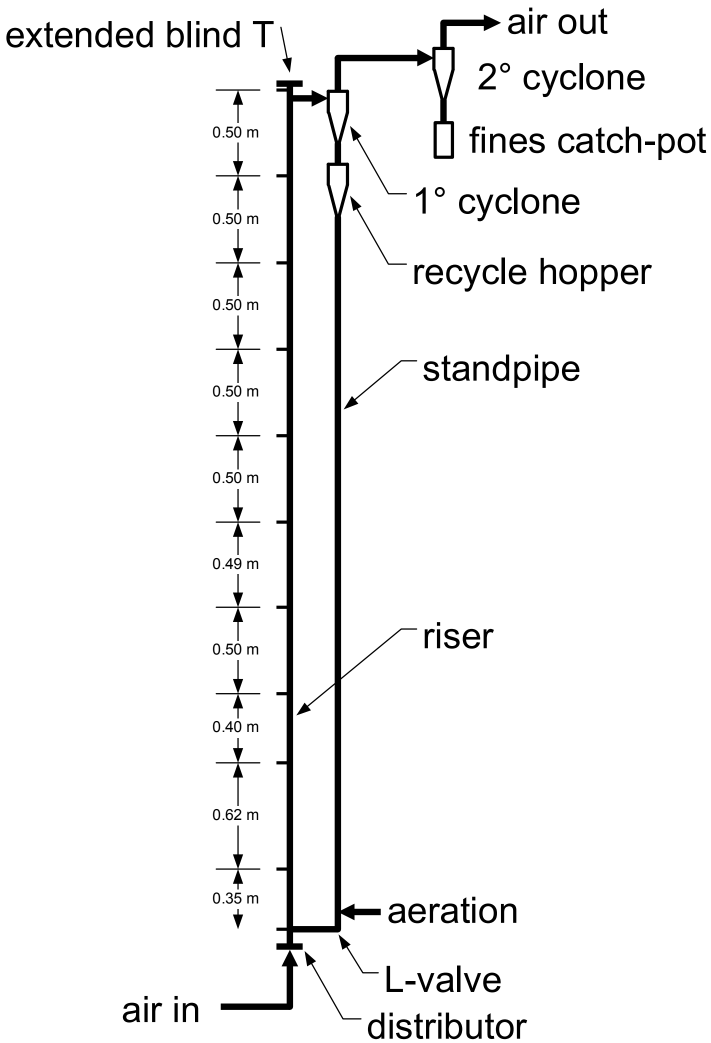
Paul den Hoed

5 June 2009

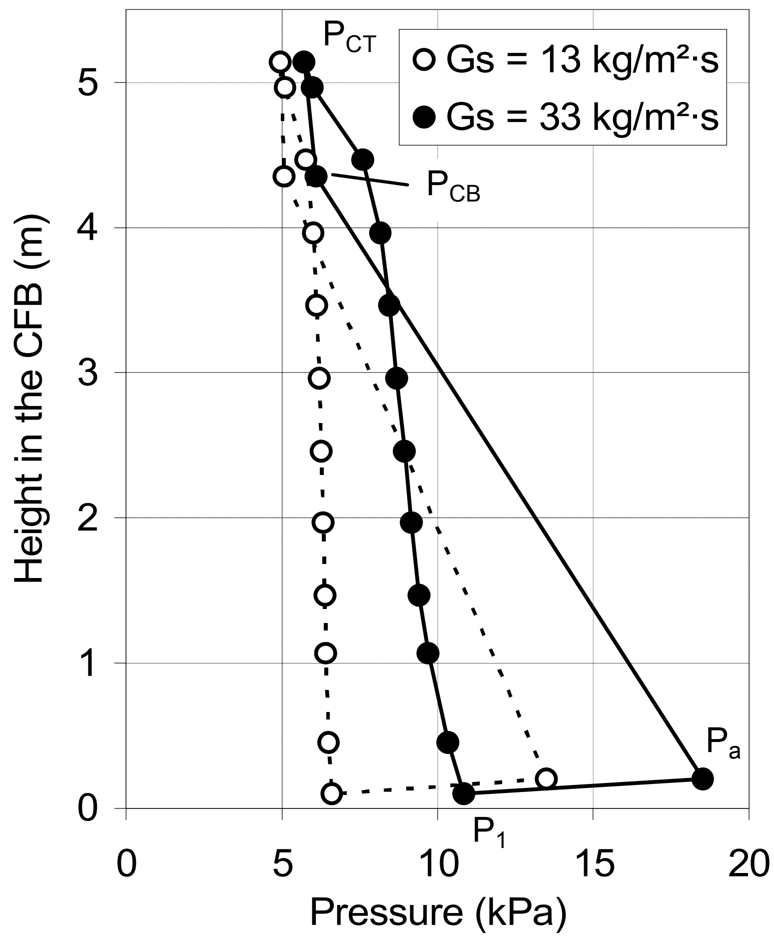
Modes of gas-solid contact



The circulating fluidized bed (CFB)



* Rutile (TiO_2), U = 5 m/s



Fluidized beds: The benefits

