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Multiphase Computational Fluid Dynamics (CFD) modeling study of slopping behavior during basic oxygen steel making (BOS) process

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Content

- Overview of existing process models for LD converter steel making
- Motivation
  - Technological gap
  - Relevant background
- Objectives
- Methodology / Model Descriptions
- Results and Discussions

Literature Reported Models

- **Static models →**

A set of **energy and mass balance** equation that enable the prediction of material demand from known initial conditions of charge composition, weight and temperature to give the required end-point specification of steel composition, temperature and weight.

(H. W. Meyer and J.A. Glasgow, 1966 ; L. Pigjaner and A. Espuna, 1991)

- **Dynamic models →**

Differential equations which describe the **rate of change of bath and slag composition throughout the blowing stage,** and are designed to take into account **variations in blowing conditions and sequence of additions** as continuous sensors' feedback data to the control system throughout the process.

(Asai and Muchi, 1970; J.R. Middleton and R. Rolls, 1973; Knoop et al., 1992; Modigell et al., 2007; E. Graveland-Gisolf et al., 2007)

Two major approaches of the modeling of LD converter steel making process:

- Detail simulation of specific process
  (e.g. decarburization, de-phosphorization etc.)
- Overall process model of LD converter steel making

Methodologies / simulation tools for modeling of LD converter steel making process phenomena :

- **Thermodynamic Modeling** → Feasibility study of different individual oxidation reaction for removal of impurities
- **Kinetic Modeling** → Prediction of rate of different reactions occurring during LD converter steel making process
- **Computational Fluid dynamics (CFD) and Physical Modeling** →Fluid flows, swirl motions, cavity formation, slag emulsification, and droplet formation

Thermodynamic and kinetic model for basic oxygen steel making process

Can be classified into :

1. **Single zone model** →

No consideration of mass flow between the reaction zones (e.g. hot spot, emulsification zones etc.)

2. **Multi-zone model** →

Mass flow and energy flow among reaction zones has been taken in account (complete application of this concept is due till date)

Some single zone models reported in literature

- **Chigwedu et. al. (2006)** assumed that the distribution of blown oxygen among the elements of metal proportional to the fraction of Gibbs free energies for the oxidation of hot metal components.
- **Jalkanen et. al. (2007)** took following assumptions/approaches:
  a) The distribution of blown oxygen among the components of the metal phase is controlled by the reaction affinity.
  b) A component of the metal phase, which has higher affinity to oxygen, is oxidized by a small part of the blown oxygen.
  c) The surface concentration of the oxidized component is changed, and the consumption of the next small part of oxygen is considered for the new concentrations of metal phase components.
- **Deo and Shukla (2012)** calculated Gibbs free energy change for all the probable reactions of basic oxygen steel making process using FactSage database (assumed that the considered system is fully mixed).

Multi-zone model reported in literature

Hack et. al. (2007) performed multi-zone process model of the LD converter steel making process using SimuSage modeling software.

The methodology of their work :

- The converter process is divided into different reaction zones.
- Inside these reaction zones, thermochemical equilibrium is assumed.
- Mass and energy exchange between the zones are defined by empirical dependences.
- Empirical dependences are determined experimentally, considering several process conditions (e.g. blow rate, lance height, and other geometrical parameters).

CFD simulation works reported in literature

- **Singh et. al. (2007)** carried out CFD simulation and physical model based studies of fluid flow inside LD converter.
- **Ersson et. al. (2008)** studied impinging air jet on a water surface using numerical fluid flow techniques.
- **Ersson et. al. (2008)** also did CFD modeling of a top-blown converter coupled with equilibrium thermodynamic databases (ThermoCalc)
- **Kundu et. al. (2012)** performed investigations on interaction of impinging oxygen jet with hot-metal bath using multiphase model

Model Descriptions – Part one

STEPS:

1. Calculate probability of reaction to occur at each blowing time, i.e. from 1 to 18 min using the formula:

$$probability = \frac{\Delta G}{\Delta G total}$$

2. $\Delta G = \Delta G^{\circ} + RT \ln K$

ΔG° is the initial del G value of each reaction which is taken from Ellingham diagram.

3. ΔGtotal=summation ΔG of all reactions.

4. Calculation of K:

a) Oxygen i/p = Probability * Total Oxygen
b) Wt. of oxide formed = 28/16 * Oxygen input
c) Activity = wt. of oxide formed / total oxide formed
d) Wt. of C removed = 12/16 * Oxygen i/p
e) Wt. of C remaining in the bath = Total C present – wt. of C removed
f) K = activity / Wt. of C remaining in the bath

4. Wt. of oxide formed in each reaction at each blowing min is calculated

5. Wt. % of of each impurity removed at each min is then evaluated

Model Descriptions – Part Two

Numerical simulation of fluid flow behaviour inside LD converter has been performed using ANSYS 15.0 software.

- RNG κ - ε turbulence models are used for simulations along with volume of fluid method (VOF).

- Assumptions :

1. Incompressible and

Newtonian fluid with

constant molar viscosity are assumed.

