Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 55
ISSUE 2
December
2012

Influence of impeller shape on the gas bubbles dispersion in aluminium refining process

M. Saternus*
Metallurgy Department, Silesian University of Technology,
Faculty of Materials Engineering and Metallurgy,
ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding e-mail address: mariola.saternus@polsl.pl

Received 15.10.2012; published in revised form 01.12.2012

Materials

ABSTRACT

Purpose: The most popular method of aluminium refining is blowing of refining gas through the liquid metal. The way the refining gas is introduced to the liquid metal significantly influences the time and course of degassing process. Rotary impellers seem to be the best solution, especially taking into account reaching good level of gas dispersion in the liquid aluminium. However, the construction of impellers also influences the obtained gas dispersion in liquid metal, especially considering the processing parameters such as flow rate of refining gas and rotary impeller speed.

Design/methodology/approach: To observe the phenomena occurring during the aluminium refining process physical modelling was applied. Test stand for such modelling was built at 1:1 scale with the transparent tank to observe the level of gas dispersion in the liquid. The built model has to fulfill the rules coming from the theory of similarity.

Findings: The choice of optimal parameters is very important to the particular type of impeller. As a result of research the processing parameters were chosen to the appropriate type of gas dispersion. The most desirable type of dispersion is an uniform dispersion. According to the research the best impeller seems to be impeller No 1.

Research limitations/implications: There are differences between results coming from modelling research and industrial test. So, the further research should be conducted with a chosen impeller in industrial conditions.

Practical implications: From industrial point of view it is important to test the impeller construction and their geometry in laboratory before industrial test. It gives some ideas how the particular impeller will behave in industry. To control the process of aluminium refining and conducting it optimally it is really important to know its mechanism better.

Originality/value: This paper presents original modelling research of aluminium refining process conducted in URO-200 reactor.

Keywords: Metallic alloys; Aluminium; Physical modelling

Reference to this paper should be given in the following way:
M. Saternus, Influence of impeller shape on the gas bubbles dispersion in aluminium refining process, Journal of Achievements in Materials and Manufacturing Engineering 55/2 (2012) 285-290.

© Copyright by International OCSCO World Press. All rights reserved. 2012

1. Introduction

Nowadays aluminium refining process is one of the technological stages of aluminium production. It gives possibility to remove hydrogen which causes porosity and other impurities such as sodium, calcium, oxides, borides, carbides [1-3]. Different kinds of refining reactors are available in aluminium industry. They can be divided taking into account (see Table 1):

- the type of reactor: continuous or batch reactor,
- the way the refining gas is introduced to the metal: by rotary impellers, ceramic porous plugs or different nozzles,
- the way the metallic and nonmetallic inclusions can be removed: flotation or applying filter.

It can be seen that the dominating reactors are the ones in which the gas is introduced by the rotary impellers. The impellers used in those reactors have different shapes and constructions. In Poland URO-200 reactor is popularly used in many aluminium foundries.

Table 1.
Refining reactors applied in aluminium industry [3-11]

Reactor	Type	Way of gas introduction	Inclusions removal
ACD	continuous	rotary impeller	flotation
AFD	continuous	rotary impeller	filter
Alcoa 469	continuous	ceramic plugs	filter
Alcoa 622	continuous	rotary impeller	flotation
Alpur	continuous	rotary impeller	flotation
ASV	batch	rotary impeller	flotation
DMC	continuous	ceramic plugs	filter
DUFI	continuous	ceramic plugs	filter
FIF-50	continuous	rotary impeller	flotation
FILD	continuous	lance with holes	filter
GBF	continuous	rotary impeller	flotation
GIFS	continuous	rotary impeller	flotation
HD-2000	batch	rotary impeller	flotation
HYCAST	continuous	rotary impeller	flotation
I-60 SIR	continuous	plugs	flotation
Jetcleaner	continuous	nozzles	flotation
LARS	continuous	rotary impeller	filter
MINT	continuous	nozzles	filter
PHD-50	batch	rotary impeller	flotation
RDU	continuous	rotary impeller	flotation
Rotoxal	batch	rotary impeller	flotation
Shizunami	batch	rotary impeller	flotation
SNIF	batch	rotary impeller	flotation
URO-200	batch	rotary impeller	flotation
URC-7000	continuous	ceramic plugs	filter

2. Types of dispersion

Schemes of flows and the level of gas dispersion in the liquid aluminium were studied by many authors [12-30]. Table 2 presents some results of these studies.

