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PHYSICAL MODEL OF ALUMINIUM REFINING PROCESS IN URC-7000

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The paper presents short characteristics of the most frequently used reactors for the continuous refining of aluminium and its alloys. Refining depends on the flow rate of refining gas. It influences the shape and size of gas bubbles. So the physical model was created to determine the level of gas bubble dispersion in liquids. Schemes of gas dispersion in liquid metal were presented taking into consideration that the gas flow rate is changing from 2 to 30 dm^3/min. The range selection of the flow rate of refining gas value for five patterns of the dispersion (no dispersion, minimum, intimate, uniform and overdispersion) was also done.

Key words: aluminium, refining, physical modelling.

Fizikalni model procesa rafinacije aluminija u reaktoru URC-7000. Članak daje kratke karakteristike najčešće rabljenih reaktora za kontinuiranu rafinaciju aluminija i njihovih legura. Rafinacija ovisi o brzini struje plina za rafinaciju. Utjecajni su oblik i dimenzije plinskih mjehura. Fizikalni model je utemeljen za određivanje razine disperzije plinskih mjehura u tekućinama. Shema disperzije plina u tekućem metalu predstavljena je uzimajući u obzir promjene brzina struje plina za rafinaciju vrijedeće za pet stupnjeva disperzije (bez disperzije, minimalna, očekivana, ujednačena i pojačana disperzija).

Ključne riječi: aluminij, rafinacija, fizikalno modeliranje

INTRODUCTION

In metallurgy the quality of the liquid metal has the biggest influence on the quality of the final products. The amount of metallic and non-metallic impurities has great impact on the consecutive stages of technological processes such as: casting, plastic working, heat treatment, etc. That is why the refining process is considered to be one of the most important parts of the basic technological stages. In order to improve the refining process it is essential to know its mechanism.

In the metallurgical industry, and especially in aluminium production the barbotage method of refining process is very popular and this method can be the leading one [1].

RECTORS FOR CONTINUOUS REFINING

Today there are many technological solutions of barbotage process. The way of gas introduction to the metal such as lance, ceramic porous plugs, nozzles, rotary impellers plays an important role in these solutions. Nowadays many batch reactors are replaced by the continuous reactors. Thus a continuous refining process becomes more and more popular [1].

There are many reactors for the continuous refining of aluminium and its alloys. Table 1 presents some of them with the basic data concerning metal flow and level of hydrogen removal, while Figure 1 shows two examples of continuous reactor: DMC and MINT. In Poland typical representative of these kind of reactors is URC – 7000 [2, 3].

Table 1. **Basic data of reactors for aluminium continuous refining [1]**

Process	Metal flow / kg/h	Hydrogen removal /cm^3(100 g Al)$^{-1}$
MINT	5000-15000	0.25–0,05
DUFI	2500-20000	0,19–0,08
AFD	19800	0,14–0,10
IMN	5000	0,25–0,09
DMC	5000	0,11-0,06
URC-7000	5000	to 0,10

REACTOR URC – 7000

Reactor URC –7000 was designed in Skawina by IMN – OML. Figure 2 presents the scheme of the reactor [4]. URC-7000 consist of two chambers: refining and filtration one. The ceramic porous plugs are located inside the refining chambers. Removal of hydrogen and

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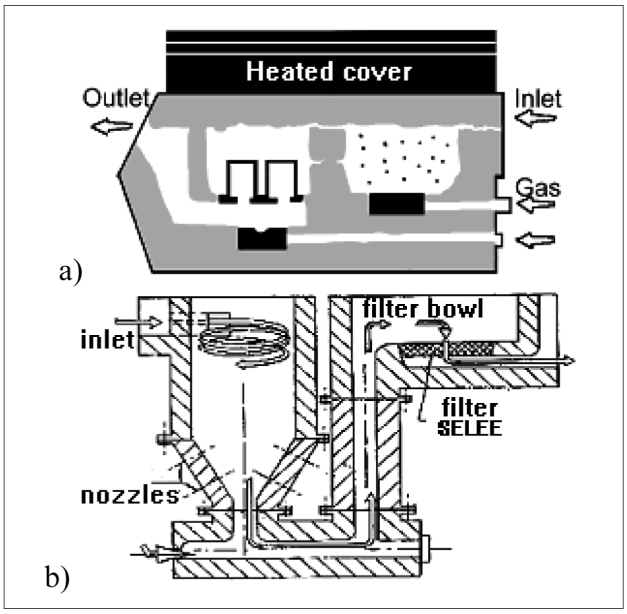

