Flow of Molten Slag through Coke Channels

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In the lower zone of the ironmaking blast furnace, liquid iron and slag descend counter-current to reducing gases through a packed bed of coke. The characteristics of the flow of these liquids and their holdup influence product quality and furnace operation. The present study aimed to establish the criteria for the passage of slag through the narrow pore necks that form between coke particles. The flow of slag through coke pore necks has been simulated using an experimental technique that assesses slag flow from a funnel entering a narrow channel of known diameter. Synthetic coke was mainly used to minimise experimental uncertainty associated with the use of variable industrial coke and to allow control of the coke mineralogy. Industrial coke and graphite were also tested. Pellets of slag with compositions in the CaO–SiO2–MgO–Al2O3 system were melted in the coke funnels and heated to 1500°C under argon, then held at temperature for a certain time. After cooling, the passage of slag through the channel was determined and the interactions of the slag and coke were characterized. Variables assessed included slag composition, coke mineralogy and channel diameter.

For the slags and cokes studied, the minimum channel diameter that allowed slag to flow was between 4.4 and 5.0 mm. For smaller diameters, slag did not flow through the channel. The flow mechanism was discussed in terms of a simple gravity and capillary/interfacial force analysis of the system.

KEY WORDS: blast furnace; dripping zone; coke; slag; liquid flow; holdup; capillary.

1. Introduction

Coke is the primary solid material in the lower zone of the blast furnace. It is also the principal source of fuel for the furnace and provides mechanical support for the burden above it. The lower zone of the blast furnace (between the cohesive zone and hearth) is often approximated to a packed bed with liquids and gases flowing through it.1) The fundamental characteristics of the liquid flows in this area are not fully understood, but influence the product quality, production rate, fuel use and asset life of the process. Therefore, fundamental studies of liquid flows in a packed bed and the channels developed between packed coke particles are important and should offer insights into blast furnace performance and operation.

In a coke packed bed, the voids (pores) formed between coke particles are generally interconnected. This interconnectivity and the pore neck size have a significant bearing on the path of a liquid flowing through the bed (illustrated in Fig. 1) and possible sites of liquid blockage.2) Cold model experimental studies of liquid flow in a packed bed1–13) have demonstrated the discrete liquid flows, as represented in Fig. 1. Fukutake et al.3) analysed these flows and characterized the forces acting on them. Equations (1) to (6), representing these forces, are given below.

\[ f_g = \rho g D^3 \]  
\[ f_i = \rho \frac{u^2}{2} D^3 \]  
\[ f_v = \mu D \frac{u^2}{2} \]  
\[ f_s = \sigma D \]  
\[ f_{ii} = \rho D (1 + \cos \theta) \]  
\[ f_p = \frac{(\Delta P \Delta A)}{D^3} \]

where, \( \rho \) is liquid density in kg/m³, \( u \) is liquid velocity in...
m/s, \( D \) is the characteristic length or liquid droplet diameter in m, \( g \) is gravitational acceleration in m/s\(^2\), \( \mu \) is liquid viscosity in Pa·s, \( \sigma \) is liquid surface tension in N/m, \( \theta \) is liquid contact angle with the bed material in degrees, and \( \Delta P/\Delta l \) is pressure drop in Pa across a bed of length \( l \) in m.

Forces 1 to 5 are related to liquid properties, interfacial properties with bed material and liquid velocity. Force 6, the gas drag force, is based on the Ergun formula used in calculating the pressure drop in packed beds. Combinations of these forces have been used to develop dimensional analysis approaches to define operational liquid holdup in a blast furnace based on the cold model studies.