There different types of gas bubbles dispersion in the liquid metal can be seen [12,13]:

- creating small gas geysers at the surface of the metal – see Fig. 1 - there is a lack of dispersion, only near the rotor relatively big gas bubbles rise up the surface,
- minimal dispersion - see Fig. 2 - single gas bubbles rise up to the surface, dispersion can be observed only in the area of gas bubble generation, there is a lack of dispersion in the whole volume of the liquid (especially near side walls and below the impeller),
- intimate dispersion - Fig. 3 - single gas bubbles rise up to the top of reactor, gas bubbles are well mixed with the liquid, there is lack of gas bubbles only near the side walls and in the bottom part of the reactor, near the impeller,
- uniform dispersion - Fig. 4 - single gas bubbles rise up to the top of reactor creating somewhere chains, gas bubbles are well mixed with the liquid in the whole reactor, the most desirable type of dispersion,
- creating swirls and chain flow of gas bubbles - Fig. 5 - gas bubbles create the chains, gas bubbles are well mixed with the liquid metal in the whole reactor, however in some parts the level of mixing is not so good, swirls can be observed at the surface, which can cause the hydrogen go back to the metal.

Table 2.
Results of research concerning the gas bubbles dispersion in the liquid aluminium [13-20]

Author	Characteristics
Hsi and et.	measurement of sound spectrum in the reactor with rotary impeller by means of hydrophone, connecting the obtained spectrum with the dispersion of the refining gas
Warmoeskerken and Smith	analysis of schemes of refining gas dispersion in reactor with rotary impeller basing on the measurement of the power in gassed metal and observation of cavity formation
Chen and Zhao	analysis of flow patterns in water model of aluminium refining process occurring in the reactor with rotary impellers by considering the radial force to the buoyancy force that prevail near the impeller
Walker and et.	analysis of flow patterns in water model of aluminium refining process occurring in the reactor with rotary impellers by measuring the local pressure fluctuations at point within the gas-liquid mixture
Zhao and Chen	
Chen and Zhao	development of non-intrusive method in which schemes of gas dispersion are related to characteristic parameters derived from the pressure fluctuations measured on the gas supply
Chen, Zhao, Lacey, Gray	analysis of gas flow patterns in water model of aluminium refining process conducted in reactor with rotary impeller basing on measurements of power by the rotor (ratio of the gassed power to the un-gassed power)

3. Modelling research

Physical modelling is very often used for modelling the process of aluminium refining by means of gas blowing [21,22]. This method allows to obtain information about the phenomena occurring in the process in easy and inexpensive way. Test stand for modelling the process of aluminium refining in URO-200 reactor (see Figure 6) was designed in the Institute of Nonferrous Metals - Light Metals Division in Skawina. It was built at 1:1 scale. Research was carried out in laboratory of Metallurgy Department at the Silesian University of Technology. Water was used as a modelling agent, and argon 4.6 as a refining gas.