Figure 1. Scheme of two selected continuous rectors: a) DMC, b)MINT [2, 3]

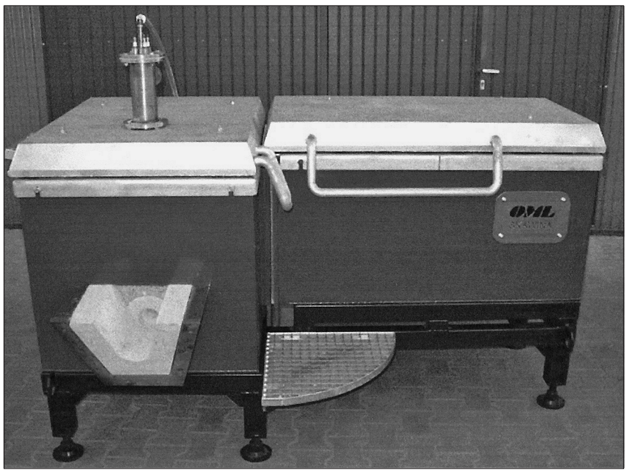

Figure 2. The scheme of URC – 7000 reactor [4]

non-wettable nonmetallic particles from liquid metal is the main task of this chamber. In filtration chamber the filter is installed, and above it in the upper part of cover - a burner. It was installed to warm up the filter and chambers.

PHYSICAL MODEL OF BARBOTAGE

Barbotage is a process during which the refining gas is blown through the liquid metal in order to remove hydrogen and others particles. The flow rate of refining gas has a great impact on the shape of gas bubbles. This influence is presented in Figure 3. The more flow rate of refining gas the greater the danger of creating the chain flow of gas. Table 2 shows the basic shapes of created gas bubbles depending on their diameters. The analysis of these shapes leads to the conclusion that it is necessary to introduce the equivalent bubble diameter. This is the diameter, the bubble would have had if it had been a spherical one [5].

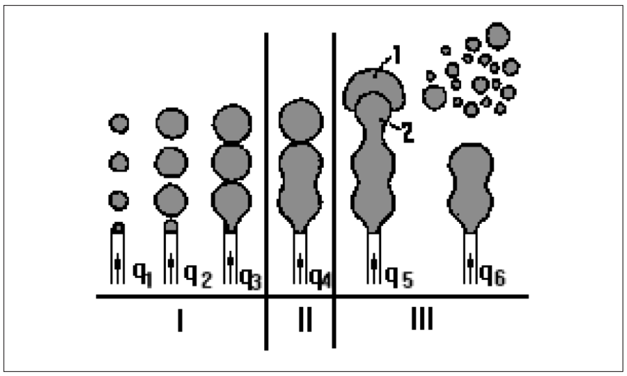

Figure 3. The influence of flow rate of a refining gas on creating the gas bubbles: I - free movement of gas bubbles, II - a creation of bubbles chain, the space between bubbles disappeared, bubbles can be deformed and the film between them is broken, III - bubble 2 hits the bubble 1 and then their disintegration is observed, as a result the chain of bubbles with different diameters is created [5,6]

For the moderate flow rate of the refining gas, the equivalent bubble diameter, which is between 0,005 to 0,015 m - depends only on the flow rate of a refining gas.

