CRITIQUE OF THE KEMLO BLOW-HOLE EMF THEORY

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The B.O.S. steel making process is understood in terms of some fundamental chemical reactions on the melt and in the slag, and some notions of the fluid mechanics of the oxygen lance penetration, and slag and foam formation. Laboratory experiments can study certain of these fundamental actions in isolation and small scale B.O.F. can be used to examine the phenomena in an industrial like situation. On an industrial plant, very little information on what is happening in the B.O.F. can be measured. Stack gas analysis and audiometric information give crude information on what is taking place in the B.O.S.

The measurement of oxygen lance electrical currents to earth via a known resistance appears to give useful information on what is taking place within the furnace itself and is therefore of interest for research and B.O.S. control.

Russian workers first monitored the lance voltage and termed it the lance e.m.f. It appears that the load resistance of the lance to earth used by the Russians was of the order of 200mΩ or higher so that not much useful information was gained. G. Kemlo at the Newcastle Steel works independently monitored lance electrical currents. He sought an optimum load resistance for extracting useful information from the lance e.m.f. His selection of 2.5mΩ has given a dramatic improvement on the usefulness of the signal over the Russian work. Currently, switched loads are under investigation.

Simply from monitoring B.O.S. operation on an industrial plant, via the lance e.m.f., and using inference and the current state of B.O.S. theory, G. Kemlo proposed a theory for the lance e.m.f. patterns in terms of blow holes through the slag. In particular, it was reasoned that as a gas pathway opened up in the slag emulsion form the melt to the flame, a positive electrical current pulse travels to ground via the oxygen lance and load resistor. The greater the oxygen flow and the lower the lance, at any given moment, the more likely is the gas pathway to form. The pathway may be intermittant in soft blowing or virtually continous in hard blowing. For each jet there is a possibility of a pathway. The opening and closing of the pathway is associated with the bifurcation between the oxygen oxidizing the carbon, with gas emission, and the iron with no direct gas emission. Should the lance penetration be such that the gas formed at the melt reflects back around the lance from all three imprringement zones, then the pathways merge around the lance. The consequence of this is a change in sign of the lance currents.

The above theory is successful in exploiting the e.m.f. signals to assess blow hardness and slag visocity, to predict the likelihood of slopping, and to give control actions to avoid and minimize slopping. It also is successful in predicting turn down phosphorus levels reasonably well in heats with a predominantly positive e.m.f., and to suggest control actions to achieve the phosphorus specifications. These are now summarized.

Blow Hardness Since each current pulse is associated with CO generation, then the greater the duty cycle between the signals local minimum magnitude and maximum magnitude, the harder the blow. The nature of the evolution of the signal pattern can be used to assess the local "maximum" and "minimum" signal magnitude. In a "classical" positive trace, one expects the minimum magnitude to be zero save perhaps for a steady increase during the blow. The maximum magnitude appears to follow the decarbonurization rate save that in the last 30% of the blow there can be a build up (doubling) which could be linked to CO_2 % build up in the flame at less than 0.30% content of the melt.* In a "classical" negative

* Authors conjecture.

trace, one expects the minimum magnitude to be zero and the maximum magnitude to follow the decarbonization rate. For cases with both positive and negative pulses, it appears most reasonable to assume that the signals are composites of both negative ones and positive ones, and some decomposition seems to be in order.

Slag viscocity The higher the predominant fluctation frequency of the signal the less the slag viscocity since this is associated with slag movement. High frequency components of the signal may well be gas phase turbulance and thus does not indicate slag viscocity.

Slopping Slopping occurs when over oxidized slags meet high carbon metal in the iron prills in the slag.The recipe for slopping is to blow hard on a positive trace to get prills into the slag and then to blow softly to oxidize the slag and prevent foam collapse via blow-holes, and to repeat the cycle. Slopping will not take place during Si oxidation in the first few minutes or so of the heat, since this oxidation takes preference over decarbonurization. Subsequent to Si oxidation, the lance may be still high so as not to interfere with the scrap and consequently soft blowing oxidizes the slag.

As the blow is hardened from a soft blowing, prills are ejected into the slag and slopping may occur if there are not sufficient blow holes to collapse the slag foam. Certainly a subsequent softening of the blow will increase the rate of slopping. Using the e.m.f. blow hardness can be controlled so as not to decrease. There is a possible feedback effect since within a certain range of operation, the harder the blow the more prills in the slag and the lower the bath level, which then softens the blow. The lance may need to be lowered to compensate this effect. Scrap can prevent adequate stirring and so there may be high carbon metal ejected into the slag later than one would like. Negative traces seem to be slop free unless they soften to positive ones during the first half or so of the heat, or unless the lance is too low. For such traces there is the possibility that the feedback effect can gradually harden the blow since within a certain range, the harder the blow the more the prills get forced back into the melt so that the melt level rises and the blow hardens.

Phosphorus control The conditions for slopping are those for high dephosphorization in the early part of the heat, so that it is preferable to adjust the heat for phosphorus reduction towards the end of the heat when the melt carbon content is low. This suggests hard blowing to keep prills in the slag until 2 minutes before the end of the blow, then radically lift the lance 1metre to soften the blow to generate FeO in the slag which can then deposphorize at the melt/slag interface. The lance can be lowered after 30 seconds or so in order not to risk slopping, particularly in a high carbon heat.

The above facts of the original G. Kemlo theory, interpretation and application are readily accepted because of their own internal consistency and confirmation in application. The following descriptions are presented to update the presentation of the original theory.

The Fluid Mechanics Picture

With positive e.m.f. traces, a reasonable picture is that of packets of gas (nominally 90%CO 10%CO_2), or streams entrained in slag turbulance, emerging from the jet footprints in the melt. The slag vertical rotation is driven from the oxygen jet and reflected gas off the melt and walls. The directions of slag rotation is from lance to melt to walls to flame and back to lance. Such a pattern of slag and gas flow creates a fast flow of gasses up the vessel walls and more turbulance towards the lance.

With negative e.m.f. signals, a reasonable picture is one of deeper, more re-entrant oxygen melt penetration so that the reflected gas swirls round the lance. The slag rotates vertically in the reverse direction to that for positive traces. That is, the slag is not so much in contact with the oxygen jet as with the emerging central column of flame. The slag thus is driven to rise vertically near the lance and come down the side walls.

With the emerging gasses flowing up the lance, many of the prills ejected and perhaps some fume could be thrust back into the melt by the oxygen jet thus enhancing decarbonization, and reducing oxidization of the slag. Also it is not inconceivable that the melt could swirl around one central lance composite penetration hole thus stabilizing the action considerably, and likewise the flame could swirl around the lance. Under such conditions lance metallization would be obviated.

A composite of the above pictures can arise in that the gas streams can emerge from the walls then swish to the centre and back, or one jet can have its emerging gasses stream up the walls while another jet can have its gasses stream around the lance.

The CO_2 conjecture

The author has elsewhere conjectured that the late signal increase on "classical" positive traces are related to the increase in percentage of CO_2 produced towards the end of the blow. Since CO_2 has an affinity for electrons, it is clear that when CO_2 is in abundance, electron concentrations diminish. Thus high internal conductivities associated with electron presence in negative regimes, become lower as the CO_2 concentration increases. This could account for "shorting" out of negative signals and even their going positive in intermittent bursts. The CO_2 could very well lose its electrons on the larger area vessel walls, rather than on the lance,giving rise to positive lance currents.