Fluidized-bed reactors and roasters can—

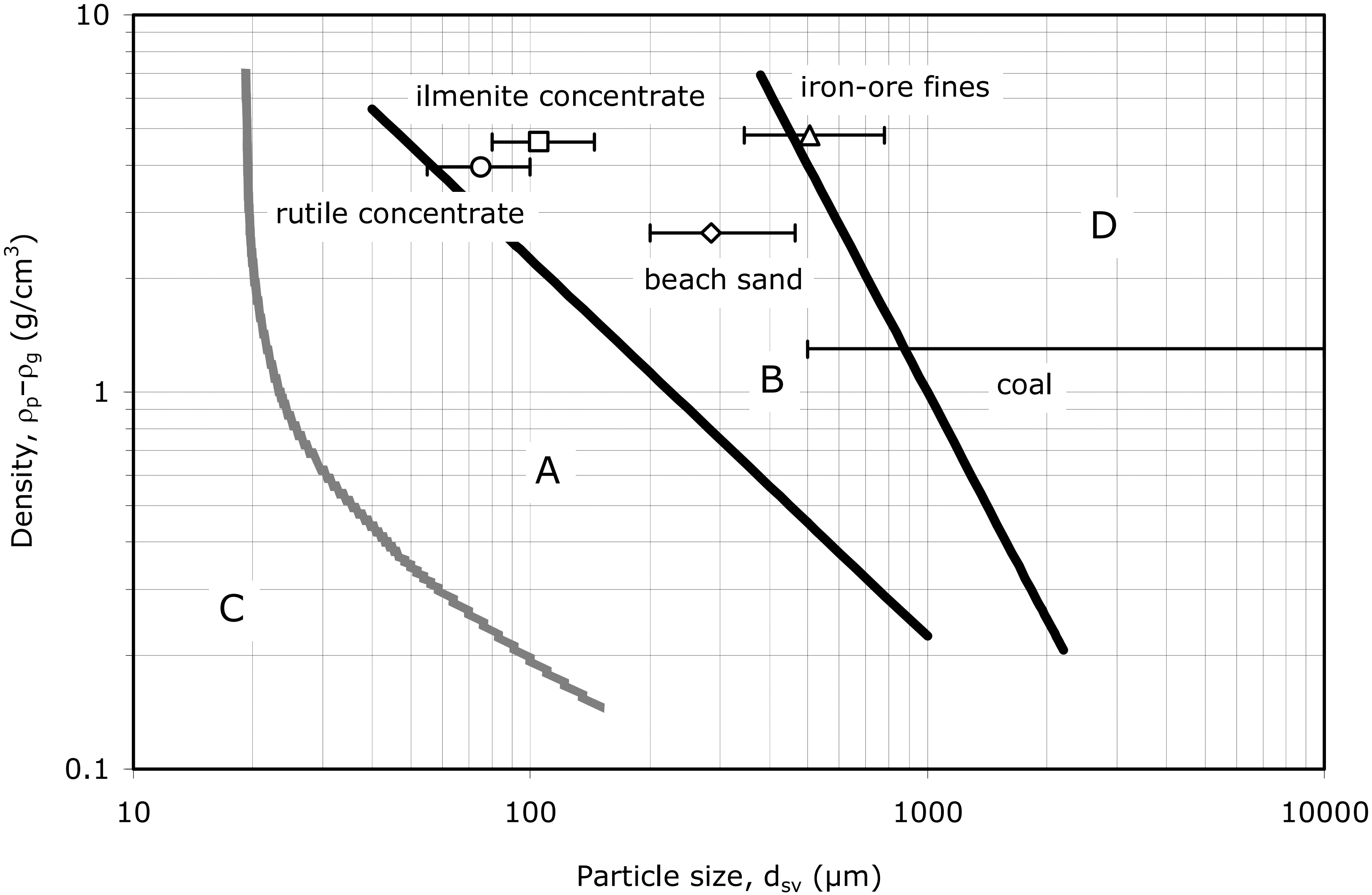
- Handle and process fine materials
- Burn discard coals, waste and biomass
- Lower pollutant emissions
- Offer the possibility of utilizing energy more efficiently