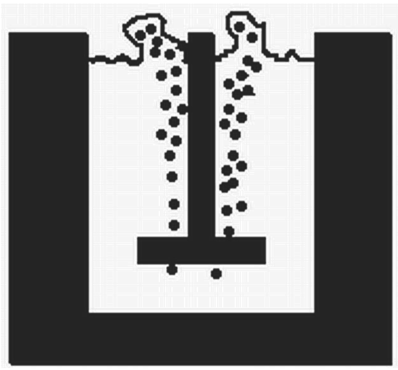


Fig. 1. Scheme of creating small geysers at the metal surface

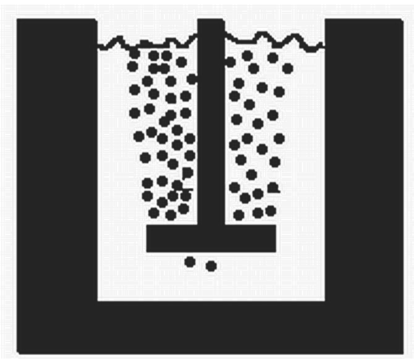


Fig. 2. Scheme of minimal dispersion

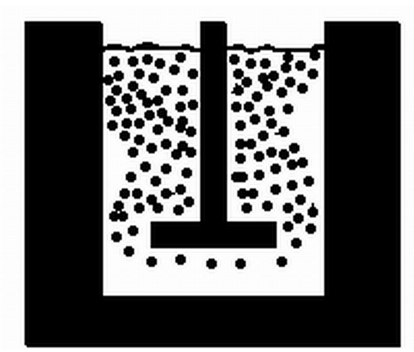


Fig. 3. Scheme of intimate dispersion

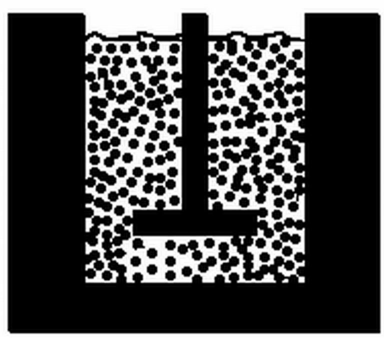


Fig. 4. Scheme of uniform dispersion

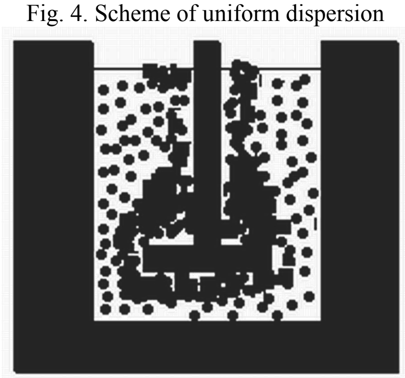


Fig. 5. Scheme of creating swirls and chain flow

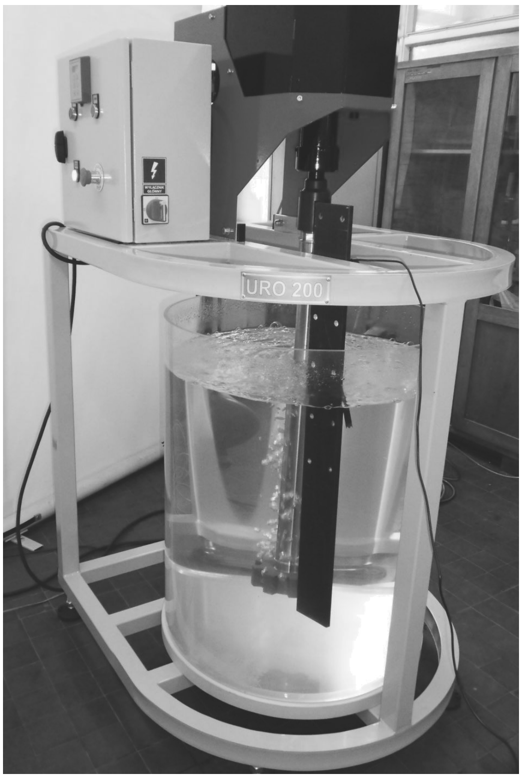


Fig. 6. Test stand used for modelling research

The built water model has to fulfill the rules coming from the theory of similarity [23-26].Taking into account the construction of the reactor the following similarities have to be fulfilled:

- geometric similarity of model and real object,
- hydrodynamic similarity for the flow of liquid in the model and real object (kinetic, dynamic and heat similarity).

In physical modelling this problem can be solved basing on the equality of appropriate criterial numbers in the model and the real object. The most important numbers, taking into account the construction of the reactor used in aluminium refining process and the hydrodynamics of liquid flow are: Euler number, Reynolds number, Froude number and Weber number. The Euler`s criteria is very important for the flows under pressure, so it can be negligible for the flows in the refining reactors. Table 3 presents the value of criterial numbers for water at temperature 293 K and aluminium at temperature 973 K.