1. No source term considered.
2. Isothermal fluid flow taken.
3. No miscibility between oxygen and hot metal.

The values of Turbulence Models parameter:

Parameters	RNG κ-ε model
C_μ	0.09
$C_{1\varepsilon}$	1.44
$C_{2\varepsilon}$	1.78
σ_κ	1.0
σ_ε	

Model Results using data from a Steel Plant (RSP, SAIL)

Oxygen flow rate=620m3/min

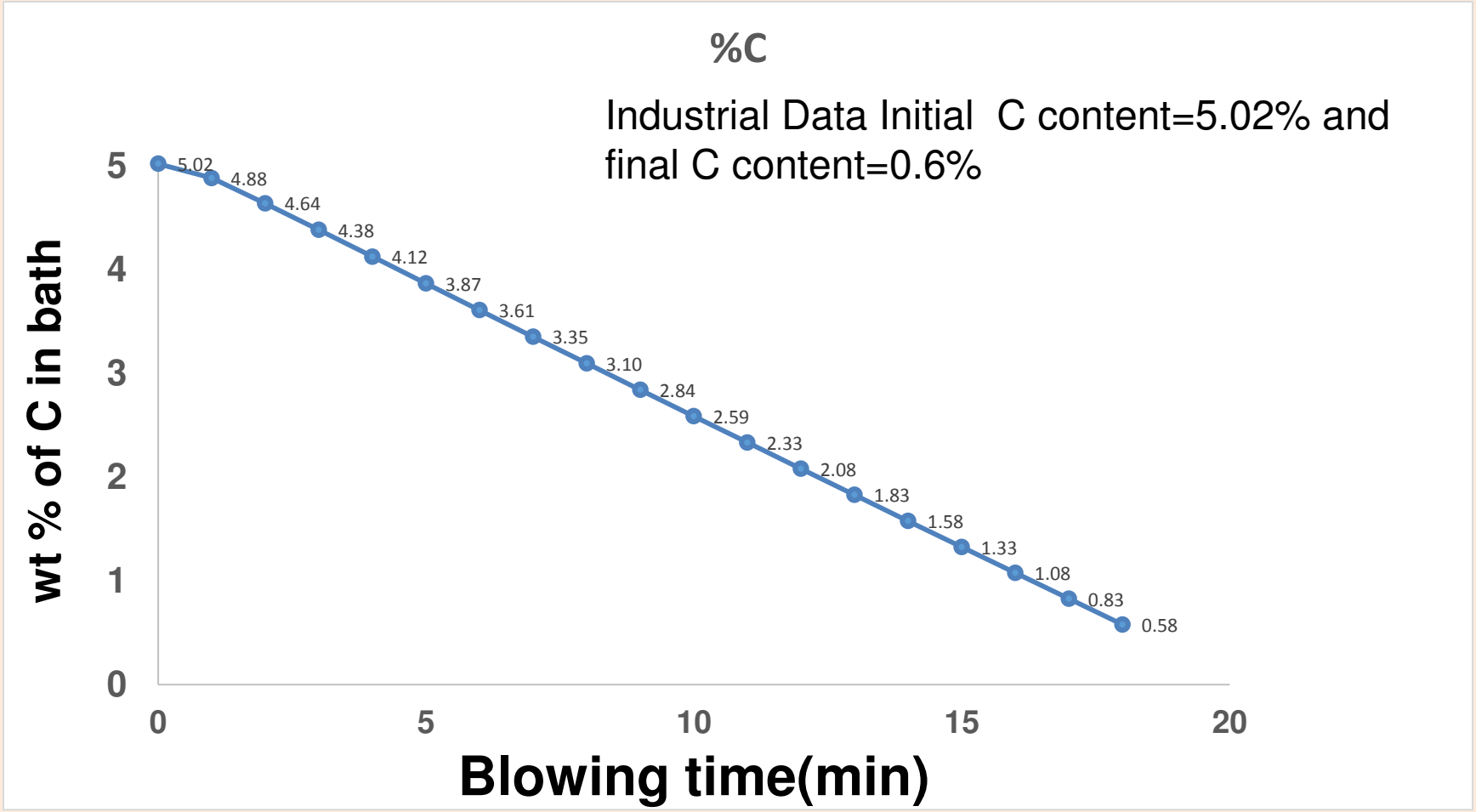
Hot metal	150t
wC	5.02%
wMn	0.7%
wSi	0.59%
wS	0.037%
wFe	89.309%
wP	0.96%