There are few high temperature (1 400 to 1 600°C) experimental studies on liquid flow through a packed bed in the literature.\(^{14-17}\) These studies were focused on relating coke bed packing properties to liquid (slag or iron) holdup in the bed. Results showed that the static liquid holdup, that is the volume fraction of liquid that remains in the bed after the liquid supply has stopped, increases when smaller coke particles are used to pack the bed, leading to more contact points and smaller pore neck sizes. It was also found that beds packed with coke particles under a certain size range could completely block the flow of liquid slag or molten iron. The reported lower limits of coke particle sizes were 8.0–10.0 mm and 4.0–6.0 mm for liquid slag and liquid iron, respectively.\(^{16,17}\)

A significant problem in any high temperature laboratory study involving the use of metallurgical coke is dealing with the difficulties caused by its material complexity (minerals, macerals and porosity) and its heterogeneity with respect to its mineral and maceral composition, distribution and morphology, and physical characteristics such as bulk density and porosity. This complexity and heterogeneity often makes it difficult to assess the effect of an individual component or variable of the coke on key behaviour such as coke reactivity, wetting characteristics, strength or many other phenomena that may be of interest. Recent attempts to minimise the effects of coke complexity and heterogeneity have resulted in the development of a coke analogue.\(^{18,19}\) This analogue has a simplified carbon structure and controlled porosity, mineralogy and mineral phase dispersion. This material offers new possibilities in the study of coke behaviour.

The focus of the investigation presented in this paper relates specifically to assessing/quantifying the critical pore neck size in a packed bed below which no flow will occur. Pore neck size has been approximated to the diameter of a cylindrical channel through a coke particle. In this paper, results of the flow of molten slag through this coke channel are presented and discussed.

2. Experimental

An experimental setup has been developed to simulate the flow of slag through the inter-particle voids of a coke bed and to test the effect of slag characteristics and interfacial properties with coke on the flowability through pore necks. The concept was to investigate the minimum channel diameter allowing for the free vertical flow of slag of a known mass. In this experiment, slag was melted in a funnel machined out of coke, coke analogue or graphite, which had an exit channel of a known mass. The channel was of a fixed length (7 mm) and the channel diameter was controlled. This channel approximates to the inter-particle pore neck of a coke bed. The funnel and slag were heated to 1 500°C in a high purity argon atmosphere in a resistance furnace (see Fig. 2(b)). The sample (funnel and slag) was held at this temperature for 30 minutes then cooled to room temperature at 5°C/min. Once cooled, the sample was removed for inspection. The extent of slag flow into or through the channel, and any interaction/reaction the slag had with the particle, were characterized using optical and electro-optical techniques.

This procedure was carried out for a number of slag and coke compositions over a range of channel diameters. The slag compositions are given in Table 1. The compositions of slags A-E were primarily chosen to be representative of slags in the lower zone of the blast furnace, but also to test the effects of changing the interfacial properties of the slag.
on the flow characteristics. FeO was excluded from the slag to limit reactions with the funnel and simplify the system studied. The density and surface tensions of the slags given in Table 1 were calculated using the National Physical Laboratory slag model. Different mineral types and mass fractions of the mineral component of the coke analogue funnel were tested to assess their effects on flow. Graphite and an industrial coke were also assessed for comparison and to aid analysis. Details of the funnel materials used are given in Table 2.

The CAx minerals added to the analogue were based on what was found in previous investigations of reacted feed cokes used at BlueScope Steel and are likely to exist in the lower zone of a blast furnace.

The mineral material in MM represents a simplified mineralogy based on the major components found in the industrial coke. They were added in the form of quartz (SiO₂), mullite (2SiO₂·3Al₂O₃) and lime (CaO). These compounds were added to achieve a nominal overall mineral matter composition of SiO₂ 58%, Al₂O₃ 37% and CaO 5% in the analogue.

The mineral mass percentage levels of 4.4 and 12% in the coke analogues represent the fraction left in the coke if all the SiO₂ has been reacted out, and the original mass fraction of the mineral component of the industrial coke, respectively.

A limited set of experiments were carried out to assess the time dependency of the flow and wetting characteristics of the slag-coke analogue system. These were carried out in a horizontal furnace under similar gas and temperature conditions to the dripping experiments. The horizontal furnace was used in two modes.

