Note

Correlation for Area of Spout Eyes in Ladle Metallurgy

(Comments on “Spout Eye Area Correlation in Ladle Metallurgy” by Subagyo, Brooks and Irons)

Kimitoshi YONEZAWA and Klaus SCHWERTDTEGER¹⁾

Oita Works, Nippon Steel Corporation, Oaza-Nishinosu, Oita City, Oita 870-8566 Japan.

1) Institut für Metallurgie, Technische Universität Clausthal, Robert Koch Str. 42, D-38678 Clausthal-Zellerfeld, Germany.

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The spout eyes are the open parts of the meniscus, where the slag is pushed away by the gas, during stirring with gas in ladle treatment of liquid steel. Some time ago, the authors carried out cold model experiments on the size of spout eyes using mercury and silicon oil as metal and slag, respectively.¹⁾ The method was that of observing the liquid surface with a video camera. The open part of the surface exhibits much stronger light reflection and can easily be distinguished, therefore, from the covered part of the meniscus. Its area and the number of the eyes, if the open part was subdivided into several eyes, were evaluated using a data processing system. The obtained results were represented in the form of non-dimensional correlations. The authors also performed some plant experiments on a 350 t ladle and demonstrated that the industrial data were close, in the non-dimensional representation, to those of the cold model. Recently, Subagyo, Brooks and Irons picked up this subject.²⁾ They claimed that the correlation for the open spout area as deduced by the authors¹⁾ was inadequate, and they proposed an alternative correlation which they believe to be better. There are certain facts in the experimental data¹⁾ which Subagyo *et al.*²⁾ did not take into account properly in the deduction of their correlation. It is necessary for avoiding further confusion to perform a new assessment of both correlations.

The original correlation deduced by the authors¹⁾ is

$$\log\left(\frac{A}{hH}\right) = -0.45593 + 0.83275 \log\left(\frac{Q^2}{gH^5}\right) - 0.14732 \left[\log\left(\frac{Q^2}{gH^5}\right)\right]^2 + 0.01789 \left[\log\left(\frac{Q^2}{gH^5}\right)\right]^3 \dots (1)$$

for $0.01 < Q^2/gH^5 < 2000$ and nozzle diameter $d=1.0$ and 1.5 mm where A is the open spout area (area of the eye, or of the eyes, if several eyes are present), h the height of the metal bath, H the height of the slag layer, Q the volumetric gas flow rate at the nozzle exit and g the gravity constant. The combination Q^2/gH^5 is a Froude number. A correlation

with the same form but slightly different coefficients was given for the nozzle diameter $d=0.05$ mm. The alternative equation of Subagyo *et al.*²⁾ has the form

$$\frac{A}{(h+H)^2} = 0.02 \left(\frac{Q^2}{gH^5}\right)^{0.375} \dots (2)$$

That is, Subagyo *et al.* chose the quantity $A/(h+H)^2$ rather than A/hH as the non-dimensional open spout area. They claim that $A/(h+H)^2$ is physically meaningful in contrast to A/hH , and they use the simple exponential expression.

In principle, the non-dimensional area of the open spout is a function of Froude number, non-dimensional slag height H/h and non-dimensional nozzle diameter d/h , if the materials are not varied and the pressure ratio between meniscus and nozzle levels is constant. In their search for the best functional relationship, the authors of the present note first used the quantity A/h^2 as non-dimensional open spout area. This quantity is practically identical to $A/(h+H)^2$ when the slag height H is much smaller than the metal height h as is so in the range of interest for ladle metallurgy. It was found that plots of A/h^2 versus Q^2/gH^5 are non-linear in log-log scale, and that A/h^2 increases with slag thickness at given Q^2/gH^5 . Assuming that this increase is independent of Q^2/gH^5 in a first approximation and that it can be described by the simple exponential term $(H/h)^\alpha$ the appropriate correlation for A/h^2 (or $A/(h+H)^2$) would be of the form

$$\frac{A}{h^2} = \left(\frac{H}{h}\right)^\alpha f\left(\frac{Q^2}{gH^5}\right) \dots (3)$$