Table 3.
Value of criterial numbers for water at temperature 293 K and aluminium at temperature 973 K

Criterial number	Water	Aluminium
Reynolds	27802.0	67392.0
Froude	84.24	21.41
Weber	0.0029	0.0029

During the research the level of gas dispersion was observed. The processing parameters were changing:

- flow rate of refining gas from 5 to 20 dm^3/min,
- rotary impeller speed from 0 to 500 rpm.

Three different shapes of impellers (see Figure 7) were tested.

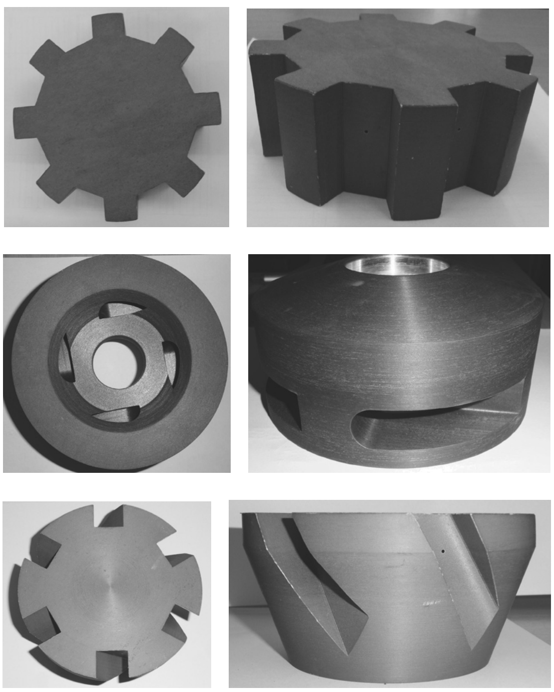
a)
b)
c)


Fig. 7. a) Impeller No 1, b) impeller No 2, c) impeller No 3

4. Results of the research

Figure 8 presents representative results of the research taking into account types of dispersion previously mentioned. Table 4 shows the choice of processing parameters to the particular dispersion type taking into consideration the type of rotary impeller. Small gas geysers are observed for every impeller and every flow rate of gas when there is no rotation.

Minimal dispersion is observed for the impeller No 1 and 3 for the low rotary impeller speed - 200 rpm. For the impeller No 3 it is also observed for each flow rate of refining gas when the rotary impeller speed is 300 rpm, and additionally for the flow rate 5 dm^3/min and 350 rpm. Intimate dispersion was registered for each impeller and all flow rates of refining gas respectively:

- for the impeller No 1 from 300 rpm, for the flow rate of refining gas equaled 20 dm^3/min even when the rotary speed is 200 rpm,
- for the impeller No 2 when the rotary impeller speed is between 350 rpm to 400 rpm,
- for the impeller No 3 when the rotary impeller speed is between 300 to 350 rpm.

Table 4.
Character of gas bubble dispersion for the particular impeller

Flow rate of gas, dm^3/min	Dispersion type				
	G	MD	ID	UD	S
	Rotary impeller speed, rpm				
Impeller No 1					
5	0	200	300	350 400 500	-
10	0	200	300	350 400 500	-
15	0	-	300	350 400	500
20	0	-	200 300	350 400	500
Impeller No 2					
5	0	0 200 300	350 400	500	-
10	0	200 300 350	400	500	-
15	0	200 300 350	400	500	-
20	0	200 300	350 400	500	-
Impeller No 3					
5	0	200	300 350	400 500	-
10	0	200	300 350	400 500	-
15	0	200	300 350	400	500
20	0	200	300 350	400	500