1- To observe when the slag flowed through the funnel channel, the sample system shown in Fig. 2(a) was placed on elevated alumina blocks that allowed direct viewing of the liquid flowing out of the channel. The funnel and alumina blocks replaced the substrate and slag drop shown in the furnace schematic given in Fig. 3. A Sony 6.1 MP high definition video camera (HDR-SR7E) was used to record any slag flowing out of the funnel channel. The time at which the slag flowed out of the channel was noted. The materials used were Slag C on a coke analogue MM (12 mass%) funnel with a 4 mm channel diameter.

2- To assess the change of wetting/interfacial characteristics with time. The slag/funnel material system was tested under a sessile drop configuration, a schematic of which is shown in Fig. 3, and the wetting angle was measured with time. Full details of the technique are given elsewhere.23) The materials used were Slag C on both a coke analogue MM (12 mass%) and a BSL coke substrate. These substrates were polished to a 1 μm finish. A 0.1 g slag drop was used to minimize the gravity distortion of the droplet. This value was established based on the method recommended by Eustathopoulos.24) No attempt was made to assess surface roughness effects or repeatability therefore the wetting angle measurements should only be considered semi-quantitative and are reported as apparent wetting angles. Further, these materials have inherent differences in porosity, making direct comparison of the wetting measurements problematic.

Table 1. Composition, surface tension and density of slags used.

| Slag | Slag composition in Mass pct | CaO | SiO₂ | Al₂O₃ | MgO | Surface tension σ,20) N.m⁻¹ | Density ρ,20) kg/m³ |
|------|-----------------------------|-----|------|-------|-----|-----------------------------|---------------------|
| A    | 46.7 31.0 12.9 8.5          | 1.5 | 0.517| 2.697 |
| B    | 44.0 34.5 12.2 8.8          | 1.3 | 0.504| 2.686 |
| C    | 40.7 37.4 12.5 8.8          | 1.1 | 0.493| 2.675 |
| D    | 34.3 43.3 12.8 8.4          | 0.8 | 0.469| 2.675 |
| E    | 10.1 67.0 20.6 0.3          | 0.2 | 0.358| 2.646 |

Table 2. Funnel materials used and their mineral components.

| Coke type | Funnel material identifier | Mineral type or mineral composition | Minerals Mass% |
|-----------|---------------------------|-------------------------------------|----------------|
| Coke analogue | No minerals | No minerals | 0.0 |
| CA1       | (CaO·Al₂O₃)              |                                      | 4.4 |
| CA2       | (CaO·2Al₂O₃)             |                                      | 4.4 |
| CA6       | (CaO·6Al₂O₃)             |                                      | 4.4 |
| MM        | SiO₂ 58%, Al₂O₃ 37%, CaO 5% |                                    | 12 |
| Feed coke* | Feed coke | Mineral matter* |                                      | 12 |
| Graphite  | Graphite | No minerals | 0.0 |

*Industrial coke was provided by BlueScope Steel Limited (BSL) and analysed in a previous study.18,19,21) 96.5% of its mineral component was made up of cristobalite, quartz, mullite, fluorapatite and an amorphous phase containing SiO₂ and Al₂O₃.
2.1. Materials Preparation

Synthetic slag was prepared by mixing appropriate amounts of laboratory grade reagents to produce the slags of composition listed in Table 1. The reported slag compositions were confirmed by XRF analysis. For slags A-D, the mixture was melted, quenched, crushed and pressed into pellets of a nominal 1.42 g. These pellets were then sintered at 800°C for 2 hours. Slag E, was pelletised and sintered at 1000°C for 4 hours, then crushed and pelletised in 1.42 g pellets and sintered at 1000°C for another 4 hours.

