INTERACTIONS BETWEEN FREEZE LINING AND SLAG BATH IN ILMENITE SMELTING

by

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To my Father in Heaven, who created it all, made this work possible and gave me the ability and strength to carry it through. I give to Thee all the glory, all the honour, and all the praise.

To Ennes, a wonderful father and friend. I am privileged to have shared but a small part of your life. The example you set changed me, and will keep doing so until we meet again.

ABSTRACT

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IN ILMENITE SMELTING

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Key words:
Ilmenite smelting, mathematical modelling, process modelling, heat transfer, DC furnace, freeze lining, slag bath, titania slag.

This study focused on the dynamic behaviour of the freeze lining and slag bath, and the interactions between these components in an ilmenite-smelting furnace process. The purpose of the work was to gain a better understanding of these issues and to ultimately contribute to an improved understanding of the ilmenite-smelting process in its entirety, and to future improvements in the design, operation and control of these processes.

A mathematical model of the freeze lining and furnace sidewall was developed. This model was used in isolation for focused characterisation of the dynamic behaviour and interactions of the freeze lining and slag bath. The influences of net power input and slag composition were studied and various aspects of the freeze lining and slag bath were considered. These aspects included freeze lining thickness, temperature distribution through the freeze lining and furnace sidewall, composition distribution through the freeze lining, slag bath temperature and slag bath composition. The thermal response of thermocouples installed in the furnace sidewall to changing conditions on the inside of the furnace was also investigated.

A mathematical model of the crust that forms on the slag bath surface was developed. This model was not used in isolation, and was only incorporated into a complete model of the process.

A mathematical model of the entire ilmenite-smelting furnace process was constructed. This model incorporated the two models mentioned above and was able to describe the metal bath, slag bath, furnace atmosphere, freeze lining, furnace sidewall and the crust that is sometimes present on top of the slag bath. The model was used to study the influence of changes in operational parameters on the slag bath and freeze lining. The operational parameters that were studied included electrical power and reductant feed rate, both relative to ilmenite feed rate. The influence of severe operational errors and furnace down time were also investigated. Operational errors included loss of all feed while maintain electrical power input, and loss of reductant feed while maintaining power input and ilmenite feed.

The above-mentioned studies were conducted by executing numerous experiments with two of the mathematical models. The experimental results were processed into sets of graphs displaying variations in the aspects that were considered. Many valuable insights resulted from the interpretation of these results.

One specific aspect that formed part of the scope of this work was the origin of the compositional invariance of the slag close to the stoichiometric M_3O_5 composition. This invariance was studied and a mechanism was proposed that explains the observed behaviour. The proposed mechanism created some questions about other mechanisms in the process. These mechanisms were also considered and elaborated on.

The models and results produced in this study provide valuable insights into the behaviour of the ilmenite-smelting process. It also represents a useful foundation for future modelling work, and finally, it presents numerous opportunities for organisations operating ilmenite-smelting furnaces to improve their understanding and even the performance of their processes.

SAMEVATTING

INTERAKSIES TUSSEN VRIESVOERING EN SLAKBAD IN ILMENIETSMELTING

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Sleutelwoorde:
Ilmenietsmelting, wiskundige modellering, prosesmodellering, hitteoordrag, DC oond, vriesvoering, slakbad, titania slak.

Hierdie studie het gefokus op die dinamiese gedrag van die vriesvoering en slakbad en op die interaksies tussen hierdie komponente van ‘n ilmenietsmeltproses. Die oogmerk van die werk was om ‘n beter begrip van hierdie sake te verkry en om by te dra tot ‘n breër begrip van die ilmenitesmeltproses in sy geheel, en tot toekomstige verbeteringe in die ontwerp, bedryf en beheer van hierdie prosesse.

‘n Wiskundige model van die vriesvoering en die oondmuur is ontwikkel. Hierdie model is in isolasie gebruik om die dinamiese gedrag en interaksies van die vriesvoering en slakbad gefokus te karakteriseer. Die invloede van netto kraginset en slaksamestelling is bestudeer en verskeie aspekte van die vriesvoering en slakbad is beskou. Hierdie aspekte het vriesvoeringdikte, temperatuurverspreiding deur die vriesvoering en oondmuur, samestellingverspreiding deur die vriesvoering, slakbad temperatuur en slakbad samestelling ingesluit. Die termiese reaksie van termokoppels in die oondmuur op veranderende toestande in die oond is ook ondersoek.

‘n Wiskundige model van die kors wat op die slakbad oppervlak vorm is ontwikkel. Hierdie model is nie in isolasie gebruik nie. Dit is slegs ingesluit as deel van ‘n groter model wat die proses in sy geheel beskryf het.

‘n Wiskundige model van die totale ilmenietsmeltproses is ontwikkel. Hierdie model het die twee bogenoemde modelle ingesluit en kon die metaalbad, slakbad, oondatmosfeer, vriesvoering, oondmuur en die kors, wat van tyd tot tyd op die slakbad teenwoordig, is beskryf. Die model is gebruik om die inlvloed van veranderinge in bedryfsparameters op die slakbad en vriesvoering te ondersoek. Die bedryfsparameters het elektriese kraginset en reduktant voertempo ingesluit, beide relatief tot ilmeniet voertempo. Die invloed van ernstige bedryfsfoute en oond aftyd is ook bestudeer. Bedryfsfoute het ingesluit die verlies van alle materaalvoer terwyl elektriese kraginset onveranderd bly, en die verlies van reduktantvoer terwyl elektriese kraginset en ilmenietvoer onveranderd bly.

Die bogenoemde studies het die uitvoering van talryke eksperimente met twee van die wiskundige modelle behels. Die eksperimentele resultate is verwerk to ‘n stel grafieke vir elke eksperiment wat variasies in die aspekte wat beskou is aantoon. Die interpretasie van hierdie resultate het gelei tot waardevolle insig.

'n Spesifieke saak wat deel was van die bestek van hierdie werk was die oorsprong van die onveranderlikheid van die slaksamestelliing naby die M_3O_5 samestelling. Hierdie onveranderlikheid is ondersoek en 'n meganisme is voorgestel wat die waargenome gedrag verklaar. Die voorgestelde meganisme het vrae laat ontstaan oor ander meganismes in die proses. Hierdie meganismes is ook beskou en bespreek.

Die modelle en resultate wat voortgevloei het uit hierdie studie gee waardevolle nuwe insig in die gedrag van die ilmenietsmeltproses. Dit verskaf ook 'n nuttige platvorm vir toekomstige modelleringswerk, en skep talryke geleenheide vir organisasies wat ilmenietsmelters bedryf om hul begrip van die prosesse en selfs die prestasie van die hul prosesse te verbeter.

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