A Transient And Highly Resolving Multiphase Approach For Blast Furnaces Based On The XDEM Technology

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Understanding multiphase flow with its complex transfer mechanism of mass, momentum and heat between individual phases is of critical importance for design, operation and meeting environmental challenges. A blast furnace is a key reactor in the steel making industry and consumes large amounts of energy and produces app 70 % of the CO_2 emissions of a steel plant. Thus, small improvements can have a large impact on production costs and the carbon footprint. In order to support improvements, a novel and innovative numerical approach based on the Extended Discrete Element Method (XDEM) [1] is applied to resolve the complex physics and phase interactions in a blast furnace. For this purpose, independently developed functionality of XDEM [2,3,4] has been integrated into a global modelling approach for the first time to treat the complex physics of a blast furnace. While the particulate phase i.e. coke and ore particles are treated as discrete entities, the gas and liquid phases i.e. liquid iron and slag are described by a multiphase Euler approach. The classical Discrete Element Method (DEM) predicts the descend of particles in the blast furnace and the solution differential conservation equations yields the thermodynamic state of each particle such as coke oxidation, drying, reduction and melting of ore particles. This accompanied by an intensive exchange of momentum, energy and mass between the discrete and continuum phases. An exchange of momentum e.g. drag force describes the flow resistance for the fluid phases and generates an according pressure drop over the height of the blast furnace. Heat transfer between the particles and mainly the gas phase and to a lesser extend with the liquid phases causes the coke and iron particle to heat up of the temperature is then the driving force for chemical reactions. The latter are reactions that form CO ($C+1/2\ O_2 \rightarrow CO$) as a reducing agent through oxidation of coke and though the Boudouard equilibrium ($C+ CO_2 \leftrightarrow 2\ CO$). The corresponding reaction rates rely heavily on the mass transfer of oxygen and carbon dioxide between the particles and the gas phase. Carbon monoxide transferred to the ore particles causes a reduction of the iron oxides according to:

$$3\ Fe_2O_3 + CO \rightarrow 2\ Fe_3O_4 + CO_2$$
$$Fe_3O_4 + 3\ CO \leftrightarrow 3\ FeO + CO_2$$
$$FeO + CO \leftrightarrow Fe + CO_2$$

Once, the ore particles reach the melting temperature of iron and slag, both constituents start melting and the formed liquid phases are transferred to the appropriate continuum phases of the Euler framework that is shown in fig. 1. The results agree well with blast furnace operation and promise to shed light on the internal physics of a blast furnace in particular and similar reactors in general.

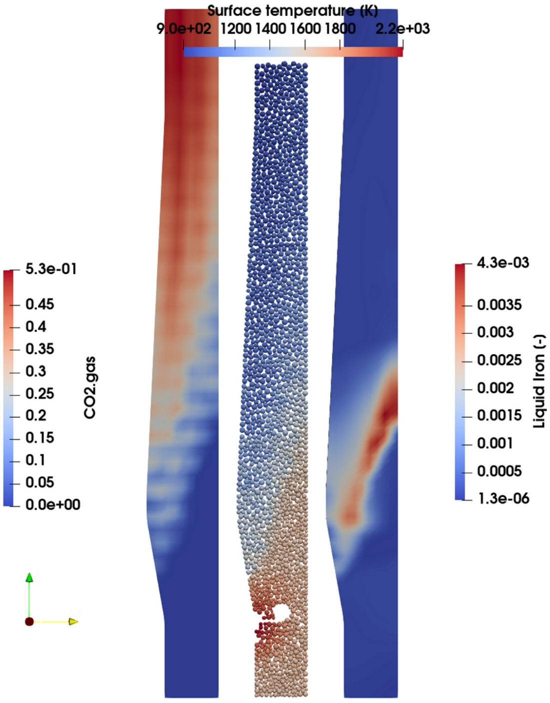

Figure 1: An unprecedented insight into the complex physics of a blast furnace physics: The left figure depicts the layered distribution of carbon monoxide resulting from the reduction of iron oxide. The centre figure shows the surface temperature of each individual particle that supplies energy for the coke particles to produce carbon monoxide as a reducing agent, to reduce iron oxides with the formed carbon monoxide and to melt reduced iron and slag. The latter are transferred to the multi-phase CFD solver and appear as volume fractions depicted in the right figure and identifying uniquely the location of the cohesive zone.

[1] B. Peters, M. Baniasadi, M. Baniasadi, The eXtented Discrete Element Method (XDEM): An Advanced Approach to Model Blast Furnace, ISBN 978-953-51-5824-0.

[2] M. Baniasadi, B. Peters, Preliminary Investigation on the Capability of eXtended Discrete Element Method for Treating the Dripping Zone of a Blast Furnace, *ISIJ international*, 58 (2018), 25-48.

[3] Mehdi Baniasadi, Maryam Baniasadi, Gabriele Pozzetti, and Bernhard Peters. A numerical study on the softening process of iron ore particles in the cohesive zone of an experimental blast furnace using a coupled cfd-dem method. Chemical Engineering Science , 2018

[4] Mehdi Baniasadi, Maryam Baniasadi, and Bernhard Peters. Simulation of the softening and melting behaviours of several layers of iron ore particles through a multiphase cfd-dem approach. Chemical Engineering Science , 2018