Fluidized beds: The benefits

Fluidized-bed reactors and roasters can—

- Handle and process fine materials
  - Direct reduction of iron (DRI) . . . . . . Siemens-VAI and Outotec
    - A world market of ~60 Mt per annum
    - The annual production of steel totals 1,400 Mt
  - Kumba Iron Ore produces 35 Mt of iron ore a year
    - It sits with ~ Mt of fines (–6 mm)
- Burn discard coals, waste and biomass
  - CFB boilers . . . . Foster Wheeler and Alstom
  - Anglo Coal produces 96 Mt coal a year
    - It sits with ~65 Mt of discard coal
- Lower pollutant emissions
- Offer the possibility of utilizing energy more efficiently

Describing fluidization: A classification



Variables and velocities defined

- Variables:
  - Particle size—Sauter mean diameter (d_{SV}), d_{10} and d_{90}
  - Particle density
  - Sphericity ($0 < \Phi_S \leq 1$)
  - Bed voidage ($0 < \varepsilon < 1$)
  - Gas density and gas viscosity
- Critical velocities:
  - Minimum fluidizing velocity, U_{mf}
  - Minimum bubbling velocity, U_{mb}
  - Transport velocity, U_{tr}
  - Terminal velocity, U_t

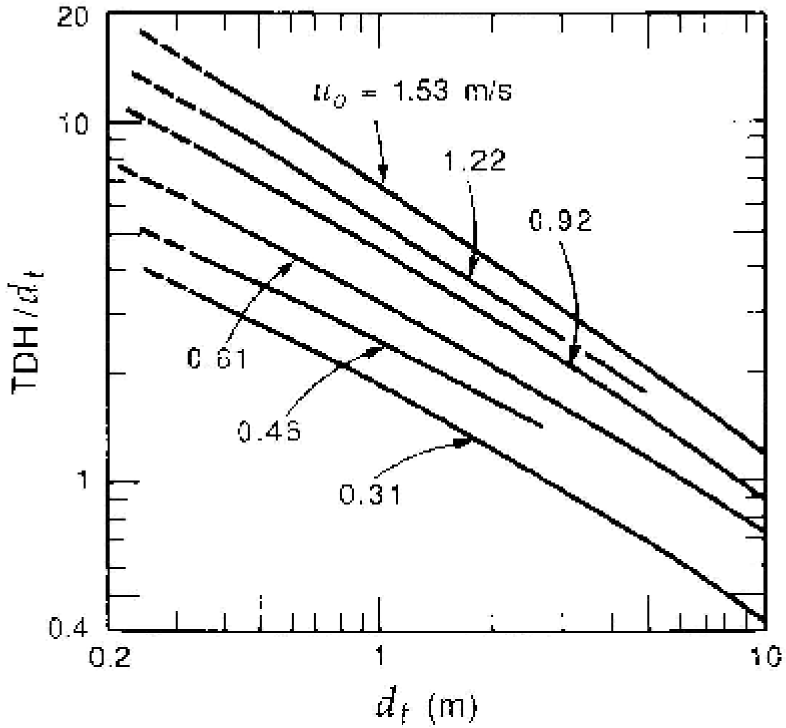
Variables and velocities related

- Dimensionless numbers:
  - Reynolds number, $Re = \rho_p \cdot U \cdot d_p / \mu$
  - Archimedes number, $Ar = d_p^3 (\rho_p - \rho_g) \cdot \rho_g \cdot g / \mu^2$
- Conditions at minimum fluidization—the Ergun equation:
  - $K_1 \cdot Re_{mf}^2 + K_2 \cdot Re_{mf} = Ar$
  - For small particles ($Re_{mf} < 20$), an approximation—
    - $K_2 \cdot Re_{mf} = Ar$
- Conditions at the transport velocity:
  - $Re_{tr} = a \cdot Ar^b$
- For a single particle falling at terminal velocity:
  - $U_t = [4 \cdot d_{10}(\rho_p - \rho_g) \cdot g / (3 \cdot \rho_g \cdot C_D)]^{1/2}$

