Resource-saving operation and control of stainless steel refining in VOD and AOD Processes - EUR 25087

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Background

This RFCS project started in 2010, it was a collaboration between:

BFI

KTH

SMS Mevac

Kobolde & Partners

Acroni

Outokumpu Stainless

Background

KTH performed numerical modeling of the VOD at Acroni and of the AOD in Avesta.

BFI, SMS and Kobolde worked with dynamic process models of the VOD and AOD, as well as with data acquisition for those models.

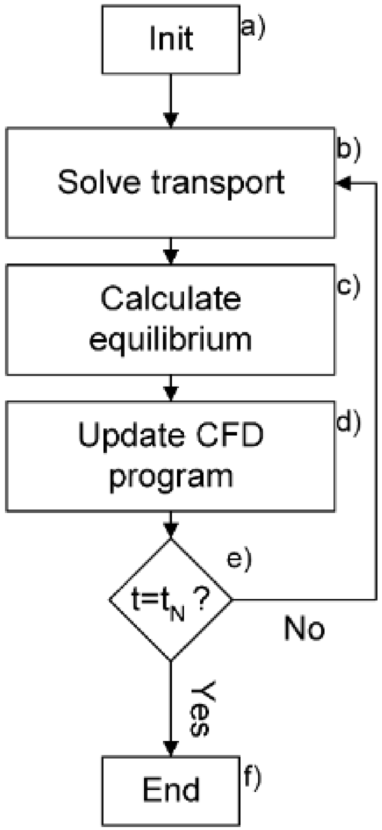
This presentation will naturally focus on the numerical aspects of this project.

CFD coupled to Thermodynamics

1. Divide the domain into several subdomains (cells).
2. Set initial values.
3. Solve for transport of momentum, heat and mass.
4. Calculate thermodynamic equilibrium in each cell.
5. Update and repeat if necessary.

The number of equilibrium calculations performed depend on the resolution in time and space.

Example: Coarse mesh of 10 000 cells, with time-step of 1 ms, performs 10 million equilibrium calculations for each real time second.



The AOD numerical model

The converter in Avesta was modeled with the following assumptions:

3-D with symmetry along the center.

The free surface is flat and bubbles can leave through it freely.

The injection takes place through 3 nozzles and gas instantaneously takes the steel temperature.

The AOD numerical model

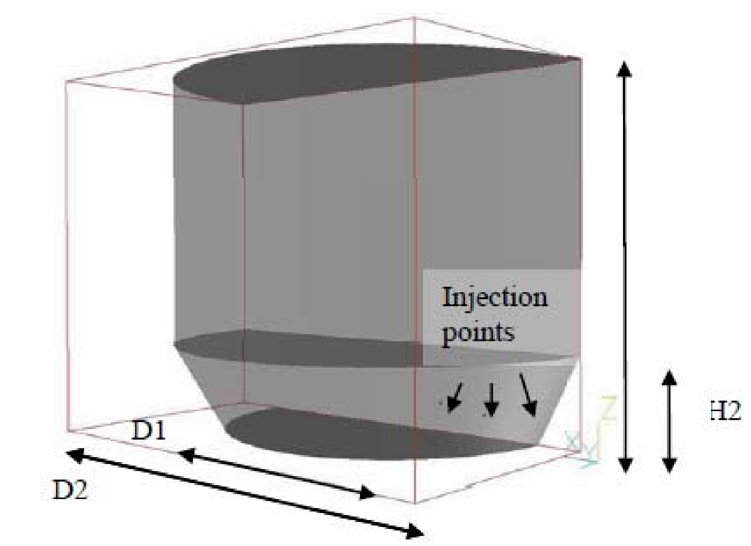
Furthermore:

Liquid temperature is taken from the TimeAOD2 model of Kobolde.

The slag phase is homogeneous and treated as liquid spherical droplets. The initial slag height is 6.3 cm.

5 Thermo-Calc database elements (Ar, C, Cr, Fe, O)

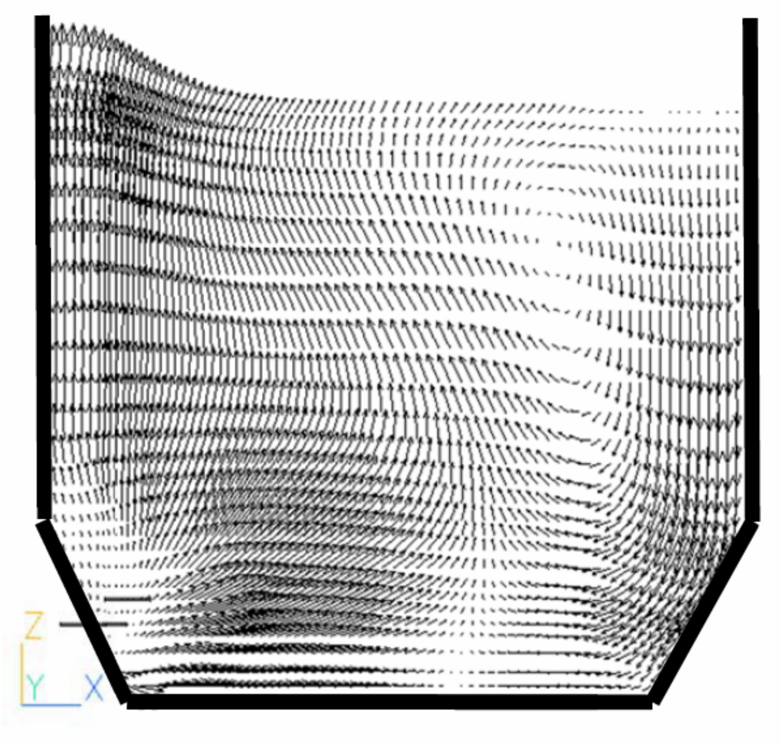
15 extra scalar transport equations (5 per phase)