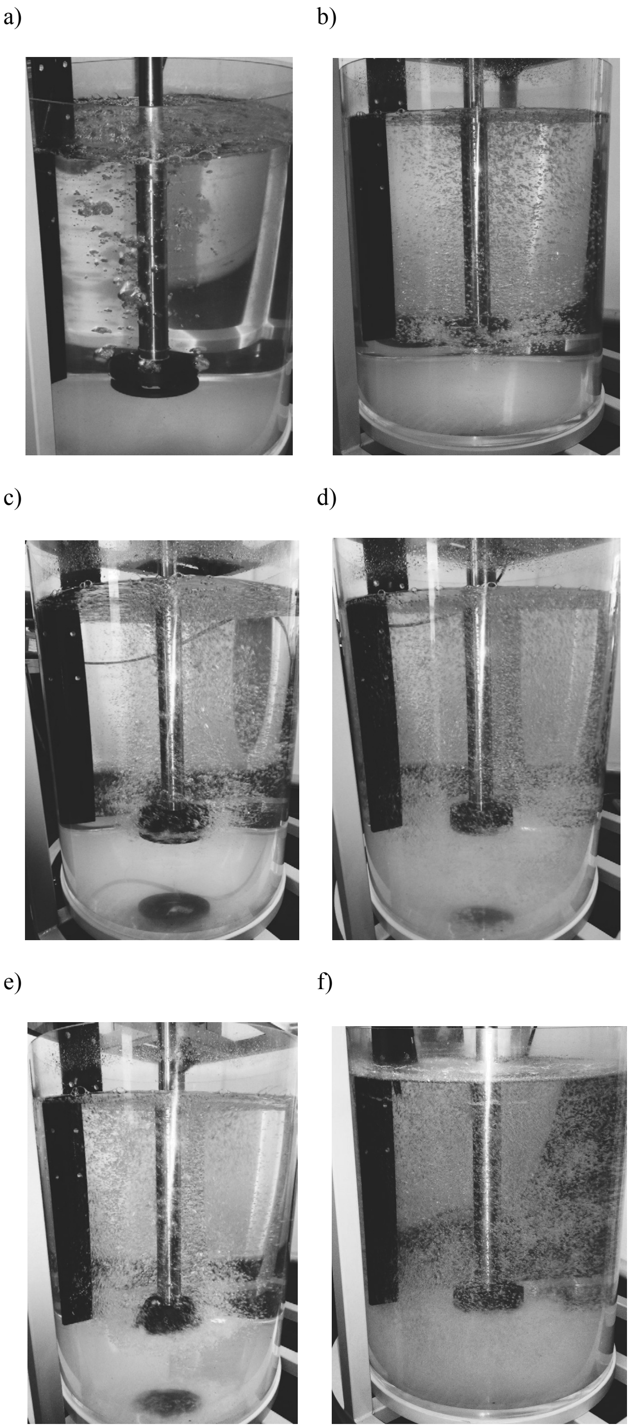


Fig. 8. Results of research: a) small gas geysers (impeller No 3, 20 dm^3/min, 500 rpm), b) minimal dispersion (impeller No 1, 10 dm^3/min, 200 rpm), c) intimate dispersion (impeller No 2, 15 dm^3/min, 350 rpm), d) uniform dispersion (impeller No 1, 15 dm^3/min, 350 rpm), e) uniform dispersion (impeller No 3, 15 dm^3/min, 350 rpm), f) case of creating swirls and chain flow (impeller No 1, 20 dm^3/min, 500 rpm)

Uniform dispersion, the most desirable, can be seen for every flow rate of refining gas for:

- impeller No 1 - when rotary impeller speed is between 350 to 500 rpm and the flow rate of refining gas is small (5-10 dm^3/min),
- impeller No 2 - when the rotary impeller speed is rather high to 500 rpm,
- impeller No 3 - when the rotary impeller speed is between 400 to 500 rpm.

The fifth case (swirls and chain flow) was observed for the impeller No 1 and 3 when the flow rate of refining gas is between 15 to 20 dm^3/min and the rotary impeller speed is 500 rpm.

5. Conclusions

The obtained results show that the best results of refining gas dispersion in the liquid metal in the URO-200 reactor can be reached when the impeller No 1 is applied. For this impeller the optimal parameters to obtain uniform dispersion are: rotary impeller speed 350 rpm and flow rate of refining gas 10 dm^3/min. Figure 9 presents the view of gas bubbles generated by impeller No 1 - it can be seen that mixing of gas bubbles with liquid is quite good and gas bubbles are rather small. Figures 10 and 11 present view of gas dispersion in the same processing parameters but for impellers respectively No 2 and 3. Impeller No 3 also gives good results, whereas the mixing in case of impeller No 2 is not satisfactory, and gas bubbles are rather big.