The coke analogue used to make the funnel was prepared using laboratory grade crystalline and amorphous carbon forms mixed with the required weight percentage of mineral matter using a carbonaceous binding material, then pressed and fired. Full details of the coke analogue preparation procedure can be found elsewhere.18,19) Coke funnels were machined to the dimensions shown in Fig. 2(a), and then exit channels were drilled to the required diameters. The channel diameters were established by optical microscopy. The range of channel diameters tested was from 1.5 mm, rising (in approximately 0.5 mm increments) to a maximum value of 5.0 mm. For the wettability assessment using sessile drop technique, pieces of the slag pellets were cut to a weight of 0.1±0.01 g to form the slag droplets.

3. Results and Discussion

3.1. Minimum Channel Diameter to Allow Slag Flow

For the slags and cokes used, the minimum channel diameter that allowed slag flow was either 4.4 mm or 5.0 mm as presented in Table 3. In the cases of channel diameters less than these values, the slag did not flow out the channel. Some of the experimental runs were repeated 2 or 3 times and the minimum channel diameters were confirmed. In a number of cases, although the slag did not flow through the funnel channel it did enter into the channel. No correlation was found between the depth the slag penetrated the channel and the coke ash or slag composition.

The minimum channel diameters that allowed slag flow were in agreement with the observations of Husslage who found that similar slags were blocked when passing through coke beds with average pore neck size below 5.38 mm.16)

Figure 4 shows a photograph of a typical coke funnel after cooling where the slag did not flow through the exit channel, and a photograph of a section through a cooled funnel showing the slag penetration into the channel.

3.2. Simple Force Balance Model

In the current experimental set-up, the six forces described by Fukutake and Rajakumar3) acting on slag flowing through coke particles reduces to two when the slag is stationary and there is negligible gas pressure drop across

![Table 3](image)

| Slag | Coke analogue ash type and (content) | Feed coke | Graphite |
|------|-------------------------------------|-----------|----------|
|      | CA1 (0.0%) CA2 (4.4%) CA6 (4.4%) CA6 (12%) MM (4.4%) MM (12%) | A – – – 5.0 – – – – | – – – – – – |
|      | B 4.4 4.4 – 4.4 – – – – | – – – – – – | – – – – – – |
|      | C 5.0 4.4 4.4 4.4 4.4 4.4 5.0 4.4 4.4 | D – – – 4.4 – – – – | – – – – – – |
|      | E – – – 4.4 – – – – | – – – – – – | – – – – – – |

![Fig. 4](image)

Fig. 4. A photograph (left) and section (right) of a funnel where slag did not flow through the coke channel (Slag B through coke analogue with 4.4 mass pct of CA6, channel diameter 4.0 mm).

![Fig. 5](image)

Fig. 5. Schematic illustration of the simplified force balance acting on statically suspended liquid slag on: (a) Inter-coke particle pore neck, (b) Coke channel entrance.
the channel: the gravitational and solid-liquid interfacial forces. Such a system is analogous to the case of applying Young’s equation\(^{24}\) to the process of infiltration of non-wetting liquids into porous media where the porosity is assumed cylindrical and open\(^{20}\) as given in Eq. (7),

\[
\rho gh = -\frac{4\sigma \cos \theta}{d} \quad \text{(7)}
\]

where \(d\) is the channel diameter, \(h\) is the molten slag head over the channel opening, and other symbols are as defined previously. This equation is based on the force balance between the weight of the liquid slag and the capillary repulsion force between slag and coke as illustrated in Fig. 5 the bigger the channel diameter, the smaller the repulsion force that prevents the slag from flowing through the channel. At a certain channel diameter, the liquid slag hydrostatic pressure overcomes the capillary pressure and the slag enters the channel.