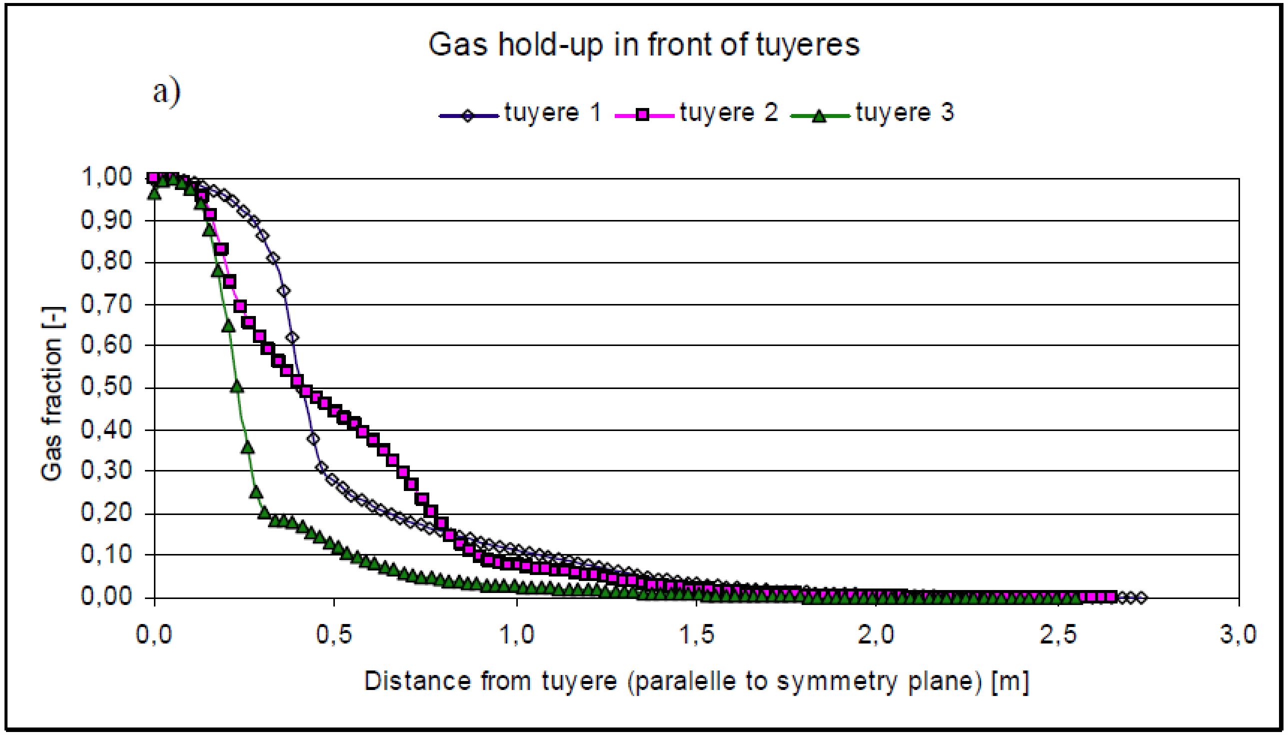
Stirring pattern in the Avesta AOD

Snapshot of the velocity vectors, close to the symmetry plane.

The flow field is not stationary!