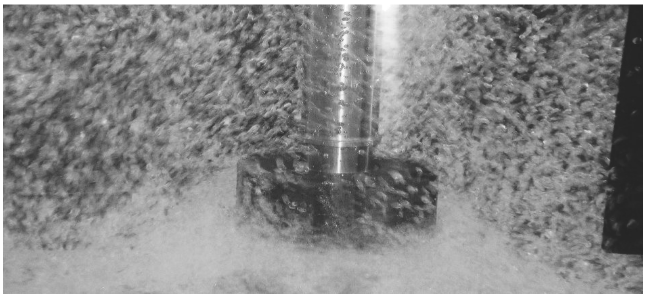


Fig. 9. Gas bubbles generated by the impeller No 1 (350 rpm, 15 dm^3/min)

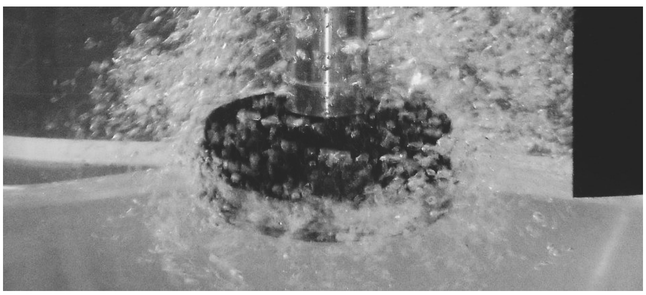


Fig. 10. Gas bubbles generated by impeller No 2 (350 rpm, 15 dm^3/min)

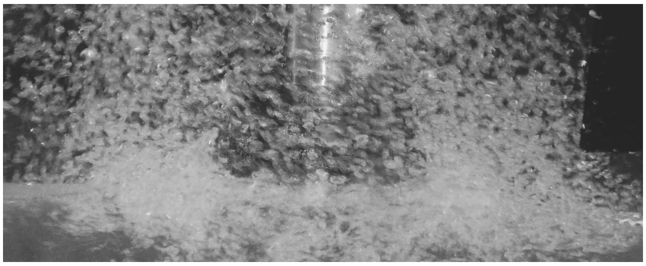


Fig. 11. Gas bubbles generated by impeller No 3 (350 rpm, 15 dm^3/min)

To sum up, impeller No 2 gives satisfactory results when the rotary impeller speed is relatively high (500 rpm). For this impeller the further research should be conducted. However, applying this impeller is not profitable taking into account the economic point of view. Impeller No 1 seems to be the best one. Thus, some more research especially in the industrial condition should be carried out to approve the choice.

Acknowledgements

Financial support from Polish Ministry of Science and Higher Education is acknowledged (contract No N N508 443236).