Using Eq. (7), plots of slag head, \(h\), versus channel diameter, \(d\), were developed and are given in Figs. 6(a) and 6(b). Values used for \(\sigma\) and \(\rho\) are those given Table 1. Characteristic values for \(\theta\) from 110 to 140° were used based on those reported in the literature for slags of a similar nature to those in this study on coke and graphite respectively.\(^{16,25}\) Figure 6(a) illustrates the effect of \(\theta\) for a fixed slag composition (slag C). Figure 6(b) illustrates the effect of changing slag composition from A to E for a fixed contact angle of 120°. In the experimental setup used, \(h\) is approximately 10 mm, ranging from 8 to 12 mm. The experimental \(h\) value was calculated from considerations of the slag \(\rho\) and mass and a frustum representing the funnel cone volume. From the conditions detailed in Fig. 6(a), for an \(h\) value of 10 mm it would be expected that the minimum channel diameter for flow would be in the range 2.5 to 5.7 mm. Similarly, for Fig. 6(b) it would be 3 to 4 mm. The minimum channel diameters that allowed the flow of slag measured in this study (Table 3) lie within these ranges and are consistent with the model predictions.

The data presented in Fig. 6 would seem to indicate a stronger effect of changing contact angle (representing that of slag on coke to slag on graphite) than that of changing slag composition for the slags studied.

### 3.3. Effect of Time on Slag Flow through the Channel

The minimum coke channel diameters presented in Table 3 are for runs that were carried out at a fixed dwell time of 30 minutes at temperature. In order to test the effect of time at temperature on the minimum channel diameter, the experiment using Slag C with the coke analogue funnel of 12 mass pct of MM and a channel diameter of 4.0 mm was repeated and held at 1500°C for 90 minutes. This was carried out in a horizontal furnace where the top of the funnel and any flow out of the channel could be directly observed and recorded to video. Selected images taken from this experiment are shown in Fig. 7. At 30 minutes, no flow was observed, consistent with the data in Table 3. At ~60 minutes, a bulb of the liquid slag started to form at the bottom of the channel. At 63 minutes a sudden flow of the slag occurred. It took less than a second for the slag to pass through the channel. It is clear that although static condi-

![Fig. 7](image-url)
tions are assumed in the experiments, there is a small dynamic component to the systems studied. It is likely that this dynamic component is a result of slag-coke analogue reactions changing the flow characteristics of the slag-coke analogue couple.

3.4. Assessment of Slag-Coke Interaction

To investigate the effects of slag-coke reactivity, attempts were made to assess changes in the interface chemistry by carrying out selected dynamic wetting measurements and SEM-EDX analyses of the slag-coke interface. A typical SEM-EDX analysis of Slag C on the coke analogue 12 mass pct MM for 30 minutes is given in Fig. 8.

There has been slag penetration into the surface pores and there would appear to be Si enrichment of the slag at and near the coke-slag interface. Similar SEM-EDX results were obtained for all slag and coke combinations. From the map in Fig. 8, it would appear the Si-rich phase near the slag and coke interface. Spot analysis indicated that the slag surrounding the MgO depleted region was slightly enriched in MgO. This indicates that some partitioning on cooling occurred in the slag.

Further examination of the interface using EDX spot analysis revealed not only a Si-rich phase near the slag-coke interface, but that directly coincident with the interface the SiO₂ equivalent concentrations could be >90 mass% and generally greater than 70%. It is not clear whether this Si enrichment at the interface is the result of a precipitation/segregation effect on cooling of the slag or a reaction with the coke. The majority of the cokes used had no SiO₂ in the ash, indicating that SiO₂ dissolution into the slag from the coke is unlikely to account for this marked increase in Si content at the interface. If slag is reacting with the coke, the most probable reaction is with carbon forming SiC. It is known that SiO₂ in slag can form SiC in reaction as given in Eq. (8).²⁶

\[
\text{SiO}_2(\text{slag}) + 3\text{C}(\text{coke}) = \text{SiC}(s) + 2\text{CO}(g) \quad \ldots (8)
\]

Given the size of this silicon-enriched layer, it was not possible to identify the reaction product. In order to assess what possible phases may have precipitated from the slag as it cooled, a phase stability diagram approximately covering Slags A to D over the temperature range 1 000°C to 1 500°C (1273 K to 1773 K) was calculated using MTDATA²⁷ as shown in Fig. 9. A key for the phases identified in Fig. 9 is given in Table 4. This calculation is for the slag phase only and takes no account of the coke or coke analogue.