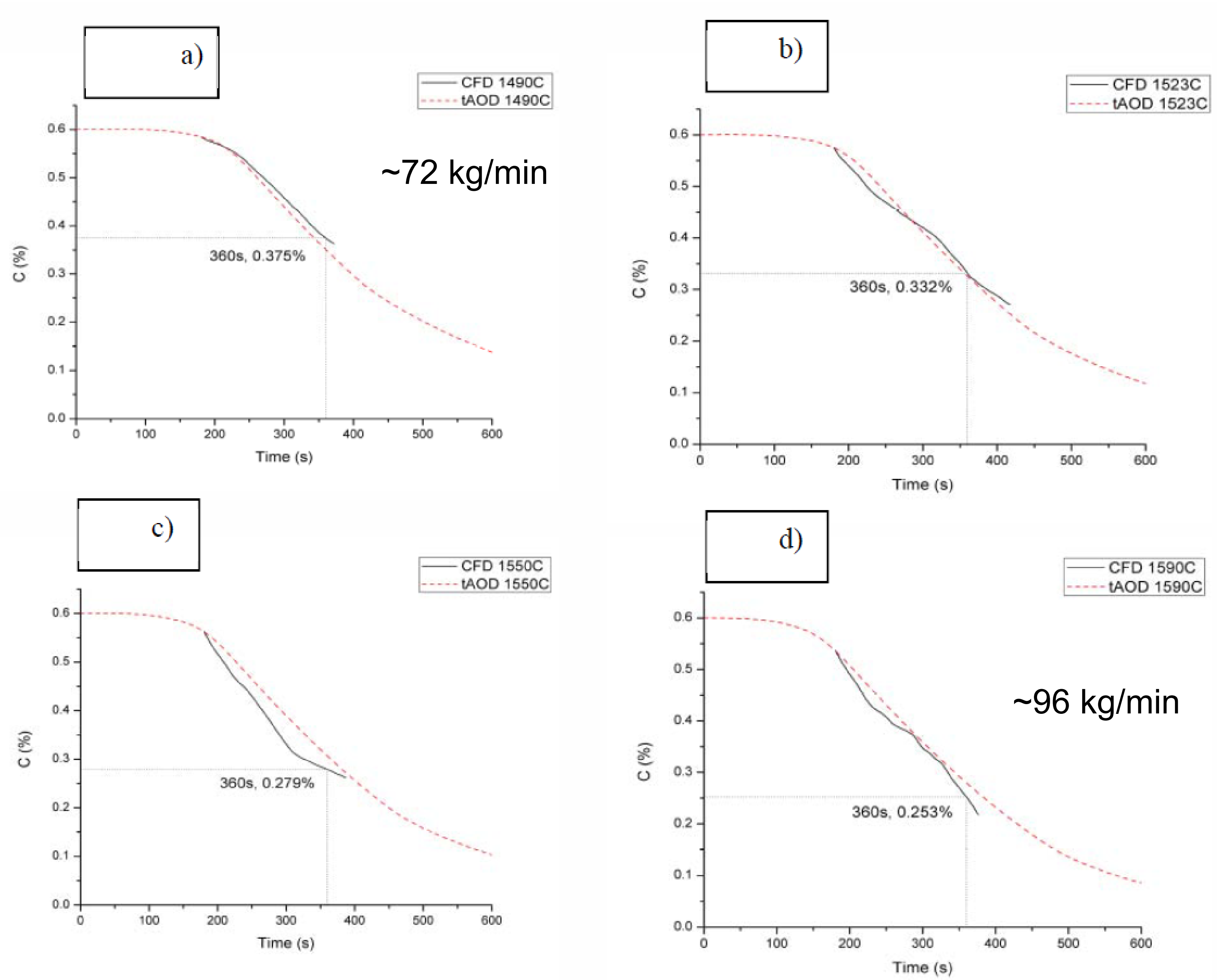


Results AOD modeling



CFD results, compared to the TimeAOD2 process model

Decarburization vs time for different bath temperatures

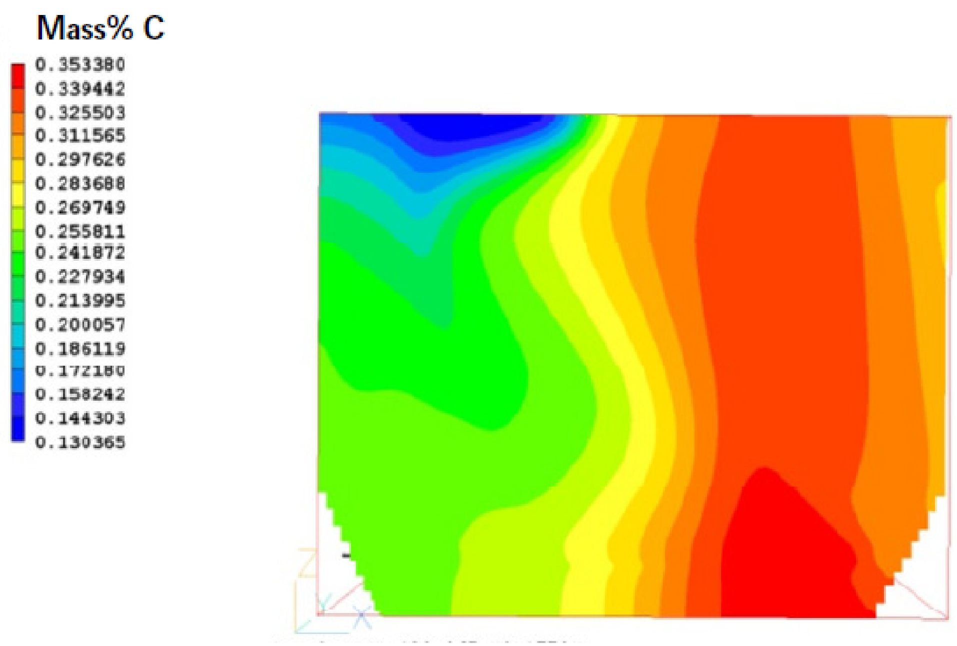


Results AOD modeling

How fast is the mixing in the AOD converter?

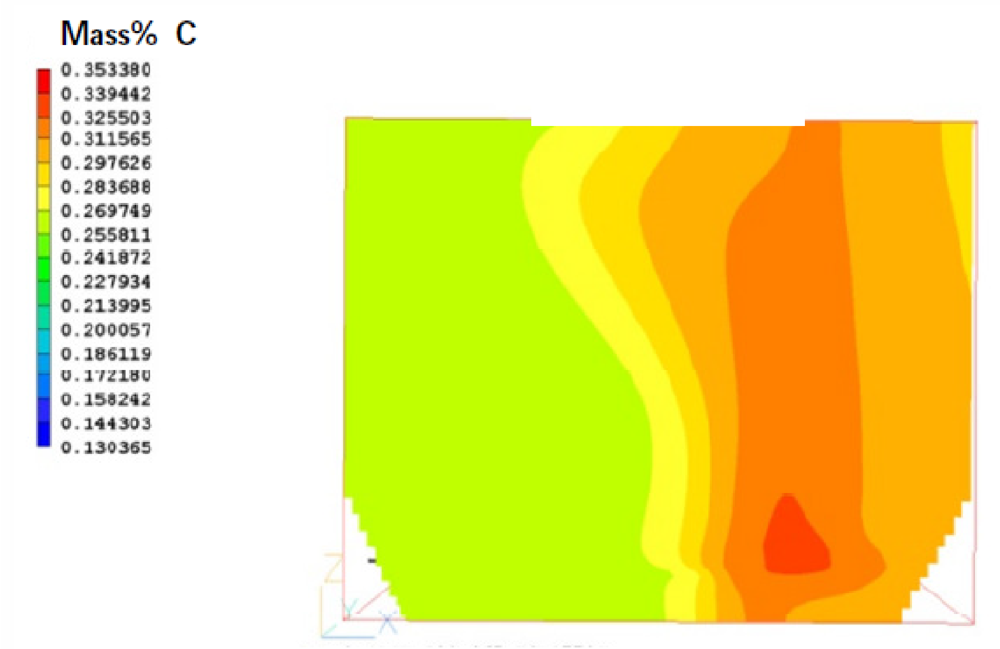
→ The oxygen is turned off and replaced with inert gas, keeping the total flow rate constant.

The concentration is then homogenized over time.



a) Start (t= 0s)

Results AOD modeling



b) Middle (t= 10s)

c) End (t= 30s)

Results AOD modeling

The **coupled CFD-Thermodynamics** solution gives decarburization results comparable to the TimeAOD process model.

Mixing **phenomena can be extracted** from the simulation. In particular, the mixing time, which for the AOD in Avesta is approximately 30 seconds.

Even with this fast mixing time there are clearly visible **concentration gradients** in the converter **during decarburization**.

The VOD numerical model

Initial data

steel weight	88190 kg
slag weight	900 kg
heat temperature	1960 K
steel C	0.0890 %
steel Si	0.0000 %
steel Cr	18.8600 %
steel Ni	7.1300 %
steel N	0.0148 %
steel S	0.0142 %
steel O	0.0778 %
steel Fe	71.6000 %
slag CaO	48.4000 %
slag SiO2	22.3200 %
slag Cr2O3	11.2000 %

2-D axisymmetrical model

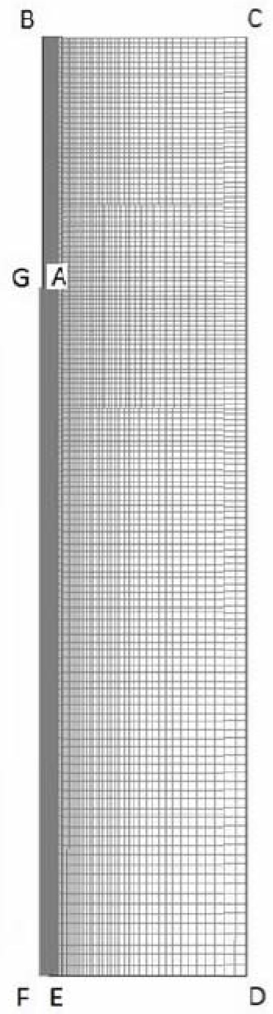
9 Thermo-Calc database elements (Ar,C,Cr,Ca,Fe,N,Ni,O,S)

3 phases (Steel, Slag and Gas)

27 extra scalar transport equations (9 for each phase)

