Distribution of Liquid Flow Rates in the Process of Bubbling with Gas Through Gas-Permeable Inserts

R A Gizatulin[1], D V Valuev[2], R S Dariev[3], V A Trifonov[4], I F Borovikov[5]

[1,2,3,4] 652050, Kemerovo region, Yurga, Leningradskaya str.26 Yurga Technological Institute branch of Tomsk Polytechnic University
[5] The Moscow State Technical University of N.E. Bauman, Moscow, 5, 2nd Baumanskaya

E-mail: valuev@tpu.ru

Abstract. The authors studied the distribution of the vertical components of the rate in the ascending gas-liquid flow when blowing through the bottom nozzle at two levels under three modes of neutral gas supply. It was estimated that under the intensities of gas (nitrogen) of 2 and 4 L/min·t the type of rates distribution in both cross-sections does not differ from the generally accepted one and practically does not depend upon the intensity of gas supply.

Introduction

The duration of the stirring operation is significantly determined by the time required for bath homogenization in terms of chemical composition and temperature which, in its turn, depends upon the rate gas-ascending flow (current stream). The easiest way to estimate the duration of the blowing through is by simulation. At the same time it is practically impossible to meet all the requirements of exact similarity of the model due to the diversity of the factors effecting the results of the blowing through and the researchers have to give up the idea of absolute similarity of the original to the model. This may be the explanation why the results of the studies we know concerning simulation of the blowing through in the ladle [1-4] do not agree with the results of direct ladle experiments [5, 6].
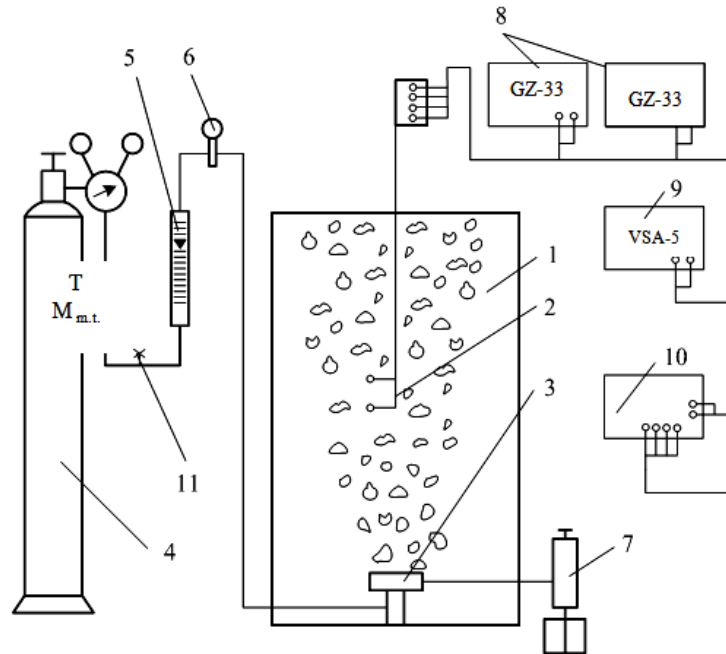
For this reason we estimated the profile of the rates depending on gas flow and different distances from the nozzle. On the transparent model we studied the distribution of the vertical components of the rate of the liquid in the ascending gas-liquid flow when blowing with bottom nozzle at two levels under three modes of neutral gas supply.

The experiments were carried out in a transparent container with the cross-section 600×600 mm and 1200 mm high. The basic drawing of the unit is shown in Figure 1. A metal rod was plunged into the container filled with water. Two platinum sensors were fixed at one end of the rod at a distance (vertical) of 50 mm from each other to measure the electric resistance of water. Nitrogen was supplied through the nozzle with a hole 1.3 mm in diameter situated in the center of the bottom of the container. Nitrogen consumption was measured by rotameter, its pressure before the nozzle – by spring manometer.

After the container is filled with water up to 1100 mm we opened the gas cylinder valve and settled the fixed gas rate with a rotameter. A certain amount of brine solution was supplied to the gas nozzle with a syringe pump. After bringing in the indicator we turned on the mechanism of aerial film rewind

(sensitivity 1300 un.) in the light-beam oscillograph. The rate of the aerial film rewind was 640 mm/sec, accuracy of time marking was 0.005 ± 0.0025 sec.