MTDATA is a commercial thermodynamic software package developed at the National Physical Laboratory in the UK that is able to calculate complex multi-component phase equilibria in gas-liquid-solid systems. It uses a Gibbs Energy minimization routine to establish the thermodynamic equilibrium of a defined system. The calculations were only undertaken down to 1000°C on the assumption that kinetic limitations would prevent further possible phase evolution of the slags under the prevailing experimental conditions. Of the phases predicted, WOLLASTONITE and PLAGIOCLASE_H are the only ones representing greater than 50 mass% that could be considered silica-rich, with little or no MgO. Neither of these phases would result in SiO₂

![Fig. 8. SEM backscattered image and EDX maps for the interface of Slag C and coke analogue with 12 mass pct MM for 30 minutes.](image-url)
levels of 70% or higher. It is therefore likely that the Si-rich phase formed at the interface is due to reaction between the slag and coke and is SiC.

The (apparent) wetting angle decreased with time for Slag C on both the coke analogue and the BSL coke and the rate of decrease was greater for the analogue than the BSL coke. Early in the experiment, Slag C on the BSL coke and the coke analogue had a wetting angle in excess of 90°, characteristic of a non-wetting system. After 60 minutes, the wetting angle of Slag C on the BSL coke approached 90° and still appeared to be decreasing with time. Over the same time, the wetting angle of Slag C on the coke analogue had dropped to an apparent value of approximately 20°. Values less than 90° are indicative of a wetting system. For quantitative and comparative wetting angle measurements the effects of substrate roughness, surface porosity and experimental repeatability have to be assessed. This has not been attempted in this experimental program. For these reasons, the authors make no claim on the absolute values of the reported wetting angles or the time of transition from non-wetting to wetting but only the dynamic trends observed.

These changes in wetting angle with time are a strong indication of reaction and offer a plausible explanation of why the flow conditions of the slag in the coke funnels may change with time. The change of the slag-coke/coke analogue system from non-wetting to wetting would be expected to draw the slag into the coke funnel channels. This has been observed, and slag has penetrated the coke funnel channels under conditions that prevented slag flowing completely through the channel.

Given the Si enriched layer on the surface of the slag and the changes in wetting angle observed in the slag-coke and coke analogue systems, there is reasonable certainty that a surface reaction is taking place that ultimately is affecting the flow conditions. As shown from Eq. (7), there is a threshold slag level at the entrance of a pore below which the slag remains suspended. Meanwhile, a surface reaction

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**Table 4.** A key of the phase labels given in Fig. 9.