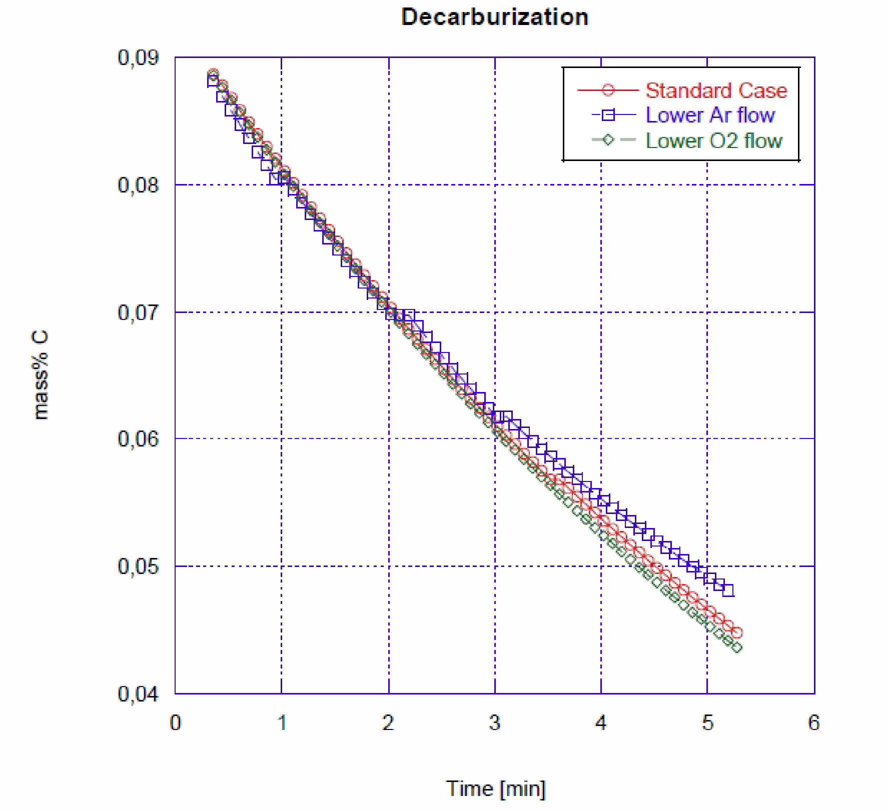
Time-step approximately 0.01 ms.

Millions of thermodynamic equilibrium calculations for 5 minutes of simulation.



Line BC:	pressure outlet
Lines AB and CDE:	no slip wall with standard wall functions for turbulence
Line FG:	symmetry axis
Lines FE and GA:	mass flow inlet (FE is the porous plug and GA is the lance nozzle)

Results VOD modeling



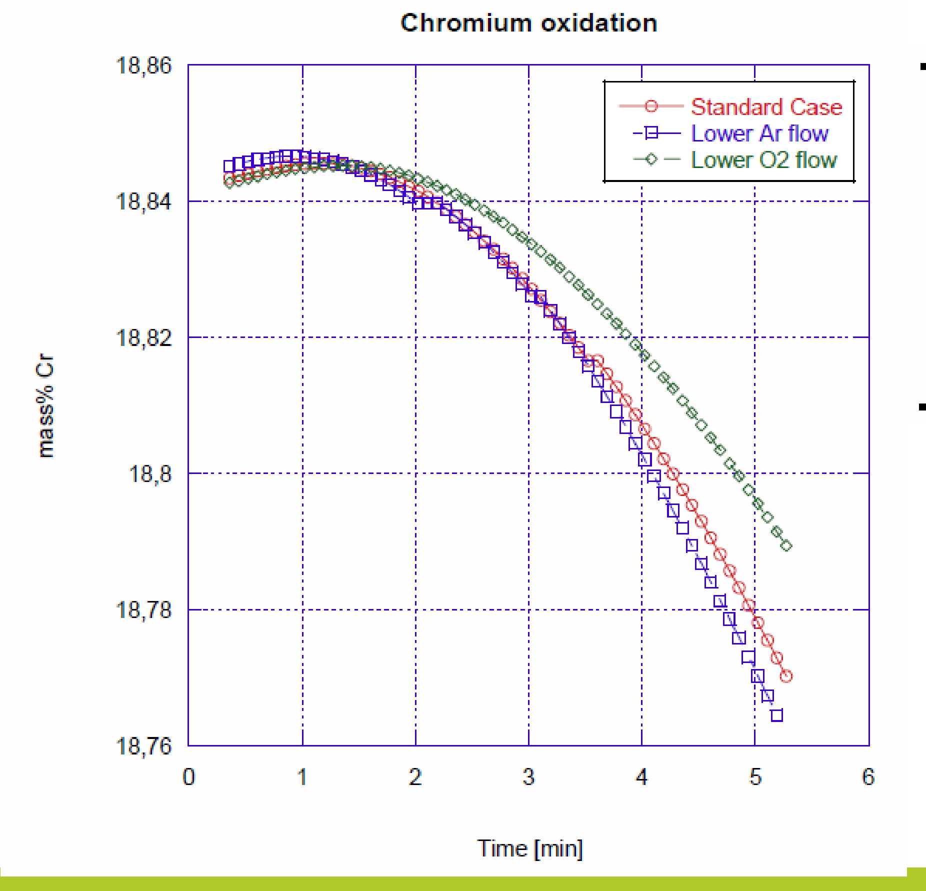
Case#	Argon flow rate [m3/h]	Oxygen flow rate [m3/h]
1	6	850
2	3	850
3	6	600

Results VOD modeling

Extrapolation of decarburization results yielded ~16 min to reach 0.01 mass% C.

This corresponded well to the BFI VOD model. Considering the approaches are completely different it gives some validity to both.