Table 2. **Possible bubbles shapes and their diameters [5]**

Bubbles diameter / m	Bubbles shape
0,005 – 0,007	spherical
0,008 – 0,01	ellipsoidal
0,01	spherical cap
continuation of growing	wobbling

The physical model of the refining process conducted in a continuous reactor was created to determinate the level of gas bubble dispersion in liquids. There are five patterns of dispersion of the gas bubbles in a liquid metal [5,7]:

a) no dispersion – the flow of refining gas is rather small, therefore there is almost a lack of gas bubbles in liquid metal,
b) minimum dispersion – the flow of refining gas is small or moderate and the mixing gas bubbles with metals is also small,
c) intimate dispersion – the flow rate of refining gas is moderate, this is why the level of mixing gas with metals is rather good, there is lack of dispersion only at the side walls and between the porous plugs,
d) uniform dispersion – the flow rate of refining gas is moderate, therefore gas bubbles are very well mixed with metal in the whole volume of reactor,
e) overdispersion – the flow rate of refining gas is high, so gas bubbles are very well mixed with the liquid metal, however the creation of swirls take place and the chain flow of gas is observed, swirls on the surface cause the secondary contaminations.

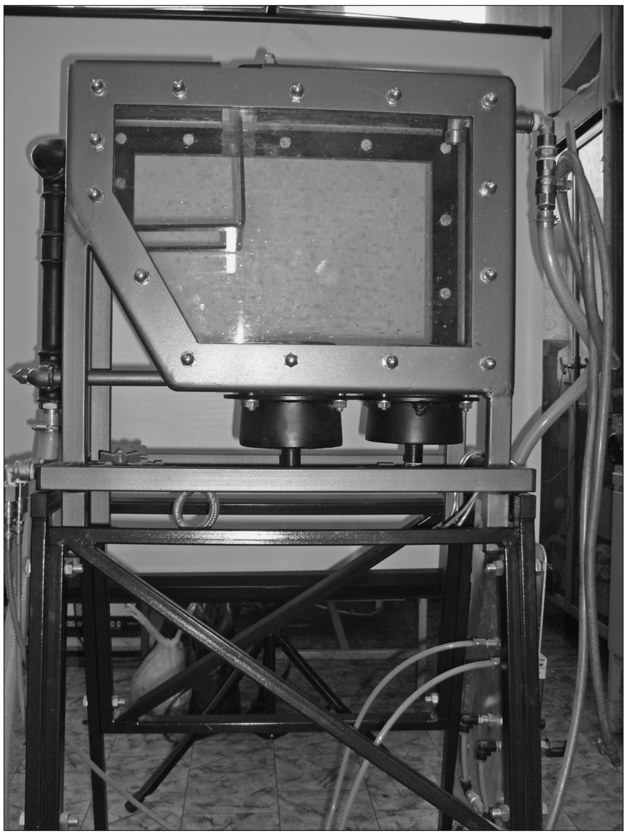

Figure 4. Scheme of modelling unit

Figure 5. Ceramic porous plug

Figure 6. Ceramic foam filter

Figure 7. Rotameters to measure the flow rate of refining gas

MODELLING RESEARCH

Modelling research was carried out in the Metallurgy Department at the Silesian University of Technology. The influence of flow rate of refining gas on bubble dispersion in liquid metal was investigated. Modelling unit was created in IMN-OML in Skawina on a scale of 1:4. It is very helpful to simulate the conditions which are in liquid metal during the refining process. Figure 4 presents the scheme of this modeling unit.

This unit consists of a steel frame and walls made from Plexiglass. This kind of construction helps to observe the gas bubble dispersion in the whole volume of liquids. In the unit at the bottom, two ceramic porous plugs (Figure 5) were installed. Identical plugs are installed in real URC-7000 reactor. Size of plugs was a perfect match with the scale of the unit. In this unit the water inlet and outlet was also installed. It is possible to regulate water flow rate.