| A | MELILITE + PLAGIOCLASE_H + WOLLASTONITE |
| B | MELILITE + CLINOPYROXENE + PLAGIOCLASE_H + WOLLASTONITE |
| C | LIQUID_OXIDE + MERWINITE + ALPHA_C2S |
| D | LIQUID_OXIDE + MERWINITE |
| E | LIQUID_OXIDE + MELILITE + MERWINITE |
| F | MELILITE + SPINE + MERWINITE |
| G | MELILITE + MERWINITE + BREDIGITE |
| H | MELILITE + MERWINITE + RANKINITE |
| I | MELILITE + PLAGIOCLASE_H + PSEUDO_WOLLASTONITE |
| J | MELILITE + MERWINITE + WOLLASTONITE |
| K | MELILITE + MERWINITE + WOLLASTONITE + RANKINITE |
| L | MELILITE + MERWINITE + BREDIGITE + RANKINITE |
| M | MELILITE + SPINE + MERWINITE + ALPHA_C2S |
| N | MELILITE + MERWINITE + ALPHA PRIME_C2S |
| O | LIQUID_OXIDE + MELILITE + PLAGIOCLASE_H |
| P | LIQUID_OXIDE + MELILITE + PSEUDO_WOLLASTONITE |
| Q | MELILITE + SPINE + MERWINITE + OLIVINE |
| R | MELILITE + BREDIGITE + RANKINITE |
| S | LIQUID_OXIDE + MELILITE + ALPHA PRIME_C2S |
| T | LIQUID_OXIDE + SPINE + MERWINITE + ALPHA_C2S |
| U | LIQUID_OXIDE + MELILITE + SPINE + MERWINITE |
| V | MELILITE + BREDIGITE + ALPHA PRIME_C2S |
| W | MELILITE + ALPHA PRIME_C2S + RANKINITE |
| X | LIQUID_OXIDE + ALPHA_C2S |
| Y | MELILITE + PSEUDO_WOLLASTONITE + RANKINITE |
| Z | MELILITE + WOLLASTONITE + RANKINITE |
| AA | LIQUID_OXIDE + MELILITE + PLAGIOCLASE_H + WOLLASTONITE |
| AB | MELILITE + MERWINITE + OLIVINE |
| AC | LIQUID_OXIDE + MELILITE + MERWINITE + ALPHA_C2S |
| AD | LIQUID_OXIDE + MELILITE + RANKINITE |
takes place increasing the slag/coke wettability to the point that allows flow. Such a flow takes a short time to occur as observed in the prolonged experimental run. For conditions such as these, where a time-related stage is required to pass a threshold in order for flow to occur, and in the case of slag flowing through a packed bed of multiple interconnected pores, an intermittent flow pattern might be expected. This observation is consistent with previous work reported by Husslage[16,17] in hot packed bed experiments where the slag flowed out of the coke bed in rivulets or slugs rather than in a uniform stream of droplets when it was supplied to the bed at a continuous rate.

From the thermodynamic analysis given in Fig. 9, it would appear that Slag A was not 100% liquid at the experimental temperature of 1500°C. MTDATA predicted a slag liquidus of 1650°C and that 24 mass% of the slag would be solid at the experimental temperature. From other observations (micrographs, pouring of slag during slag preparation and the slag funnel experiments) slag A appeared to be fully liquid. If the slag did contain 24% of solid, this would have significantly affected its flow characteristics, resulting in a high (apparent) viscosity. This may explain why Slag A has the largest minimum diameter for flow.

3.5. Effect of Mineral Content of the Coke and Coke Analogue on the Minimum Channel Diameter for Slag Flow

From this study, no obvious effect of the mineral matter content of the coke or coke analogue could be discerned from the results. At this point, it is not clear why. It is reasonable to expect that different ash types and different amounts of ash in the coke or coke analogue would result in different interface conditions between the slag and coke funnel. This in turn should have had an effect on the flow of the slag through the channel. If this were so, the effects appear not to have been discriminated in the current experimental programme. Further work may be required to differentiate these effects.

4. Conclusion

High temperature experiments were carried out to simulate the passage of slag through the pore necks between coke particles in the lower zone of an ironmaking blast furnace. Slag pellets were melted at 1500°C in coke or coke analogue funnels feeding into channels of known diameter. It was determined that there is a minimum channel diameter needed to allow free flow of slag. For the slag/coke systems tested, the minimum channel diameter ranged between 4.4 and 5.0 mm. The results were in good agreement with previously reported figures of pore neck diameter that led to blockage of similar liquid slags in coke beds. A simple force analysis based on gravity and interfacial forces, where the slag surface tension and wettability play a dominant role in the resistance to slag flow through the channel, was found to adequately describe the system. Separately, the flow pattern showed time dependency that was explained in light of the time-dependent interfacial properties between the slag and coke tested. A description of the slag slug-flow pattern though the coke was given in view of the analysis of the forces acting on the liquid phase and the time dependent interfacial properties. This approach could form the basis of a predictive model for establishing flow conditions through a coke packed bed subject to further characterisation of the influence of coke and slag properties.

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