Results VOD modeling



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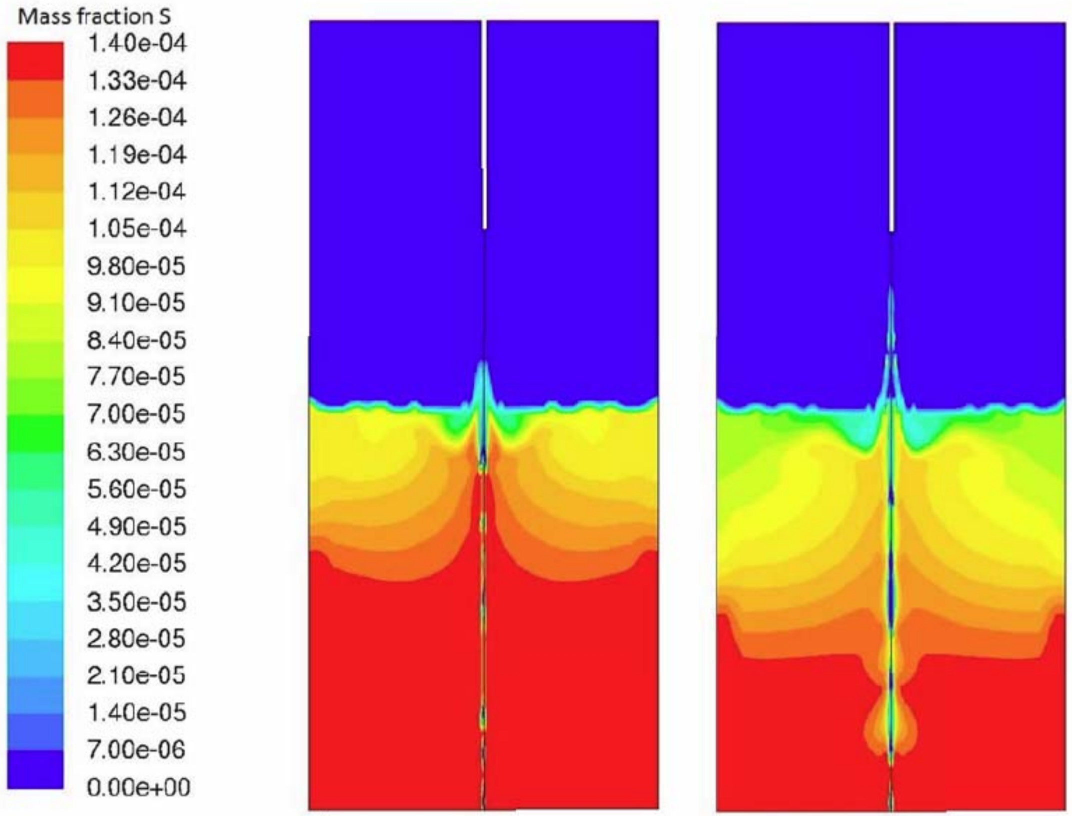
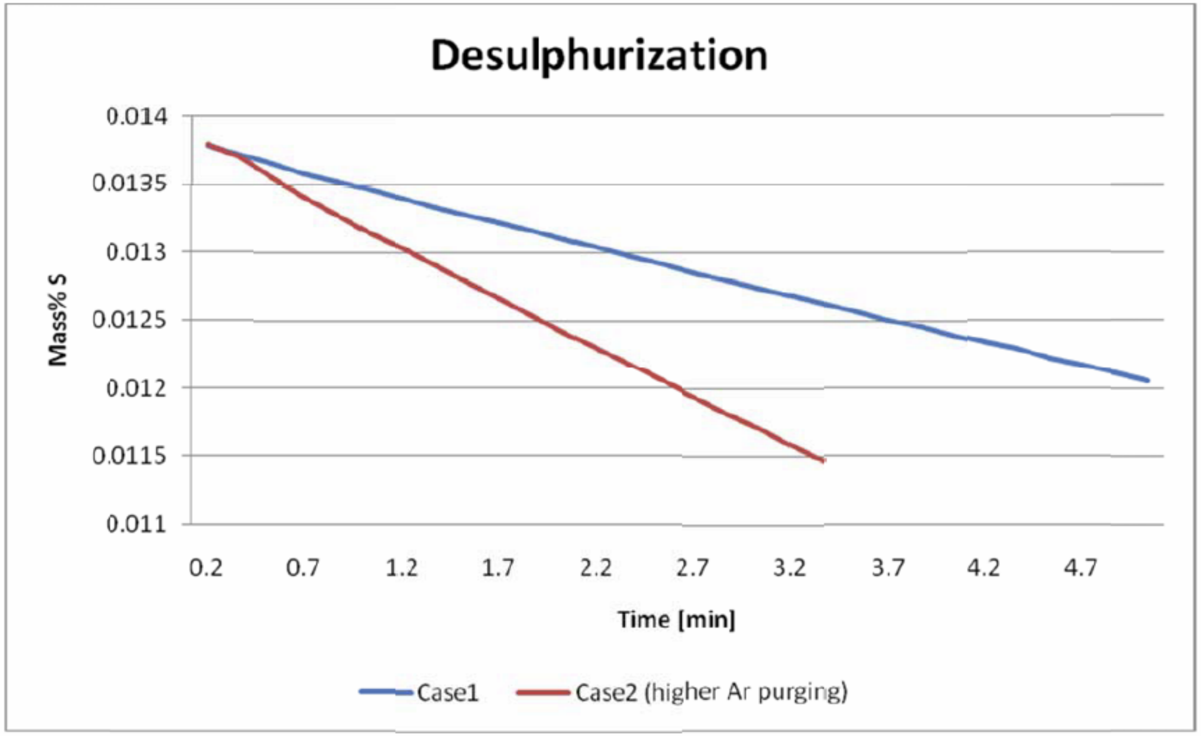


Desulphurization for 6 and 12 Nm3/h Argon purging.

Results VOD modeling

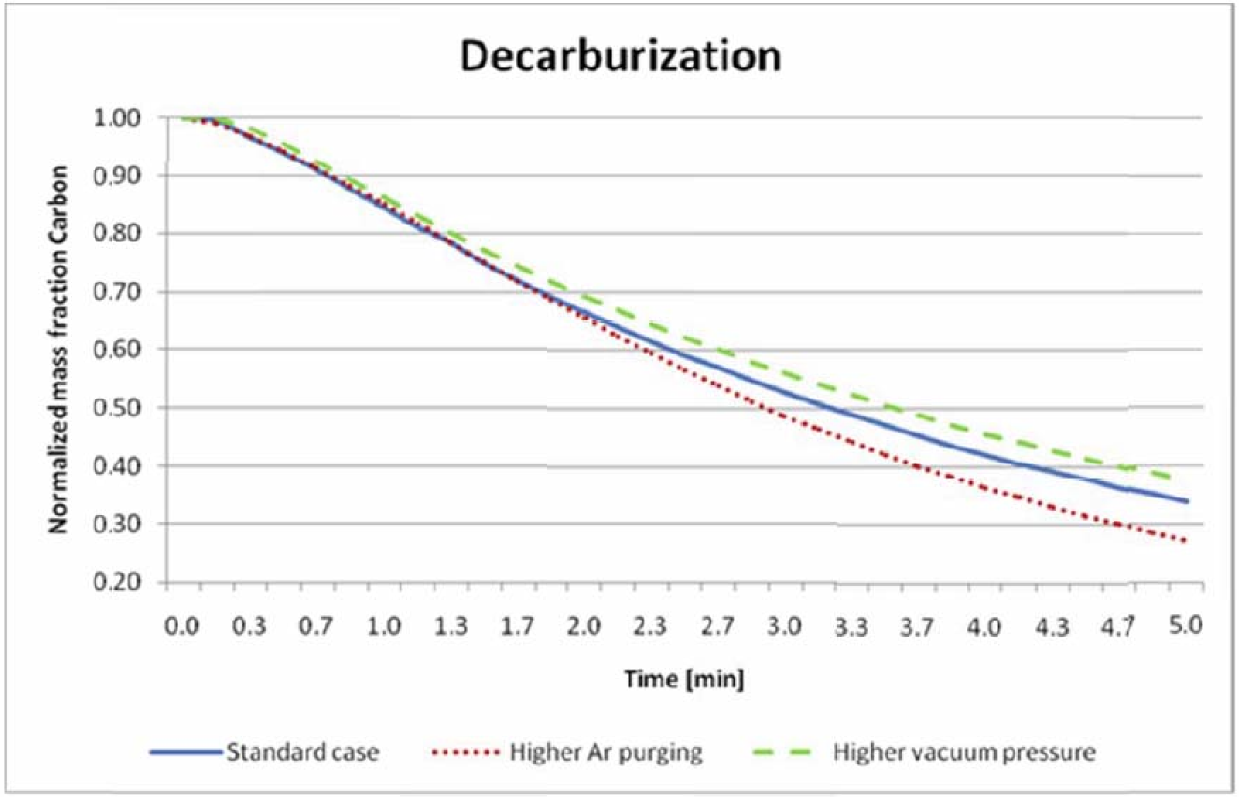


Desulphurization for 6 and 12 Nm3/h Argon purging.

