The Formation and Breakup of Molten Oxide Jets Under Periodic Excitation

Mirco Wegener, Luckman Muhmood, Shouyi Sun, and Alex V. Deev
CSIRO Process Science and Engineering, Box 312 Clayton South, Victoria 3169, Australia

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The experiments on the capillary breakup of slag jets at high temperatures are presented in this article. The impact of external excitations on the disintegration process was investigated in a furnace with optical access filmed at frame rates up to 10,000 fps. A synthetic calcia-alumina slag was used to form jets at different temperatures (1570–1660°C) and jet velocities (0.6–1.4 ms^{-1}). The impact of external vibration on the breakup was evident: for low jet velocities, the jet length decreased, the droplet size increased, satellite droplet formation was hindered, and a distinct "pumping mechanism" was observed. For jets with higher velocity, the jet length decreased by 30%, the droplet generation frequency increased from 20 to 250 droplets per second, the drop sizes were uniform, and satellite formation was also suppressed. In this case, the ideal case in which the volume of one wave instability forms one droplet was achieved. © 2014 American Institute of Chemical Engineers *AIChE J*, 00: 000–000, 2014

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Introduction

Jets, filaments, and threads of molten oxides or slags are of interest in a number of high-temperature applications. They are formed intentionally or unintentionally by the interplay of the involved phases: liquid metal, slag, and/or gas. For example, splashing occurs in the basic oxygen furnace where a supersonic gas jet impinges on the melt surface[1] and creates jets or filaments of molten material which finally breakup into droplet cascades. Richardson[2] gives examples of jet-like molten material ejection from metal droplets due to collapsing gas bubbles formed by a chemical reaction at high temperatures. In an after-treatment process for heat recovery from blast furnace slags – the dry slag granulation[3] – molten slag is poured onto a spinning disc to form filaments and/or sheets which breakup into droplets. The uniformity of the particle-size distribution plays a significant role in the succeeding heat exchanger stage. In inviscid melt spinning, the growth of such capillary instabilities on liquid calcia-alumina jets has to be avoided to facilitate continuous filaments.[4] The concept of liquid droplet heat exchangers (LDHX) – as proposed by Bruckner[5] although not yet realized – is based on the capillary breakup of multiple jets of molten slag into uniformly sized droplets to facilitate direct heat transfer to a counter-current gas stream.

The capillary breakup of low-temperature liquid jets (<500°C) in a gaseous environment has been studied theoretically and experimentally in a comprehensive manner. No literature seems to be available which deals with the dynamics of jet formation, wave instabilities, breakup, and finally droplet formation of high-temperature oxide melts. Hence, no direct experimental verification of existing theories and concepts of jet breakup is available for this group of high-viscosity/high-surface tension liquids. The source of instabilities which eventually triggers the breakup in jets with low velocity is the surface tension.[6,7] In this so-called Rayleigh breakup regime, gas effects can be neglected. More important is the relative magnitude of the competing gravitational, inertia, viscous, and capillary (surface tension) forces which governs the dynamics of instability. For example, if the capillary force is dominant compared to inertia (this force ratio is expressed by the Bond number), disturbances propagate both upstream and downstream. In the reversed case, inertia forces are dominant over surface tension forces and the disturbances only propagate in the downstream direction.[7] At same time, the Weber number which determines the fluid dynamic regime has to be considered, that is, dripping or jetting.

The exact characteristics and especially the origin of these disturbances are still unknown.[8] They can come from both interactions with the ambient surroundings and from the jet itself. Their growth very much depends on the working conditions and the above mentioned relative magnitude of forces in play.[8] According to Rayleigh, breakup occurs if the wavelength of the perturbation is longer than the circumference of the jet.[9] In the ideal case, the volume of the liquid contained within one wavelength of a disturbance will form one main drop.[10,11] Eggers and Villermaux[12] point out that the jet breakup mode depends on the amplitude of the initial perturbation in a highly sensitive manner. Therefore, a small deviation from the optimum frequency of the disturbance may lead to nonlinearities and one or more (and most likely undesirable) satellite droplets – depending on the fluid properties and the strength of the disturbance.[13] The ratio of the size of

Correspondence concerning this article should be addressed to Mirco Wegener at mirco.wegener@alumni.tu-berlin.de.