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EFFECTS OF PRESSURE ON THE RATE OF TIN EVAPORATION FROM LIQUID IRON

WPŁYW CIŚNIENIA NA SZYBKOŚĆ PAROWANIA CYNY Z CIEKŁEGO ŻELAZA

In the paper, tin elimination from liquid iron alloy via low-pressure evaporation has been analysed. The experiments were performed using a single-chamber VIM 20-50 vacuum induction furnace at 1923 K and the operating pressure of 0.05 to 557 Pa.

Keywords: liquid iron, evaporation, vacuum induction furnace, mass transfer coefficient

W prezentowanej pracy dokonano analizy procesu eliminacji cyny z ciekłego stopu żelaza na drodze odparowania w warunkach obniżonego ciśnienia. Eksperymenty realizowano w jednokomorowym indukcyjnym piecu próżniowym VIM 20-50 w temperaturze 1923 K i zakresie ciśnień roboczych od 0,05 do 557 Pa.

1. Introduction

The basic sector that provides the market with construction materials is the metallurgical industry. At present, the worldwide metallurgy is dominated by two technologies. The first technology is based on production of pig iron in a blast furnace and its processing in oxygen converters to obtain steel while the other technology is aimed at steel smelting using secondary raw materials in electric arc furnaces (EAFs). In recent years, the contribution of the latter technology to global steel production has been 28% to 33%. Prognoses for 2050 suggest that the proportion of EAF process and the conventional technology (BOF) of steel production will be reversed with regard to the present situation [1], resulting in an increase in scrap material use from 45% (now) to 60% compared to iron ores for the whole steel production.

Steel scrap, used as raw material in the discussed technology, shows high chemical composition variations, which mainly results from a significant change in the structure of scrap that is processed in metallurgical devices. The use of so-called process scrap in the charge decreases with increasing application of post-consumption scrap. Markedly reduced amounts of the process scrap lead to the use (for metallurgical purposes) of higher amounts of post-consumption scrap, mostly from used cars or household products. This kind of scrap is a potential source of impurities because it may contain steel components fused with other materials that are undesirable for the metallurgical charge. This group of impurities consists of non-ferrous metals (copper, tin, lead, zinc, bismuth etc.); their sources may be metal and paint coatings or components of electrotechnical appliances. When the impurities can be eas-

ily removed during the steelmaking process, their increased contents in the charge do not pose any problem contrary to a charge with higher amounts of non-ferrous metals – their elimination during classical steel smelting is very difficult. Such impurities are e.g. copper and tin.

High contents of these metals in the scrap material affect their contents in EAF steels. Due to the fact that tin, like copper, forms fusible eutectic systems with iron that are seen at grain boundaries during solidification, its high contents may induce hot brittleness of steel. This unbeneficial effect of tin on steel properties has led to studies on its possible removal from liquid iron alloys.

In the paper, tin elimination from liquid iron alloy via low-pressure evaporation has been analysed. It should be noted that in literature, few papers regarding the kinetics of tin removal from liquid iron melted using the VIM technology can be found [2-4] and those available mainly refer to tin removal using the VOD or plasma melting technologies [5-8].

2. Experimental part

The subjects of investigations were synthetic Fe-Sn alloys made of ARMCO iron and p.a. grade tin.

All experiments were performed using a single-chamber SECO-WARWICK VIM 20-50 vacuum induction furnace. The research device is illustrated in Fig. 1.

During the experiment, an alloy sample of specific weight was placed in a magnesite crucible mounted inside the furnace induction coil. After closing the furnace, pre-specified vacuum was generated by the pump system. The pressure level was

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obtained by means of mechanical, Roots and diffusion pumps. During the next stage of experiment, the charge material was heated up to the set temperature and a 30-minute melting process was conducted. At precisely determined time intervals, metal samples were collected and subjected to a chemical analysis. For temperature measurements, a pyrometer and a PtRh-Pt thermocouple (as a control device) were used. When the test was completed, liquid metal was poured into the graphite ingot mould. The metal was also tested for tin contents. The chemical analyses were performed using the atomic absorption spectrometry technique with a Perkin Elmer analyser.
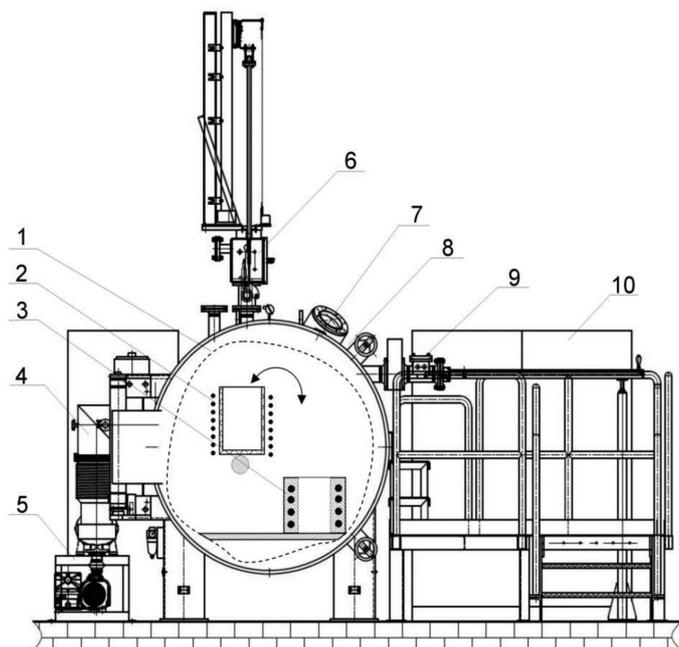