Fluidized beds in chlorination

- A disparity:
  - South Africa and Australia produce 50% of the world's TiO_2 feedstock
  - They produce only 5% of the world's TiO_2 pigments and no metal
- The chloride process—
  - Produces $TiCl_4$
  - Chlorinators are bubbling fluidized beds
  - Temperatures run at 1000°C

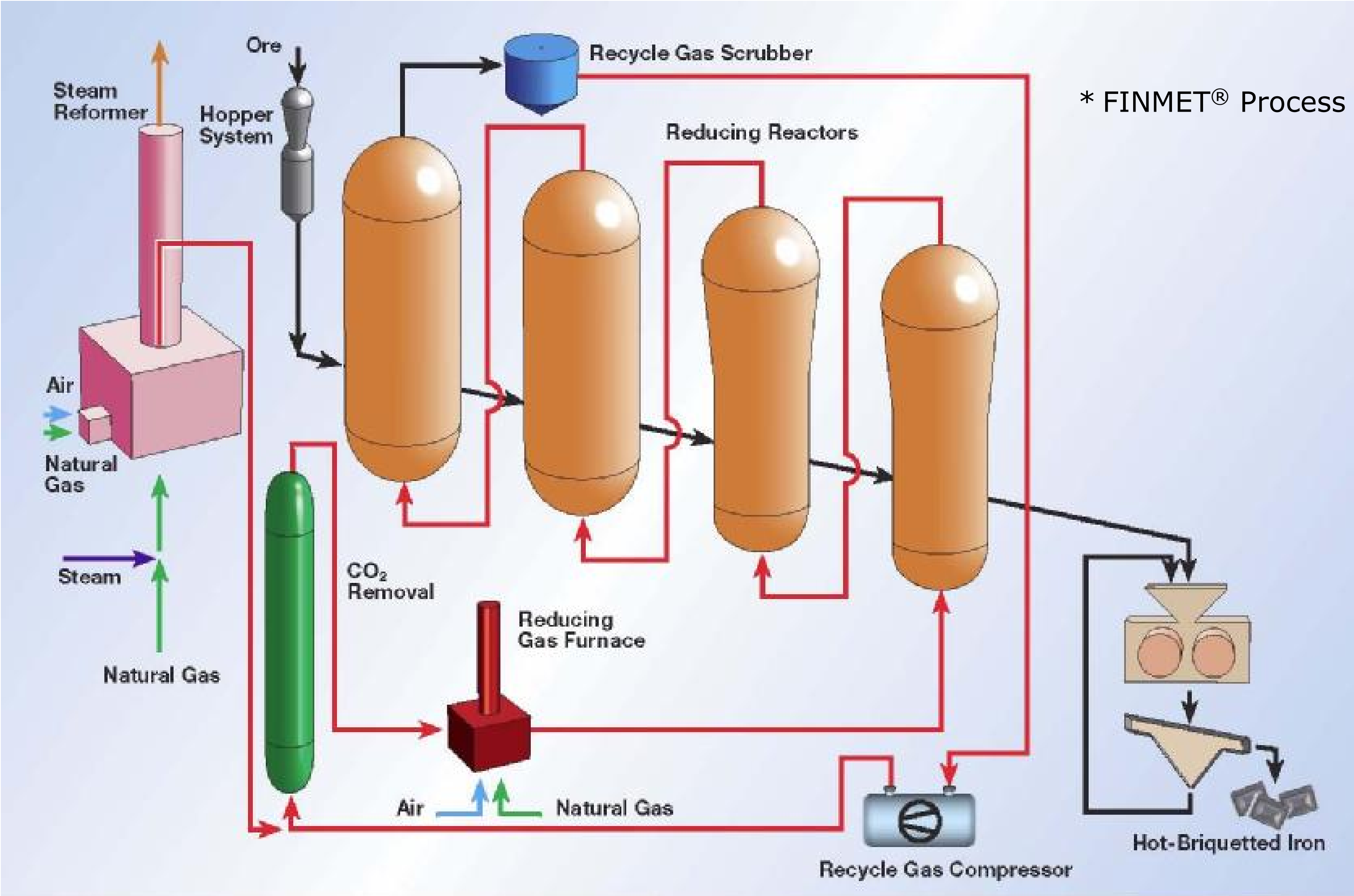
* Kunii & Levenspiel, 1991



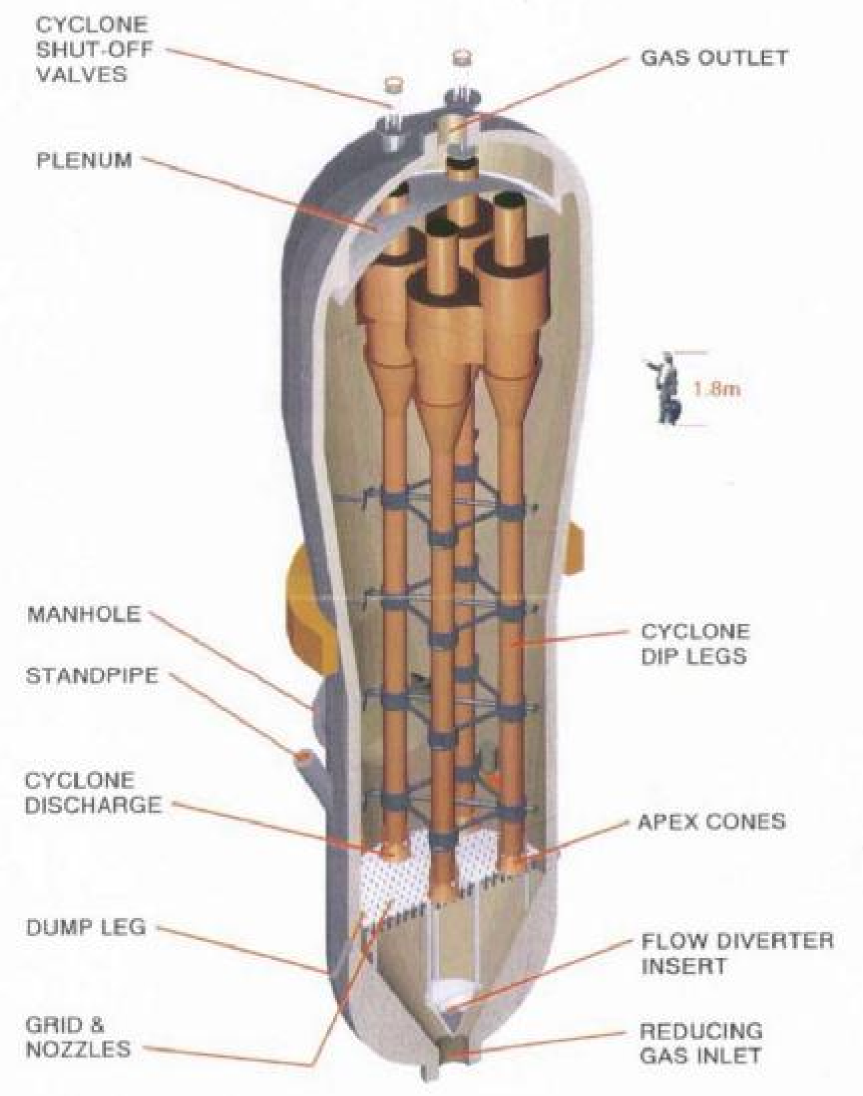
Bed diameter

* TDH = transport disengaging height

Fluidized beds in DRI



Fluidized beds in DRI



* FINMET® Process
Reactors 1 and 2

Temperature . . 400–800°C
Pressure . . 12 bar (gauge)
U . . . . 1–4 m/s
50 μm < d_p < 8 mm