Scrap	20t
wC	0.11%
wMn	0.36%
wSi	0.021%
wS	0.022%
wFe	99.487%

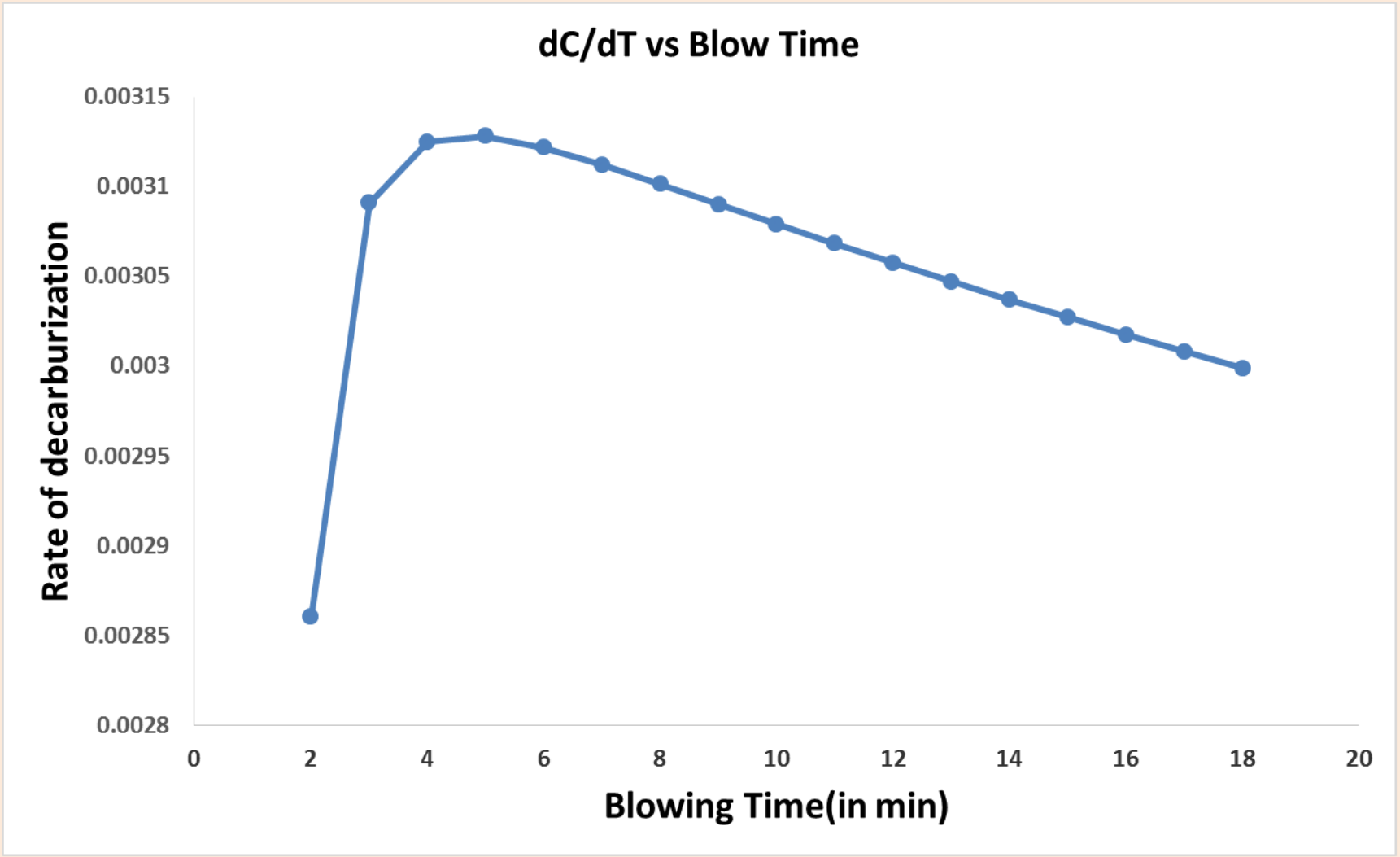
LIMESTONE DETAILS	
MASS	7.6t
wCaO	93.5%
wSiO2	1.5%
wS	0.27%

DOLOLIME DETAILS	
MASS	2.8t
wMgO	40.5%
wCaO	58%
wSiO2	0.85%
wS	0.25%

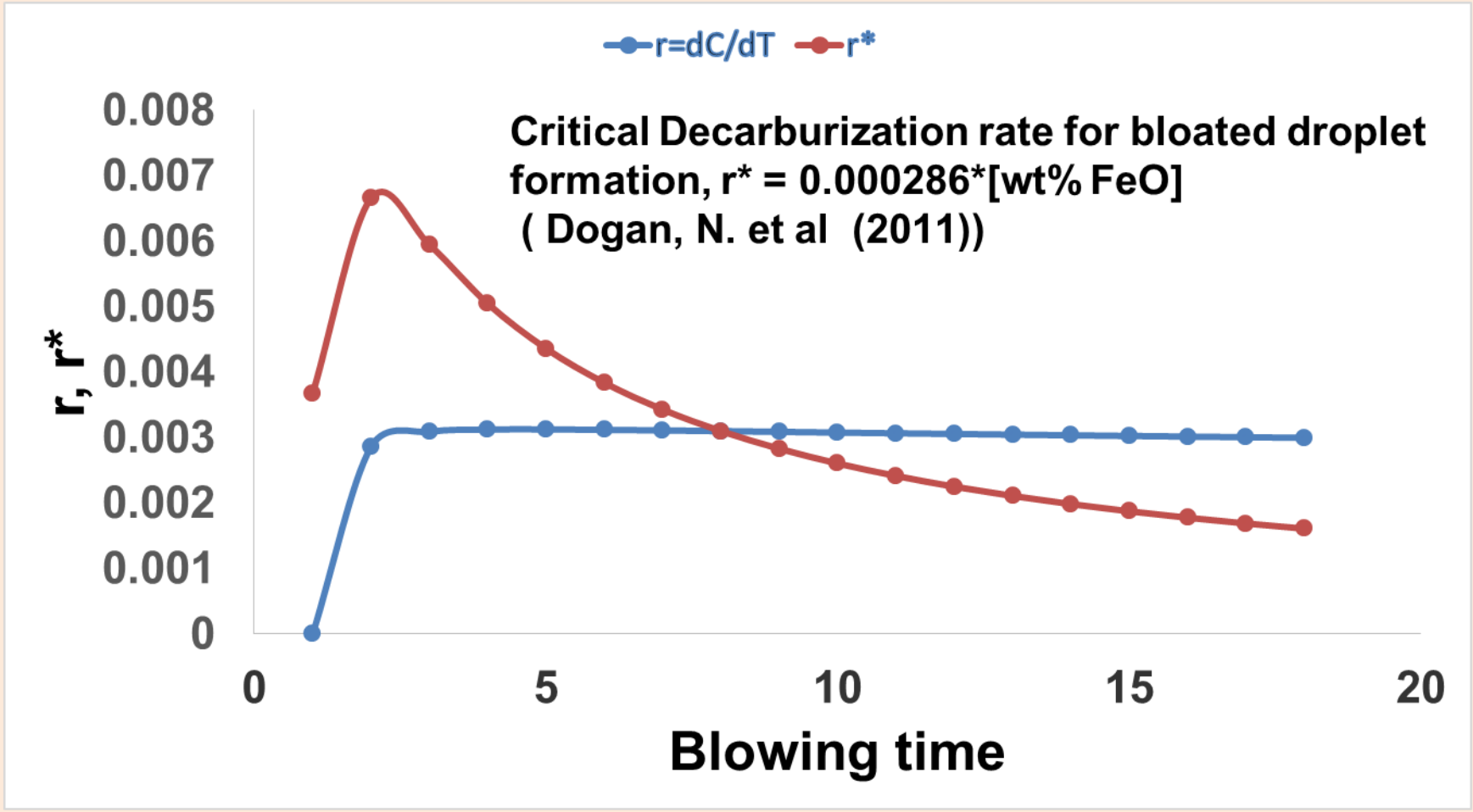
Variation of carbon percentage as per plant data