Fig. 1. A diagram of VIM 20 – 50 furnace: 1 – furnace chamber with water-cooled jacket; 2 – induction coil with electric drive enabling pouring out the crucible content; 3 – ingot mould with the heating option; 4 – diffusion pump; 5 – system of mechanical pumps; 6 – mechanical sampling system; 7 – eyehole; 8 – coil tilt control system; 9 – mechanical additives introduction system; 10 – control cabinet

The basic experimental parameters are presented in Table 1.

TABLE 1

Basic experimental parameters

Process temperature, K	Sn content in the alloy, %mass	Operating pressure, Pa	Sample weight, g
1923	0.2-1.5	0.05 to 557	12000

3. Study results

A change of tin concentration in liquid iron during melting was correlated using the following algorithmic function:

$$-\log \frac{C_{Sn}^t}{C_{Sn}^0} = A \cdot t \tag{1}$$

where: C_{Sn}^t – tin concentration in the alloy after time t, %mass,
C_{Sn}^0 – initial tin concentration, %mass,
t – time, s,
A – constant.

To determine the value of overall mass transfer coefficient based on the experimental results, the following equation [9] was applied:

$$2.303 \log \frac{C_{Sn}^t}{C_{Sn}^o} = -k \cdot \frac{F}{V}(t - t_o) \tag{2}$$

where: F – evaporation areas (the interface),
V – liquid metal volume,
$(t - t_o)$ – process duration,
k – overall mass transfer coefficient.

For the calculations, the "A" value of the equation (1), which describes a tin concentration change versus time, was used.

In Table 2, values of the experimental overall mass transfer coefficient determined based on the equation (2) for tin evaporation from liquid iron are presented.

TABLE 2

Values of the experimental overall mass transfer coefficient for tin in the process of vacuum Fe-Sn alloy melting

No.	Sn content in the alloy, % mass	Pressure, Pa	k_{Sn}, m s^{-1}
1	0.2	557	0.17·10^{-5}
2	0.2	101	0.83·10^{-5}
3	0.2	24.3	0.93·10^{-5}
4	0.5	2	1.28·10^{-5}
5	1.5	2	1.40·10^{-5}
6	1	2	1.21·10^{-5}
7	0.2	1.2	1.29·10^{-5}
8	1.5	0.09	1.17·10^{-5}
9	0.2	0.05	1.40·10^{-5}
10	0.5	0.05	1.44·10^{-5}
11	1	0.05	1.46·10^{-5}
12	1.5	0.05	1.41·10^{-5}

4. Discussion of results

The study involved a kinetic analysis of tin evaporation from liquid iron with respect to the pressure effects on the process. For all experiments, reduced tin contents in the alloy were observed. It is illustrated by the data presented in Fig. 2.
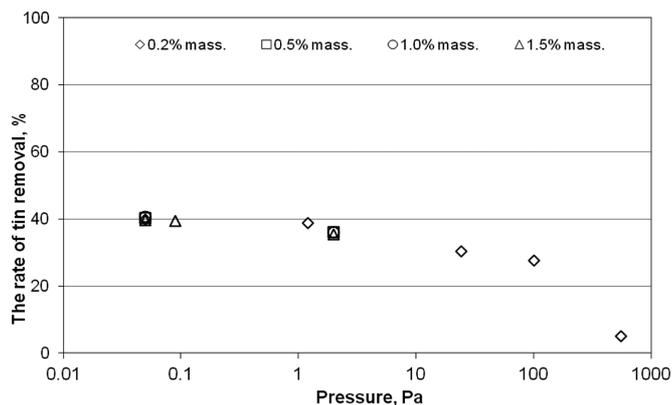
Fig. 2. Level of tin elimination from the Fe-Sn alloy

The determined values of experimental overall mass transfer coefficient are $0.17 \cdot 10^{-5}$ to $1.46 \cdot 10^{-5}$ ms^{-1} (Table 2). They are in a good agreement with the literature data obtained by other authors [2, 3].