References

[1] C.J. Simensen, G. Berg, A survey of inclusions in aluminium, Aluminium 56/5 (1980) 335-340.
[2] M. Saternus, J. Botor, Refining process of aluminium conducted in continuous reactor - physical model, Archives of Metallurgy and Materials 55/2 (2010) 463-475.
[3] M. Saternus, J. Botor, W. Wężyk, Modelling of aluminium refining process in the continuous reactor, Proceedings of the International Symposium on "Liquid Metal Processing and Casting" LMPC'2007, P.L. Lee, A. Mitchell, J.-P. Bellot, A. Jardy (Eds.), SF2M, 2007, 313-318.
[4] M. Saternus, J. Botor: Refining of aluminium and its alloys by means of inert gases, Ores and Non-Ferrous Metals 4/48 (2003) 154-160 (in Polish).
[5] S. Kato, Hydrogen in aluminium and aluminium alloys, Sumitomo Light Metal Technical Report 34/3 (1993) 59-77.
[6] S. Terai, M. Yosida, Developments in treatment of aluminium melts, Proceedings of the 8th Internationale Leichmetalltagung, Leoben-Wien, 1987, 236-243.
[7] Y. Ohno, D.T. Hampton, A.W. Moores, The GBF rotary system for total aluminium refining, Light Metals, Proceedings of Sessions, TMS Annual Meeting Warrendale 1993, 915-921.
[8] P.J. Flisakowski, J.M. McCollum, R.A. Frank, Improvements in cast shop processing using Pyrotek`s HD-2000 and PHD-50 rotary injector system, Light Metals, Proceedings of Sessions, TMS Annual Meeting Warrendale, 2001, 1041-1047.
[9] G. Maeland, E. Myrbostad, K. Vegas, Hycast I-60 SIR - a new generation inline melt refining system, Light Metals, Proceedings of Sessions, TMS Annual Meeting Warrendale, 2002, 855-859.
[10] J.M. Chateau, Latest trends in molten metal in-line treatment, Aluminium Times, 04/05 (2003) 34-35.
[11] R. Tilak, J. Curiel, Aerospace alloy refining efficiency data for LARS™, Light Metals, Proceedings of Sessions, TMS Annual Meeting Warrendale, 2003, 881-884.
[12] J.Y. Oldshue, Fluid mixing technology, Chemical Engineering, McGraw-Hill Publications Co., New York, 1983.
[13] J.J.J. Chen, J.C. Zhao, Bubble distribution in a melt treatment water model, Light metals, Proceedings of Sessions, TMS Annual Meeting Warrendale, 1995, 1227-1231.
[14] J.J.J. Chen, J.C. Zhao, P.V. Lacey, T.N.H. Gray, Flow pattern detection in a melt treatment water model based on shaft power measurements, Light Metals, Proceedings of Sessions, TMS Annual Meeting Warrendale, 2001, 1021-1025.
[15] R. Hsi, M. Tay, D. Bukur, G. Tatterson, G. Morrison, Sound spectra of gas dispersion in agitated tank, Chemical Engineering Journal 31 (1985) 153-161.
[16] T.A. Sutter, G.L. Morrison, G.B. Tatterson: Sound spectra in an aerated agitated tank, A.I.Chem. Eng. Journal 33/44 (1987) 668-671.
[17] M.M.C.G. Warmoeskerken, J.M. Smith: Flooding of disco turbines in gas-liquid dispersion, A new description of the phenomena, Chemical Engineering Science 40 (1985) 2063-2071.
[18] M.L. Walker, J.C. Zhao, J.J.J. Chen, Bubble flow patterns detection in the water model of a metal treatment unit, Proceeding of the PACRIM Congress, The Australian Institute of Mining and Metallurgy, 1995, 605-609.
[19] J.J.J. Chen, J.C. Zhao, A non-intrusive method for flow pattern detection in gas-liquid reactors - gas supply line pressure fluctuation measurements, Proceedings of the IChemE Symposium Series 146 (1999) 295-303.
[20] J.J.J. Chen, J.C. Zhao, Gas line fluctuation analysis of a gas-liquid reactor, Journal of Thermal Science 14/3 (2005) 267-271.
[21] J.L. Song, F. Chiti, W. Bujalski, A.W. Nienow, M.R. Jolly, Study of molten aluminium cleaning process using physical modeling and CFD, Light Metals, TMS (2004) 743-748.
[22] K.A. Carpenter, M.J. Hanagan: Efficiency modeling of rotary degasser head configurations and gas introduction methods, Part 1 - Water tank test, Light Metals, Proceedings of Sessions, TMS Annual Meeting Warrendale, 2001, 1017-1020.
[23] M. Warzecha, T. Merder, H. Pfeifer, J. Pieprzyca, Investigation of flow characteristics in a six-strand CC tundish combining plant measurements - physical and mathematical modelling, Steel Research International 81 (2010) 987-993.
[24] K. Michalek, K. Gryc, J. Moravka, Physical modelling of bath homogenization in argon stirred ladle, Metalurgija 48 (2009) 215-218.
[25] K. Michalek, Z. Hudziczek, K. Gryc, M. Tkadleckova: Study of homogenization and transfer processes in the casting ladle using physical modelling, Proceedings of the 19th International Conference on Metallurgy and Materials, 2010, 42-46.
[26] T. Merder, J. Pieprzyca, Numerical modelling of the influence subflux controller of turbulence on steel flow in the tundish, Metalurgija 4 (2011) 223-226.