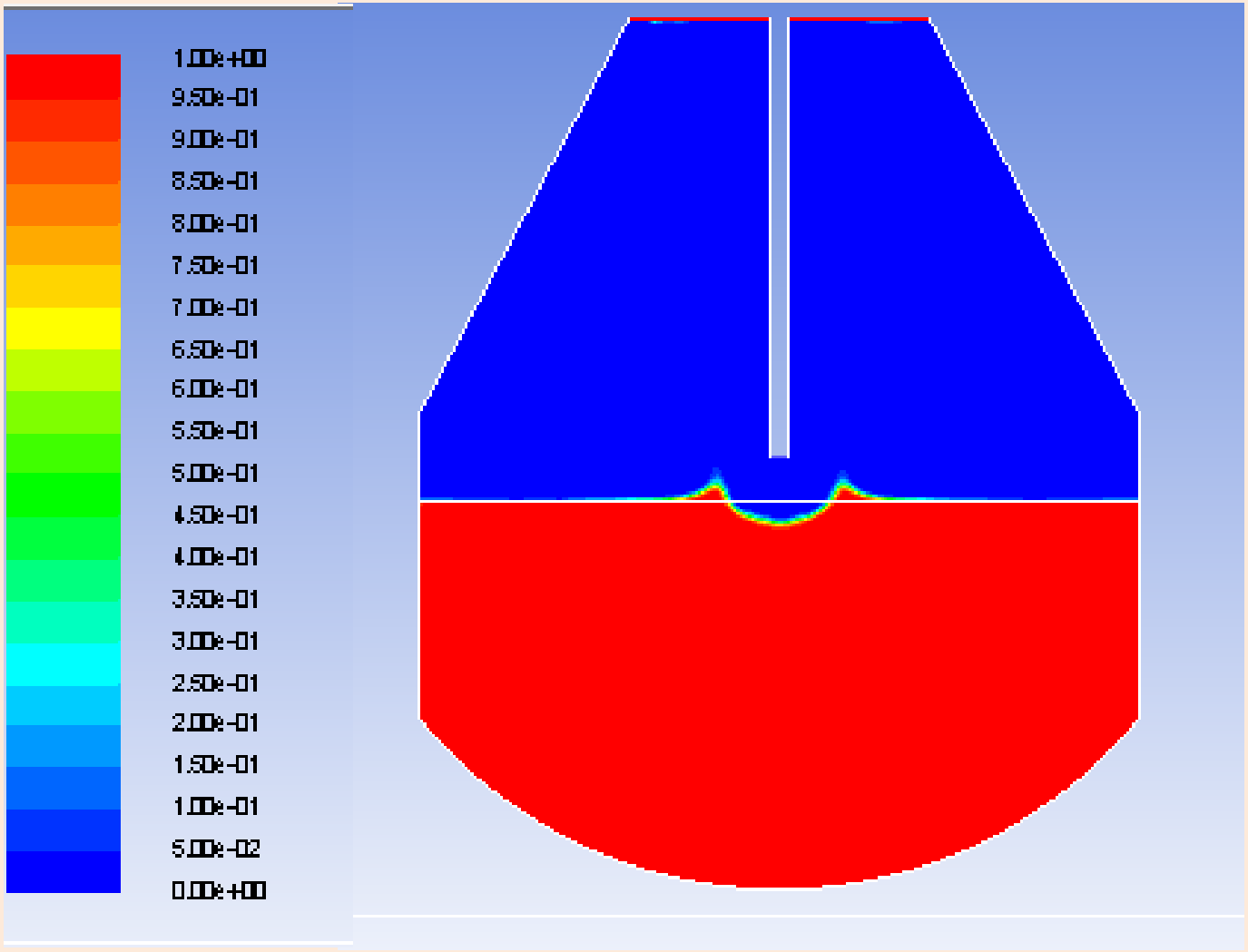
Variations of Decarburization during blowing period