Results VOD modeling – Vacuum pressure

Standard:
110 mbar – 5mbar/min

High pressure:
220 mbar – 10 mbar/min



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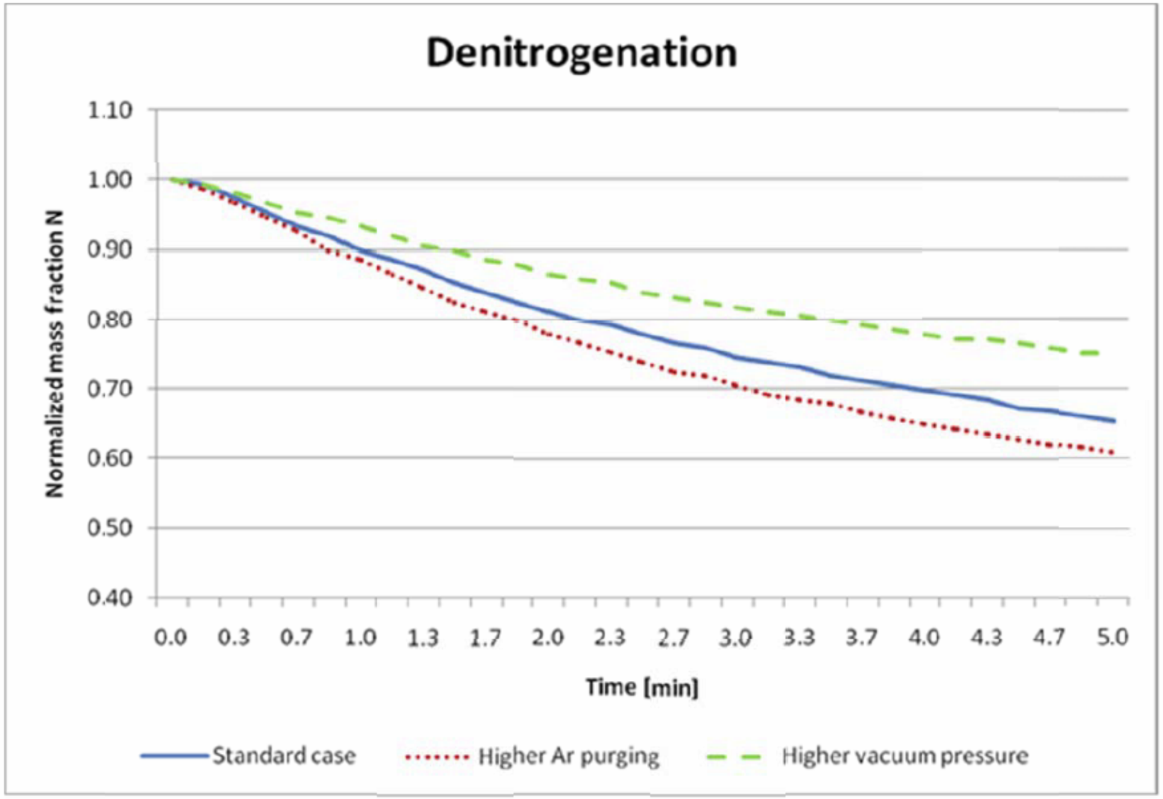

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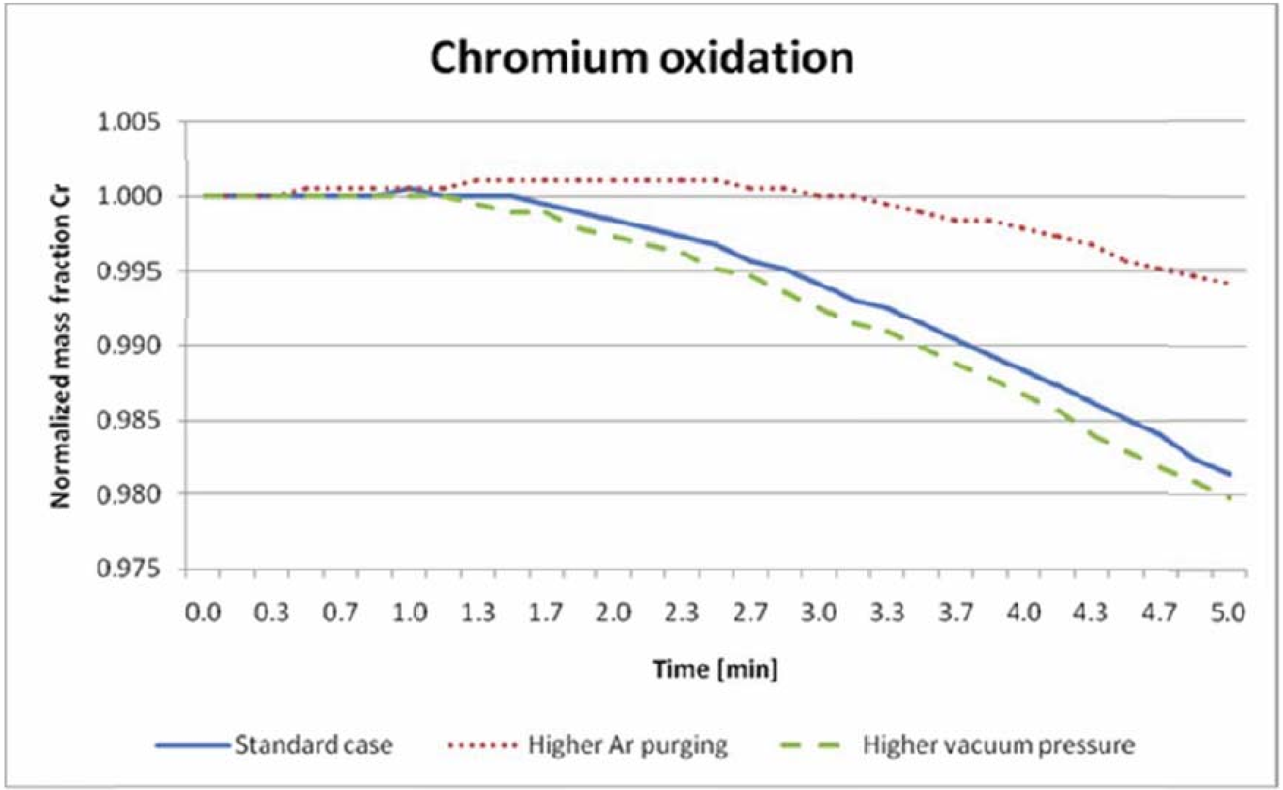