Figure 1. The diagram of the unit to study the liquid flow rates distribution 1 – container with water; 2 – sensors; 3 – nozzle; 4 – gas cylinder; 5 – rotameter; 6 – manometer; 7 – pump; 8 – audio frequency generator; 9 – rectifier; 10 – light-beam oscillograph; 11 – control valve

The indicator does up with the liquid drawn by gas bubbles. When the brine solution reaches the first sensor, water resistance reduces within the gap between the circular and the point electrode and the electric current intensity increases in the sensor circuit. The electric current intensity increases in the second sensor circuit and this is recorded in the aerial film. The change of electric current intensity on the second sensor was controlled by the tester which marked the rush of current in the circuit. After the rush of current the mechanism of aerial film rewind was turned off. After the experiment was over a three-minute pause was made under continuous gas supply until complete homogenizing of the bath. Before the start of the next experiment standard electric current intensity was set for each circuit by changing the output generator voltage. After the adjustment the next experiment was carried out according to the same plan. The time records on the oscillograms allowed determining the interval between the electric current intensity change in the first and in the second sensor circuits. The rate of the liquid flow (ϖ – m/s) under bubblering was found from the formula:

$$\varpi = \frac{l}{\tau},\qquad(1)$$

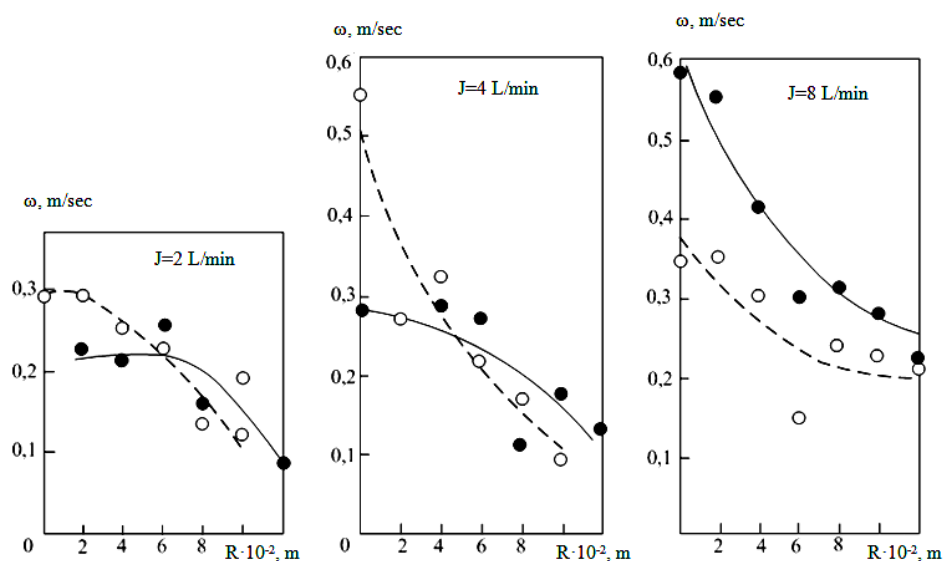where $l = 50$ mm – distance between the sensors;

τ – the time when the salt solution travels from one sensor to the other, sec.

The rate of the flows was measured in the horizontal planes situated at the heights H making 570 and 800 mm from the nozzle exit, along radius R at a pitch of 2 cm starting from the plume centre to its perimeter. The measurements were carried out under the intensities J of gas supply 2, 4 and 8 L/min which corresponded to the intensity of gas supply from 4.3 to 17.2 m^3/h in a 100-tonne ladle. In every

coordinate under the given blowdown mode the measurements of the rate were completed (depending on the how the measurements vary) from 6 to 21 times. Altogether about 500 measurements were completed.

The distribution of the vertical component of liquid flow rate distribution in the ascending gas-liquid flow obtained in the course of experiments is shown in Figure 2.