In the investigations, significant effects of pressure on the rate of the process were demonstrated. For the pressure below 10 Pa, practically no effect of pressure on the process rate was observed (Fig. 3), which means that for these pressures, the analysed process is not determined by mass transfer in the gaseous phase. To confirm this observation, a theoretical mass transfer coefficient (k_{Sn}^t) was calculated, assuming that the process rate is determined by the two other stages, i.e. mass transfer in the liquid phase (β_{Sn}^l) and evaporation from the interface (k_{Sn}^e).

Thus, it was assumed that for pressures below 10 Pa, the following equation is true:

$$\frac{1}{k_{Sn}^t} = \frac{1}{\beta_{Sn}^l} + \frac{1}{k_{Sn}^e} \tag{3}$$
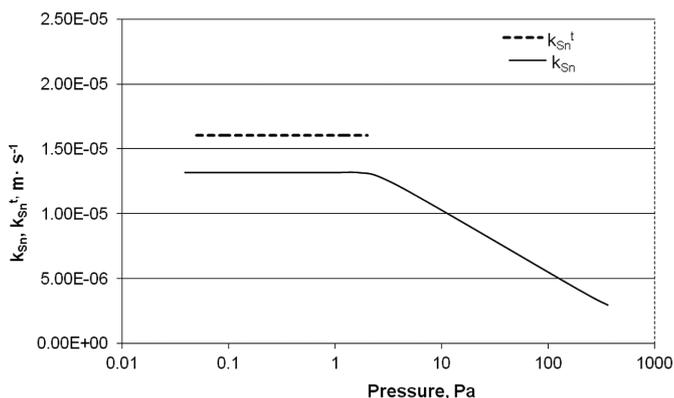

Fig. 3. Effects of pressure on the overall mass transfer coefficient for the process of tin elimination from liquid iron (0.2 %mass Sn)

Moreover, the investigations showed that for processes conducted at pressures above 100 Pa, diffusion control is observed and the determining stage is mass transfer in the gaseous phase. The summary resistance related to the other two stages ranged from 8% to 45% of the overall process resistance.

Kinetically, the alloy composition may affect all stages of the evaporation process. For mass transfer in the liquid phase, this effect is expressed by a value of the diffusion coefficient

for the evaporating component in the liquid metal alloy as well as by the near-surface velocity of the inductively stirred metal [10-14]. When the process is determined by this stage, the rate of the process should depend on the alloy composition. This effect was observed for the experiments conducted at 0.05 Pa where an increase in tin content in iron is accompanied by an increased rate of its evaporation. It is illustrated by the data presented in Fig. 4.
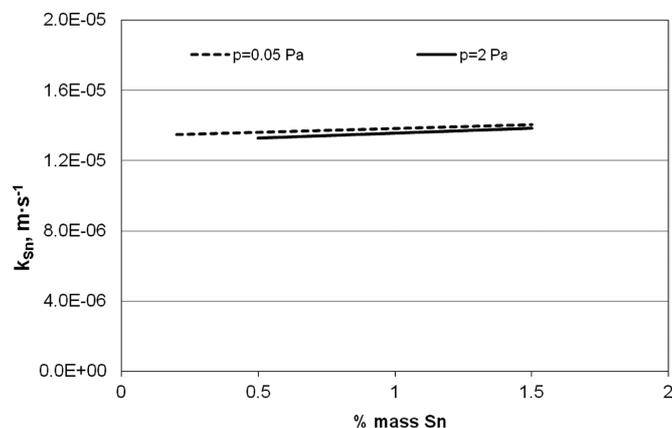

Fig. 4. Effects of tin content in the alloy on the rate of tin evaporation from Fe-Sn

5. Summary

The experimental results of Fe-Sn alloy vacuum refining in the induction furnace allowed for the following conclusions:

- Within the range of 10 Pa to 100 Pa, a strong relationship between the overall mass transfer coefficient and pressure in the system is observed, which may mean that within this pressure range, the process control is changed and resistances of mass transfer in the gaseous phase over-lap resistances in the liquid phase. At pressures below 10 Pa, the kinetic parameters stabilise so the process is determined by mass transfer in the liquid phase and the interface phenomena.
- At pressures above 100 Pa, it can be assumed that the process occurs in the diffusion area and it is controlled by resistances of mass transfer in the gaseous phase.

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