To simulate the real conditions of refining process in URC-7000 the ceramic foam filter (Figure 6) was also fixed in the modelling unit. It is also equipped with two rotameters (Figure 7) which give the possibility to measure the flow rate of a refining gas.

RESULTS OF THE RESEARCH

The oxygen soluble in water was removed as an analogy to hydrogen desorption process from aluminium. The modelling research was carried out changing the flow rate of refining gas in the range from 2 dm^3/min to 30 dm^3/min. The air was blown through the modelling unit. Gas bubble dispersion in liquids was registered by the digital camera. Water was used as a modeling liquid, because their properties are similar to aluminium properties (Table 3).

Figures 8, 9, 10 and 11 present the examples of minimum, intimate, uniform dispersion and overdispersion. All examples were shortly characterized.

Table 3. **Properties of liquids used in modelling research**

Liquid properties		
Kind of liquid	**Water**	**Aluminium**
Temperature / K	293	973
Dynamic viscosity η / Pa · s	0,00101	0,00100
Surface tension σ / N/m	0,072	0,680
Density ρ / kg/m^3	1000	2700
Criterial number		
Weber number $We=v^2L\,\rho/\sigma$	0,467	0,133
where: L – plug diameter = 0,11m v – linear speed = 0,0175 m/s		

In Table 3 there are also presented values of Weber number which shows the ratio of inertial forces to surface tension forces. The class of value for water and alu-

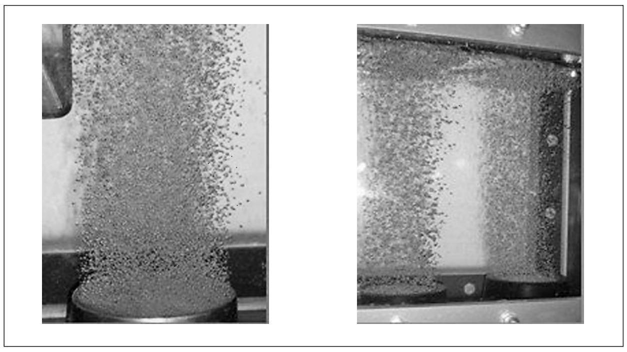

Figure 8. Minimum dispersion – single gas bubbles climb to the top of the unit, dispersion is observed only in the area of gas bubble creation, there is no mixing in the whole liquid volume

minium is the same, so water is suitable in such kind of modelling research.

Basing on this the flow rate of refining gas was assign to the kind of gas bubble dispersion in the liquids. This selection is presented below:

- q = 2-6 dm^3/min – minimum dispersion,
- q =7–10 dm^3/min – intimate dispersion,
- q =11–25 dm^3/min – uniform dispersion,
- q > 25 dm^3/min – overdispersion.

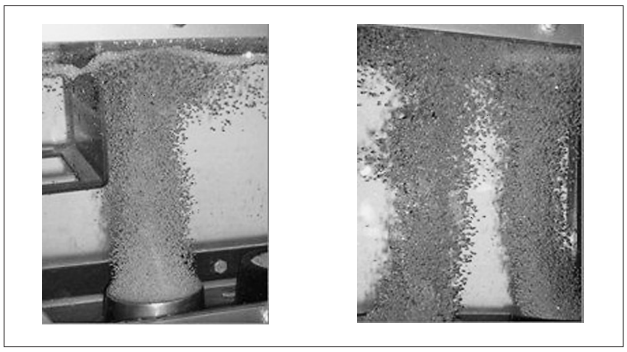

Figure 9. Intimate dispersion - single gas bubbles climb to the top of the unit, mixing of the gas bubbles with liquid is good, lack of dispersion is only observed near the side walls and in the central part of the unit between the porous plugs