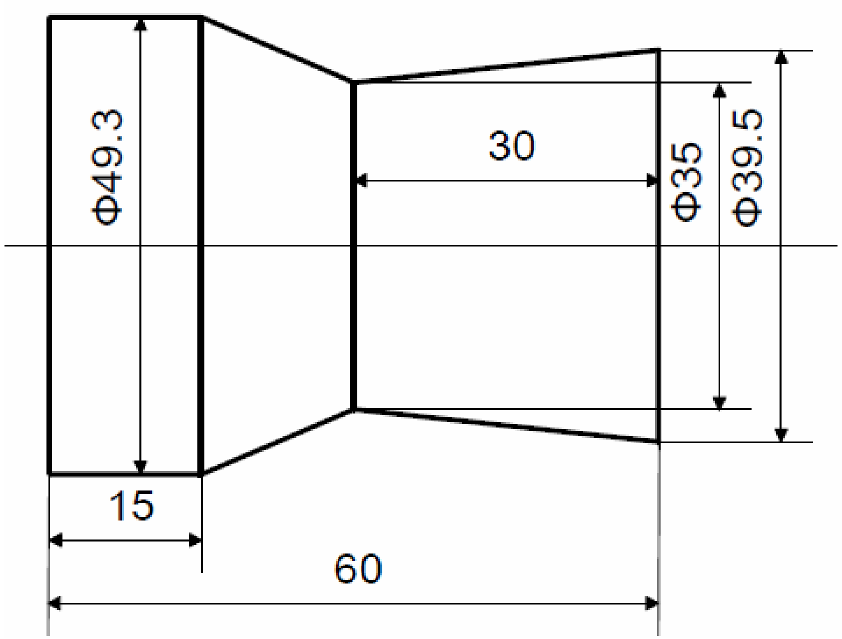
Results VOD modeling – Vacuum pressure

Decarburization and Chromium oxidation is **not largely affected** by an increased vacuum pressure.

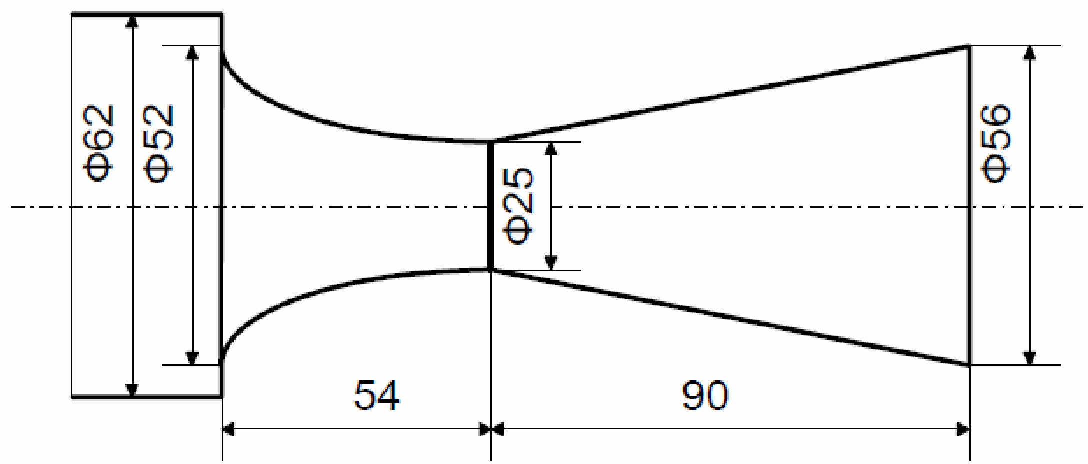
This is also **confirmed by experimental measurements** of SMS Mevac and Acroni at the Acroni plant, as well as by the dynamic VOD model of BFI.

In other words: it may be possible to **save money** by running vacuum pumps at **lower power**.

Results VOD modeling – nozzle configuration



Nozzle type A



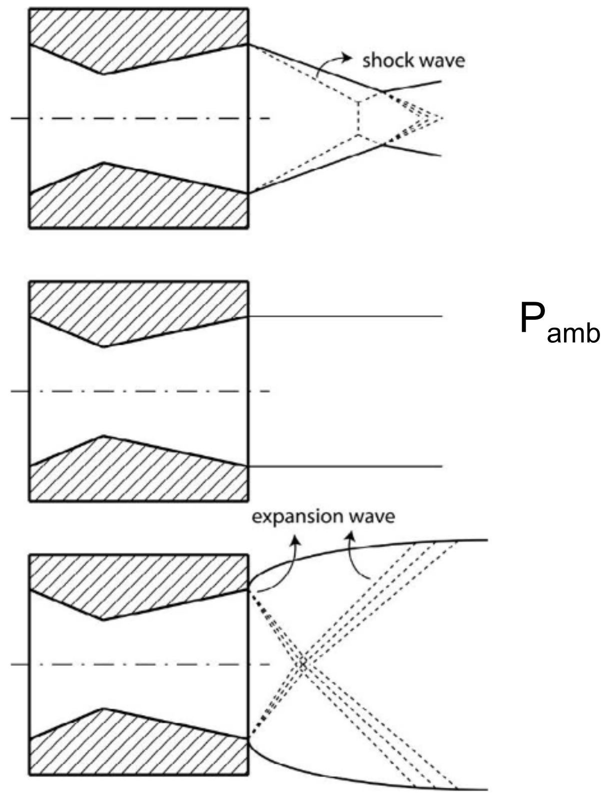
Nozzle type B

Results VOD modeling – nozzle configuration and ambient pressure

Over expansion (inefficient, may damage nozzle)