From Figure 2 we can see that under all blowdown modes the rate decreases as we move away from the center irrespectively to the distance from the nozzle. The rates of the flows at 570 mm under the intensities of gas supply of 2 and 4 L/min at corresponding coordinates are practically the same. When gas flow increases up to 8 L/min· flow rate at the given height increases.

Figure 2. Rate distribution in the ascending gas-liquid flow

At the height H = 800 mm under small gas flows (2 and 4 L/min) the rates, as well as at 570 mm are close to each other in corresponding coordinates. Under maximal in our experiments gas flows (8 L/min) the flow rates at the given height also increase.

The flow rate at the upper level is higher than that at the lower level. This disagrees to the data provided in papers [7, 8]. At the same time under small intensities of gas supply the results of our experiments are similar to the data in [9-10].

The curves in the diagrams are regressions of the following type

$$\varpi = A + BR + CR^2,$$ (2)

where R – distance from the axis of the flow, cm.

The values of the coefficients of the regression and coefficients of the pair correlation are presented in the table.

Table 1 – Values of the coefficients of regression $\varpi = A + BR + CR^2$, and coefficients of correlation (g)

J, l/min	H, mm	A	B	C	g
2	570	0.294	$-0.117 \cdot 10^{-3}$	$-0.192 \cdot 10^{-2}$	-0.929
	800	0.187	$+0.0225$	$-0.254 \cdot 10^{-2}$	-0.767
4	570	0.504	-0.0687	$+0.230 \cdot 10^{-2}$	-0.906
	800	0.290	$-0.555 \cdot 10^{-2}$	$-0.758 \cdot 10^{-3}$	-0.818
8	570	0.375	-0.0337	$-0.172 \cdot 10^{-2}$	0.747
	800	0.619	-0.0584	$0.233 \cdot 10^{-2}$	-0.878

In Figure 3 we provide the results of our calculations of the liquid flow according to the zones of the stream cross-section and the cumulative sum. The liquid flow for every zone was calculated according to the formula
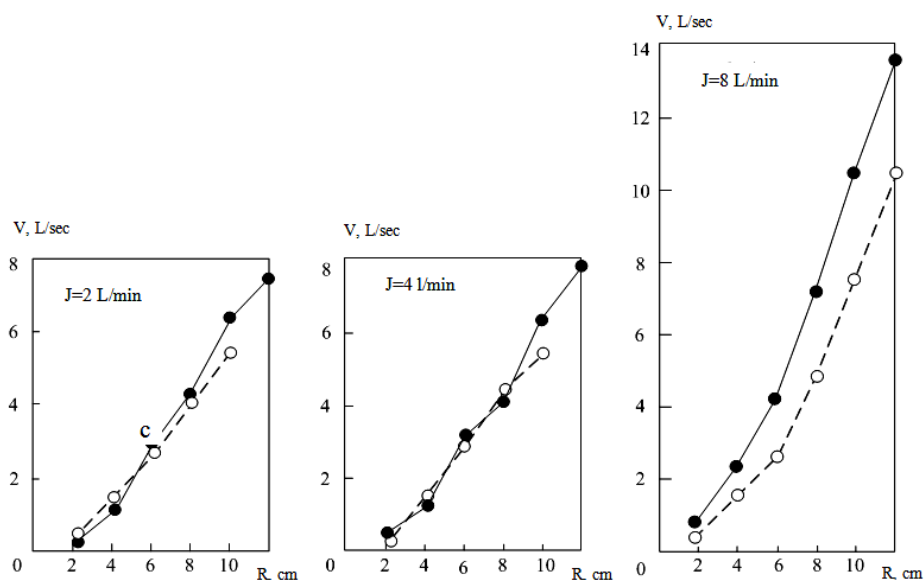
$$V = \omega_i F_i,$$

$$(3)$$

where $F_i = \pi R^2$ –area of the central zone with the radius of 2 cm; $F = \left(R_i^2 - R_{i-1}^2 \right)$ – area of the rest ring zones of the cross-section;

ω_i – flow rate of the liquid at the outer generating line of the ring.

Such method of calculation results in exaggerated amount of the liquid but the type of the dependence does not differ from the dependence obtained if applying the average rate for each zone.