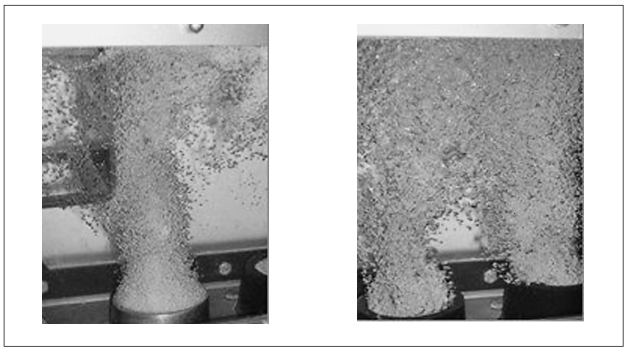

Figure 10. Uniform dispersion – single gas bubbles in places start to create the chains, gas bubbles are very well mixed with the liquid, the lack of dispersion is observed only in the lower part of the unit (near the porous plugs), swirls on the surface cause good mixing in the upper part of the unit

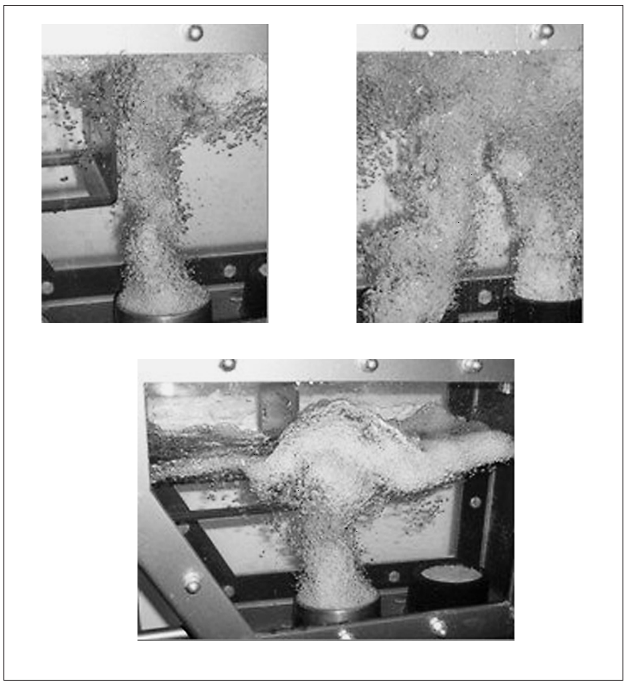

Figure 11. Overdispersion – gas bubbles create the chains and therefore the chain flow of refining gas is observed, this flow creates favourable conditions for swirls to form, gas bubbles are very well mixed with the liquid, however swirls cause that the dispersion moves back from some parts of the modelling unit

SUMMARY

Modelling research which was carried out, confirmed the existence of four schemes of dispersion. It is hard to claim that the first case of dispersion: no dispersion exists when the refining gas is blown through the liquid. Even when the flow rate of refining gas is very low (q = 1 – 2 dm^3/min) single gas bubbles go up to the surface creating a stream of bubbles, so minimum dispersion is obtained. The most desirable case of dispersion is uniform dispersion. The flow rate in the refining process should be in range from 11 to 25 dm^3/min. Flow rate of refining gas about 15 dm^3/min is considered to be optimal. If the flow rate is bigger than 15 dm^3/min creating chains of bubbles can be observed. The most dangerous for refining process is when the hydrogen and particles which are removed come back to the liquid metal. That can happen when the flow rate is too big. The swirls on the top of liquid metal cause that part of removed impurities goes back to metal.

Generating tiny small bubbles of refining gas and the suitable dispersion in the liquid metals is very profitable for the speed and effectiveness of barbotage process. Because process of bubbles creating and bubbles movement is very complex it is hard to describe them in an analytical way. Thus the modelling research is carried out. Its aim is to establish the creation condition of the biggest area of mass exchange. This is possible by obtaining large amount of the smallest bubbles. It is of course very important to keep the geometrical resemblance (as it was done in this work). Apart from this the equality of criterial number has to be kept. So the next stage of this work should concentrate on this criterial number resemblance.

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Note: The responsible person for English language is the M. Saternus.