Prediction the time for formation of bloated droplet

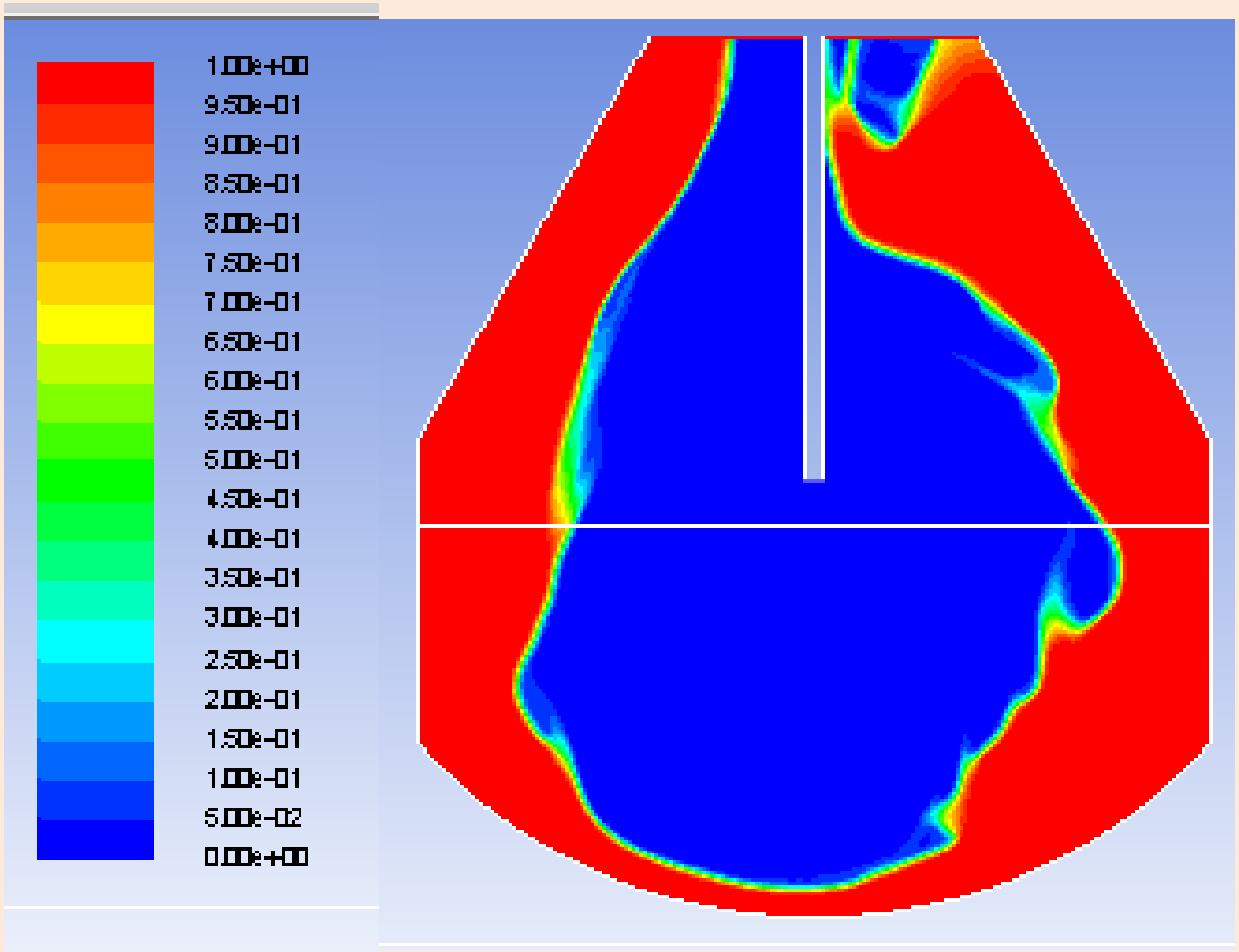


Contours of volume fraction of metal slag mixture (80% hot metal and 20 % slag) After 1.1 sec)