When completing the calculations we did not take into consideration the area of the cross-section taken by the gas phase as the amount of real volume content of the gas (relation of the section part taken by the gas phase to the whole section of the ascending flow $\varphi = F_g/F$ under our intensities of gas supply for both heights is less than 0.01. The exact value is impossible to determine as the boundaries of the flow are fuzzy.

Figure 3. Liquid flow for the zones of the section as a cumulative sum

From Figure 3 we can see that under small gas flows (2 – 4 L/min between 570 and 800 mm) there is no suction of water into the ascending flow. As the zone of bubbling expands new amounts of the liquid are merely involved into the ascending motion. A different situation is observed under J = 8 L/min. Here we can speak about suction of surrounding water into the gas-liquid flow as, starting from R = 4 cm the volume of the liquid passing through every next zone is always larger at 800 mm than at 570 mm.

Conclusion

We applied a transparent model to study the distribution of the vertical components of the rate in the ascending gas-liquid flow in the process of blowing through the bottom nozzle at two levels under three modes of neutral gas supply. It was estimated that, under the intensities of gas (nitrogen) supply of 2 and 4 L/min the type of the rates dependence in both sections does differ from the generally accepted one and does not practically depend on the intensity of gas supply. Under the gas supply of 8 L/min rate distribution differs from the generally accepted distribution both at the height and in the section of the flow.

We applied the cold model to study the distribution of the gas phase in three horizontal sections of

the ascending gas-liquid flow blown from the bottom according to the method of remote laser probing. It was established that distribution of the gas flow density in the horizontal plane is described by the exponential dependence; distribution of the gas flow over the main part in the cross-section is similar, i.e. it does not depend upon the intensity of gas supply and the distance between the cross-section and the nozzle. The real volume gas content of the flow is maximal at its axis and decreases exponentially as we move away from it. The expansion angle of the gas flow in general is determined by the density of the gas flow at the nozzle edge; as the flow ascends its value decreases. The results of the study were used for simulating the bubbling stirring of the molten metal.

References

[1]   Kadukov V G Kogan A E Fomin N A Stirring intensity effect upon the duration of blowing J Izv. Vuzov 6 (1986) 46 – 57

[2]   Chinakhov D A Gas dynamic control of properties of welded joints from high strength alloyed steels J China Welding. Vol 23 3 (2014) 27-31

[3]   Saprykina N A Saprykin A A Borovikov I F Sharkeev Y P Influence of layer-by-layer laser sintering conditions on the quality of sintered surface layer of products J Source of the Document IOP Conference Series: Materials Science and Engineering 91 (2015)

[4]   Galevskiy G V Rudneva V V Galevskiy S G Il'yashchenko D P Kartsev D S Nanosized borides and carbides for electroplating. metal-matrix coatings: specifications, performance evaluation J IOP Conference Series: Materials Science and Engineering. 125 (2016)

[5]   Chinakhov D A Chinakhova E D Gotovschik Y M Grichin S V Influence of welding with two-jet gas shielding on the shaping of a welding joint J IOP Conference Series: Materials Science and Engineering. 125 (2016)

[6]   Il'yaschenko D P Chinakhov D A Danilov V I Sadykov I D Pysical nature of the processes in structure forming, phase and chemical composition of pipe permanent joints when MMA welding J IOP Conference Series: Materials Science and Engineering. 125 (2016)

[7]   Pimnev A L Zemenkova M Yu Zemenkov Yu D Il'yashchenko D P Mechanical properties of the assembly welded joint of the oil transportation tank after a long-term service J IOP Conference Series: Materials Science and Engineering. 127 (2016)

[8]   Saprykin A A Ibragimov E A Babakova E V Engineering and technology based on rapid prototyping J Applied Mechanics and Materials 770 (2015) 622-627

[9]   Dmitrienko V I Rozhikhina I D Nokhrina O I Aizatulov R S Platonov M A Reduction of barium and strontium in the ladle treatment of steel J Steel in Translation Vol 42 4 (2012) 305 – 307

[10] Chinakhov D A Increasing reliability of welded joints of hydraulic cylinders in heading machines J Journal of Iron and Steel Research International 17 (2010) 4-7