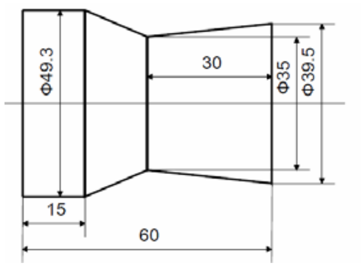
Optimum expansion

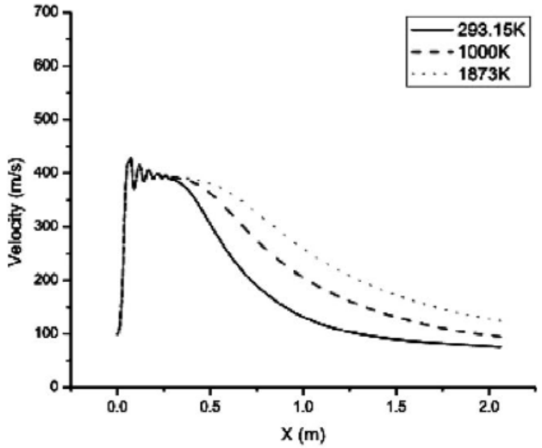
Under expansion (inefficient, may damage nozzle)



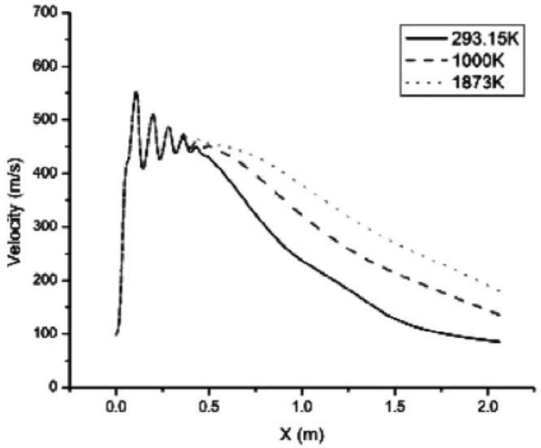
Gas flow from left to right

Results VOD modeling – nozzle configuration, jet velocity

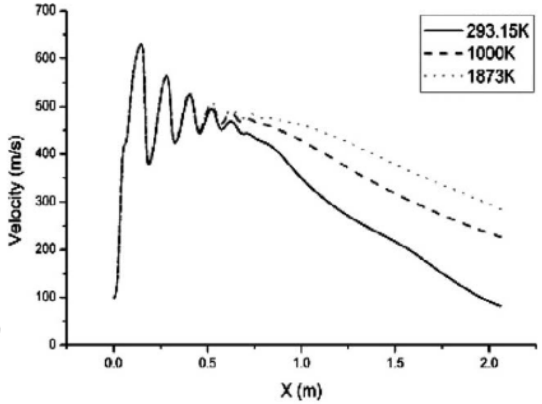




a. 400mbar

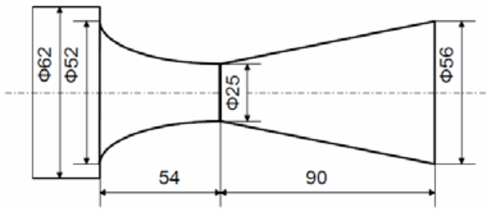


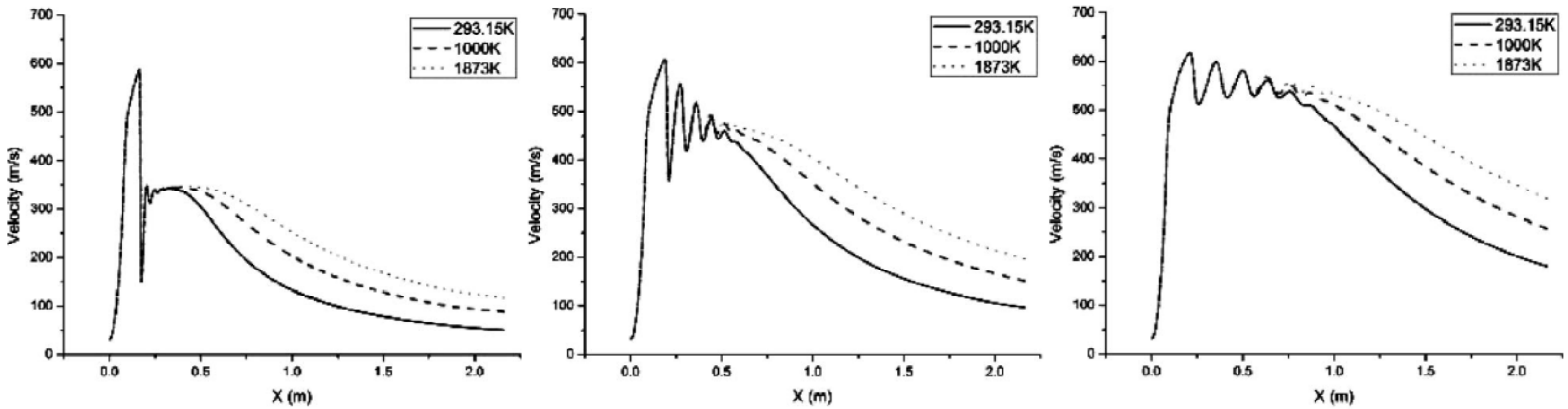
b. 200mbar



c. 100mbar

Results VOD modeling – nozzle configuration, jet velocity





a. 400mbar b. 200mbar c. 100mbar

Results VOD modeling – nozzle configuration, jet force

Nozzle A	Jet Force (N)		
	Temperature (K)		
Ambient Pressure (mbar)	1 873	1 000	293.15
400	135.33	135.42	136.12
200	159.95	160.09	159.29
100	171.87	172.07	171.26

Force evaluated at 1.3 m from the nozzle (initial position of bath surface)

Ambient pressure has a large impact on the force.

Temperature has almost no impact!

Nozzle B	Jet Force (N)		
	Temperature (K)		
Ambient Pressure (mbar)	1 873	1 000	293.15
400	122.83	122.71	123.01
200	166.39	166.54	166.59
100	190.81	191.02	191

Results VOD modeling – nozzle configuration, jet force

The jet force at 1.3 meters after the nozzle (initial position of bath surface)

Temperature: 1 873 K	Jet Force (N)			
Ambient Pressure	400 mbar	200 mbar	100 mbar	10 mbar
Nozzle A	135.33	159.95	171.87	181.38
Nozzle B	122.83	166.39	190.81	216.96

Lower pressures favor Nozzle B and higher pressures favor Nozzle A.

Nozzle A is also cheaper to manufacture.

Summary

The **CFD** models were able to predict parts of the **AOD** and **VOD** processes.

The results were **validated** against process models which were trimmed to the specific plants.

The methodology of using **CFD coupled to Thermodynamic databases** show **great promise** as a **fundamental tool** to investigate high temperature phenomena in steel production.

Thank you!

Results VOD modeling – Nitrogen pick-up

Case#	O2 flow from lance [Nm3/h]	N2 flow from plug [Nm3/h]	N2 flow from lance [Nm3/h]	Pressure
1	850	6	0	220mbar - 10mbar/min
2	790	6	60	220mbar - 10mbar/min