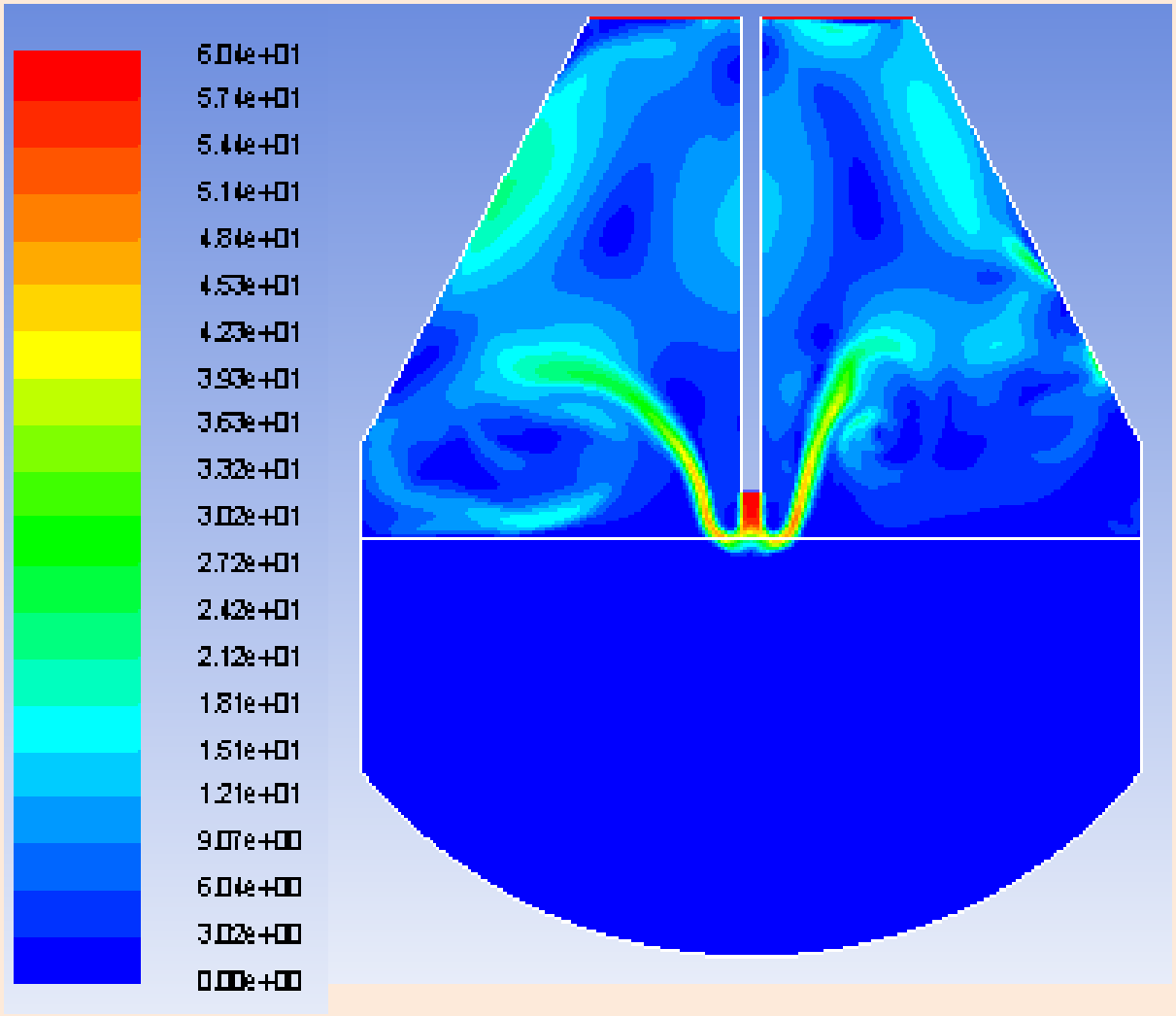


Oxygen flow rate=620m3/min, Capacity = 150 tonne

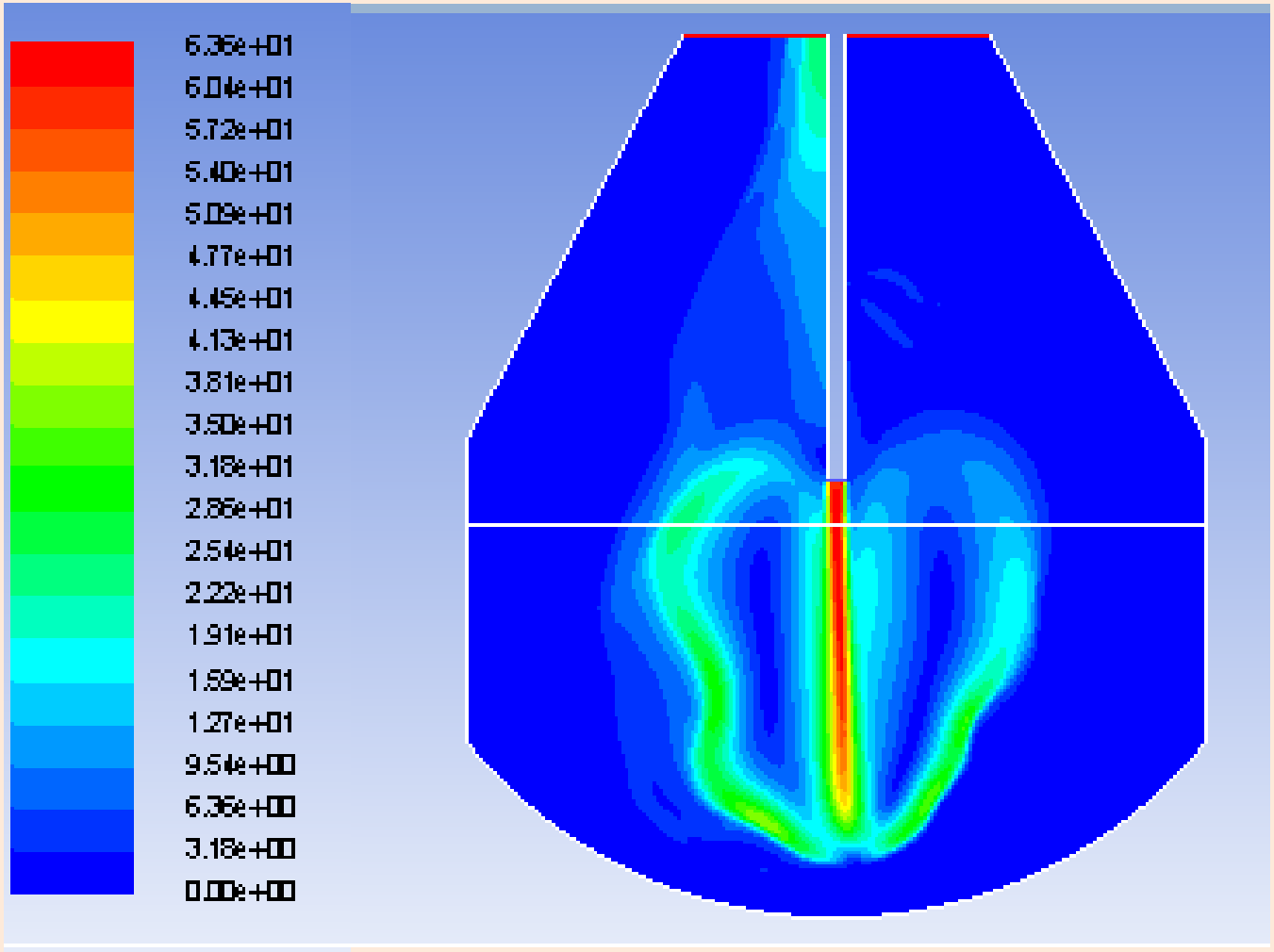
Contours of volume fraction of metal slag mixture (80% hot metal and 20 % slag) After 24 sec