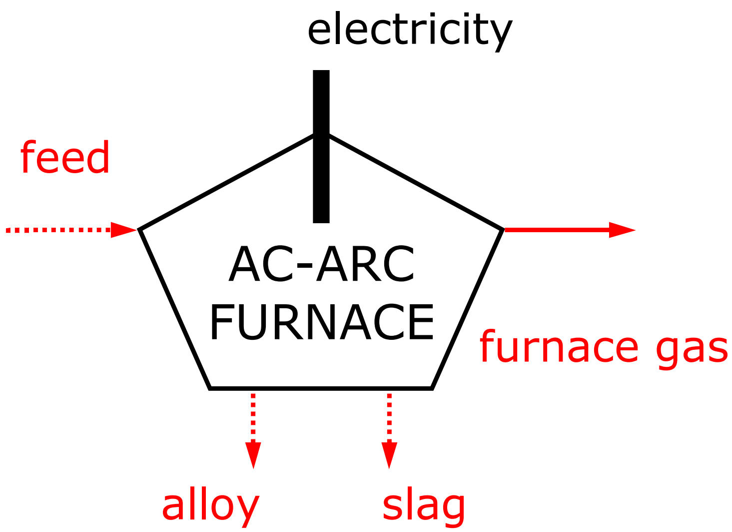
* Schenk, 2008

Saving energy—1

Outokumpu process

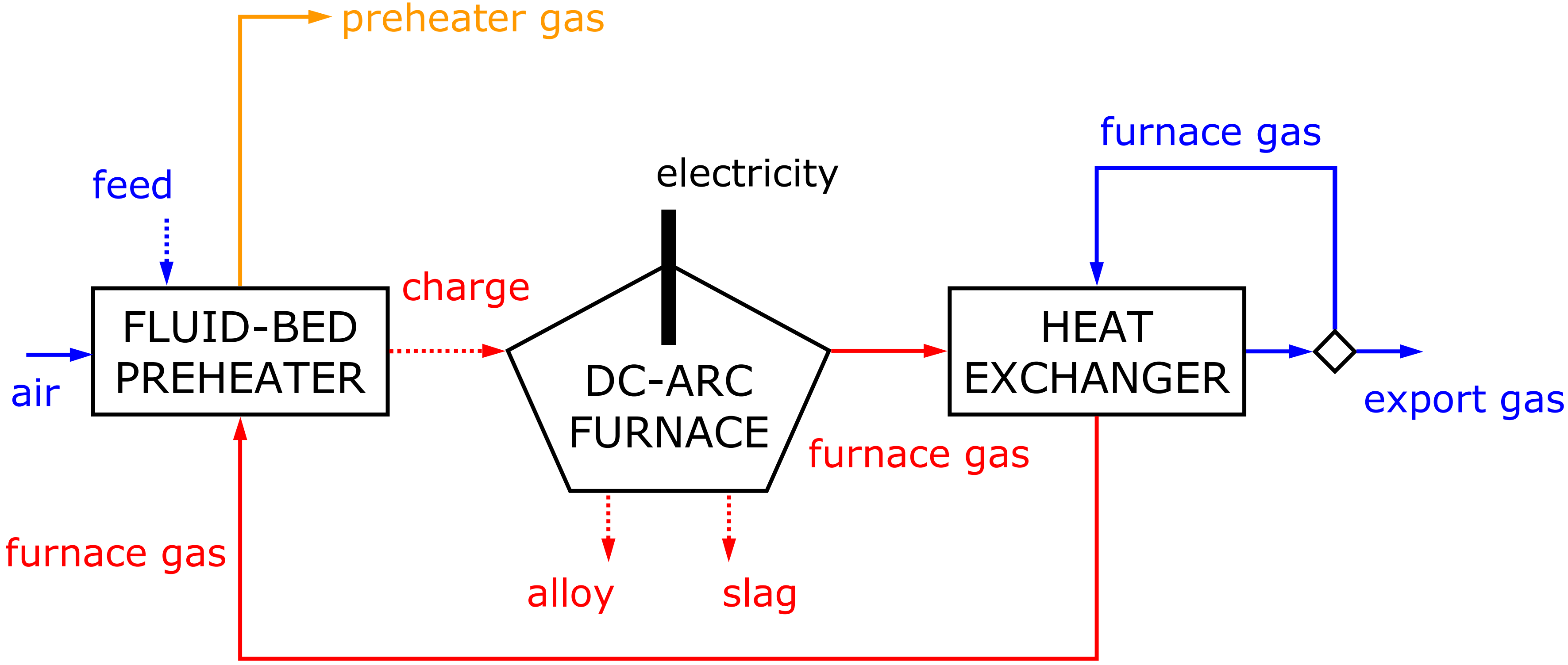
- Chromite fines are pelletized
- Feed is preheated to 600–700°C
- Submerged-arc furnace