A precise value of the exponent α could not be determined from the data. But it was evident that α is in the vicinity of 1. Hence, taking $\alpha=1$ the correlation (3) is

$$\frac{A}{h^2} = \frac{H}{h} f\left(\frac{Q^2}{gH^5}\right) \dots (4)$$

which is identical to

$$\frac{A}{hH} = f\left(\frac{Q^2}{gH^5}\right) \dots (5)$$

All this has been stated in the previous text.¹⁾ It is puzzling that Subagyo *et al.*²⁾ claim that their Eq. (2) is better than Eq. (1) “in terms of prediction” when in fact it is worse.

Figures 1 and 2 show the plots of $A/(h+H)^2$ or A/hH versus Q^2/gH^5 for the nozzle diameters $d=1.0$ mm and $d=1.5$ mm, respectively. The increase of $A/(h+H)^2$ with slag height H can be recognized in Figs. 1(a) and 2(a). The same can be found in the data for $d=0.05$ mm¹⁾ which are not given in this note in the form of diagrams. Figure 1(b) illustrates, for the nozzle diameter of 1.0 mm, that the traces for the different slag heights intermingle or are very close to each other. That is, a systematic influence of H on A/hH does not exist. Figure 2(b) shows that the traces for the different heights merge towards a common function (dashed curve in Fig. 2(b)). Thus, there is practically no influence of H on A/hH also with these data. The same is evident again

Fig. 1. Dimensionless representation of cold model data obtained with nozzle diameter $d=1.0$ mm. (a) Plot of dimensionless spout eye size $A/(h+H)^2$ as a function of Froude number showing an influence of slag height H on $A/(h+H)^2$. (b) Plot of dimensionless spout eye size A/hH as a function of Froude number showing practically no influence of slag height in this correlation.

Fig. 2. Dimensionless representation of cold model data obtained with nozzle diameter $d=1.5$ mm. (a) Plot of dimensionless spout eye size $A/(h+H)^2$ as a function of Froude number showing an influence of slag height H on $A/(h+H)^2$. (b) Plot of dimensionless spout eye size A/hH as a function of Froude number showing practically no influence of slag height in this correlation.

Fig. 3. Comparison of the cold model data with the new correlation proposed by Subagyo, Brooks and Irons.²⁾

Fig. 4. Comparison of the cold model data with the original correlation of Yonezawa and Schwerdtfeger.¹⁾

in the data for the nozzle with $d=0.05$ mm. Figure 3 shows all the data for the nozzle diameters of 1.0 and 1.5 mm as plot of $A/(h+H)^2$ versus Q^2/gH^5 together with the function given by Eq. (2) and Fig. 4 is the corresponding diagram for A/hH together with the function given by Eq. (1). Clearly, the correlation (1) is more satisfactory than the correlation (2).

It is correct that the plant data reported by the authors¹⁾ of this note agree better with Eq. (2) than with Eq. (1). But the plant data can not be used as a basis for deriving a correlation function, as has been done so by Subagyo *et al.*,²⁾

because of their lack of precision. The slag height H is not accurately known and the open spout area A is more an estimate than a measured datum. For instance, if the slag height has been 4 cm instead of the used 5 cm the plant data points would shift to Q^2/gH^5 values larger by a factor of about 3 and would be located very closely to the curve given by Eq. (1). Also the measured A values were probably too large because slag and steel could not be distinguished well and the total light area was taken to be the open spout. Physically real reasons may exist for the deviation. All this has been

discussed by the authors in their previous paper.¹⁾ Thus, it is nice that the (original) plant data are close to the laboratory correlation but they cannot be preferred against the precisely controlled cold model data in deriving correlations. In conclusion it may be suggested to leave it with Eq. (1) than using Eq. (2).

REFERENCES

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- 2) Subagyo, G. A. Brooks and G. A. Irons: *ISIJ Int.*, **43** (2003), No. 2, 262.