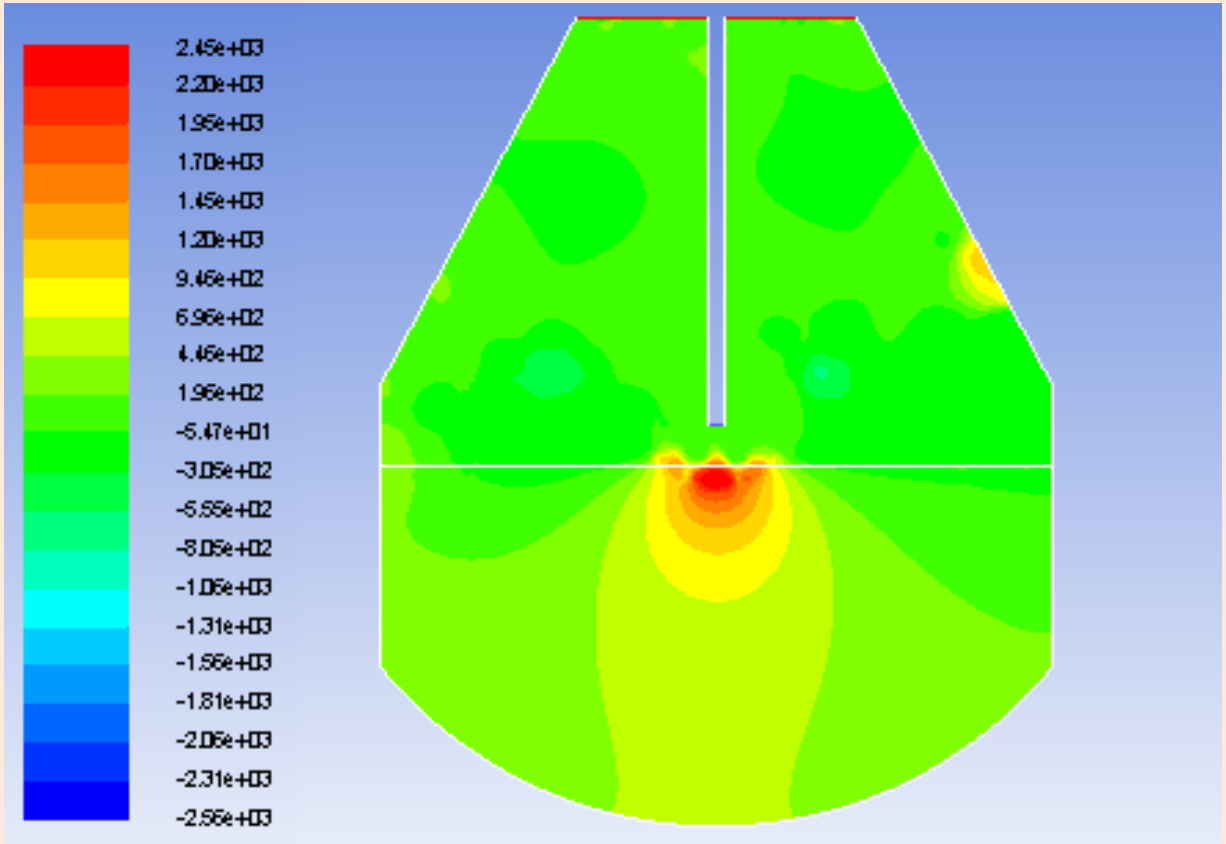
Contours of velocity magnitude after 1.1 sec



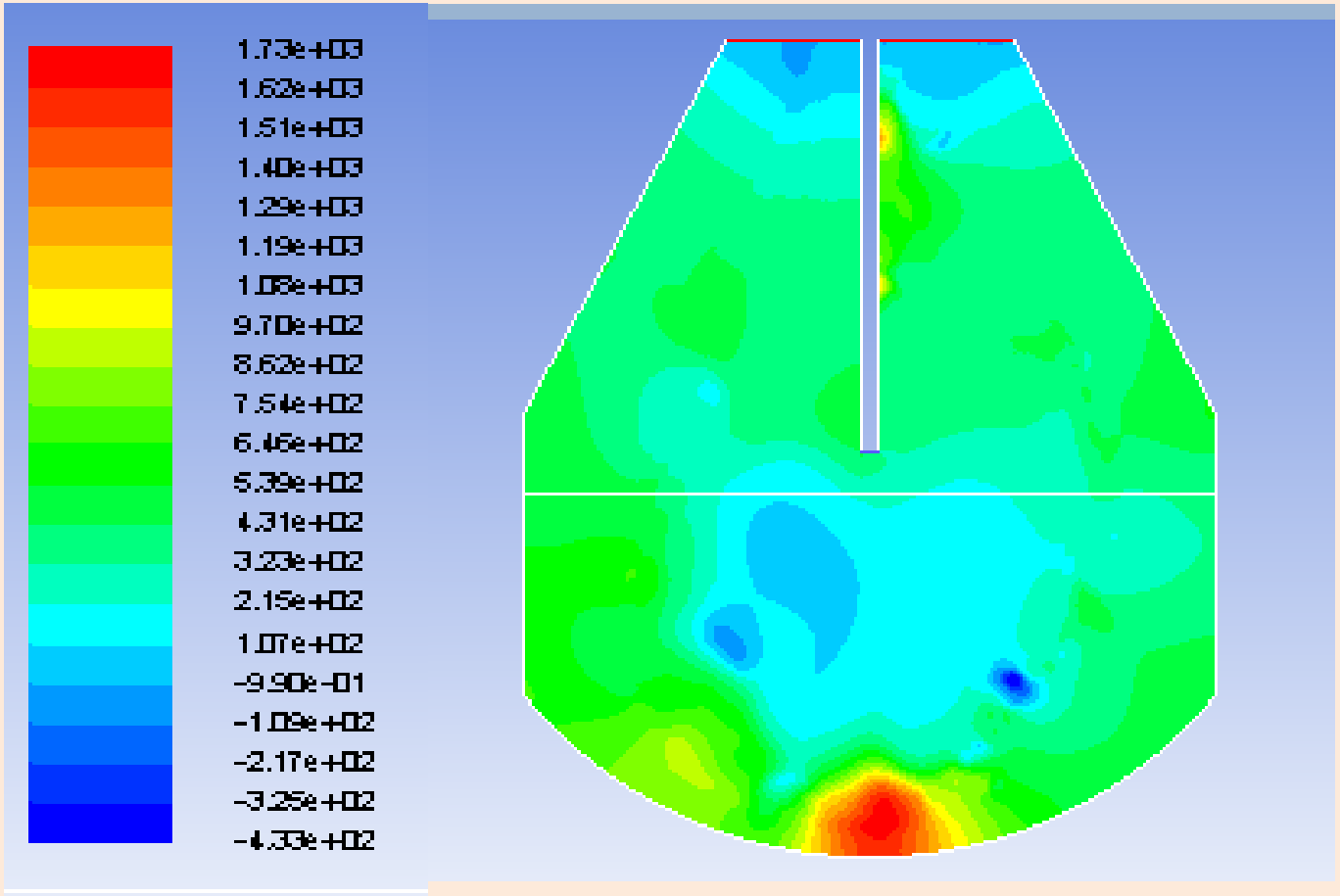
Contours of velocity magnitude after 24 sec