* Base case



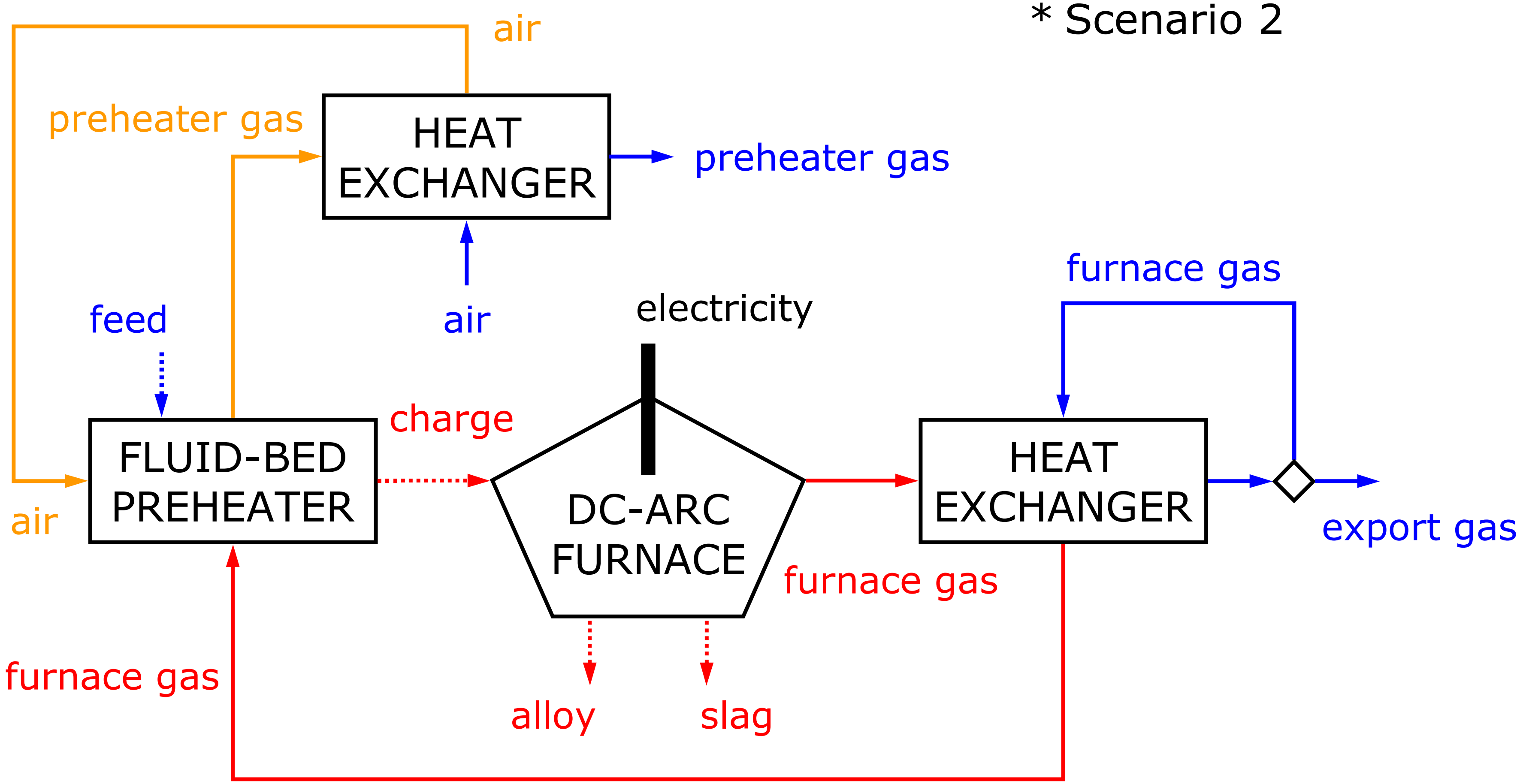
Saving energy—2

* Scenario 1



Saving energy—3

* Scenario 2



Energy saved—4

	Base case	Scenario 1	Scenario 2
Furnace power . . . . . (MW)	63	48	48
Process energy (MWh/t alloy)	4.0	2.9	2.9
Furnace off-gas . . . . (kt/a)	131	131	131
Gas to preheater . . . (kt/a)	—	92	66
Air to preheater . . . . (kt/a)	—	224	160
Preheater off-gas . . . (kt/a)	—	330	241
Export gas . . . . . . (kt/a)	—	36	62