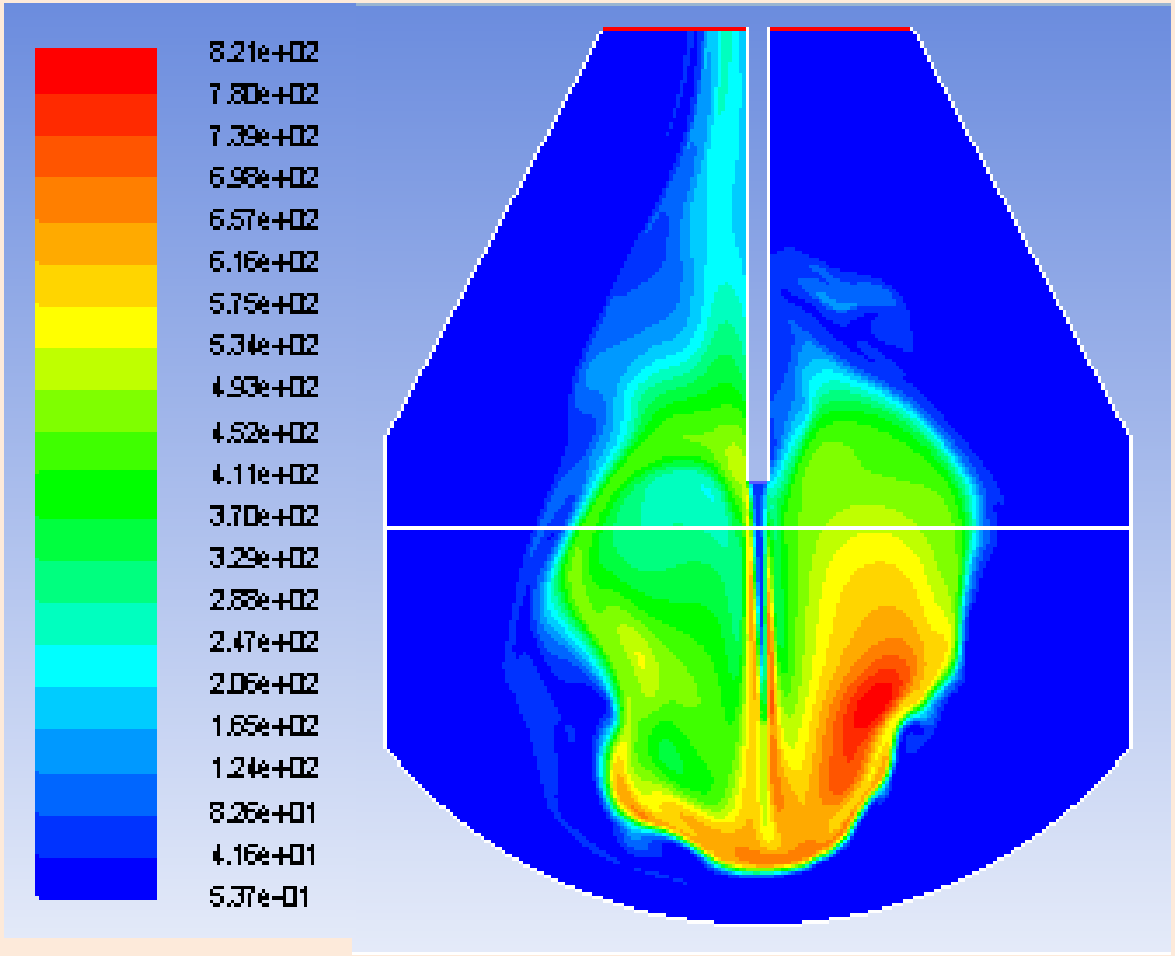
Contours of dynamic pressure after 1.1 sec



Contours of dynamic pressure after 24 sec



Contours of turbulent intensity after 24 sec



Conclusions

1. This Thermodynamic and CFD based model of BOS process predict

- **decarburization process reasonably well.**
- **But removal process of other impurities (e.g. Si, P, Mn) are predicted less accurately** → to overcome this limitation more detail considerations of emulsification and different kinetic factors are needed to be done.

2. Based on calculated decarburization rate prediction of slopping starting time is around 8 min 24 sec for the specific conditions and input data used.

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