

ANALYSIS OF THE OPTIONS OF COPPER REMOVAL FROM LIQUID IRON BY EVAPORATION

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This paper describes an analysis of the Fe-Cu system from the perspective of determination of the influence of temperature (1 873 – 2 043 K) and copper mass concentration (0,1 – 1,5 % wt.) in liquid metal on the options of separation by vacuum refining. In order to establish the options of evaporating a component from the liquid metal in the system being analysed, Olette's volatility ratio was determined.

Key words: metallurgy, evaporation, iron alloys, options of copper

Analiza opcija odstranjivanja bakra iz tekućeg željeza ispravanjem. U radu se opisuje analiza Fe-Cu sustava sa stanovišta određivanja utjecaja temperature (1 873–2 043 K) i koncentracije bakra (0,1–0,5 % mas.) u tekućem metalu na izbor separacije vakuumskom rafinacijom. Da bi se postigle opcije isparavanja komponente iz tekućeg metala u analiziranom sustavu, određen je Oletteov omjer isparavanja.

Ključne riječi: metalurgija, isparavanje, željezne slitine, odstranjivanje bakra

INTRODUCTION

The phenomenon of evaporation of volatile components of metal bath plays a significant role in numerous technological processes of extractive metallurgy. In this context, one should mention such operations as steel vacuum processing, smelting of steel and special alloys in vacuum induction furnaces, rectification of non-ferrous metals or the metal scrap processing technologies [1-4].

On one hand, vacuum-based metallurgical technologies enable obtaining metals characterised by high purity, which consequently find a wide range of applications in numerous industries, and on the other hand, they enable removal of impurities which cannot be eliminated by other means.

EQUILIBRIUM COMPOSITION OF THE GASEOUS PHASE OVER THE LIQUID FE-CU SOLUTION

In order to calculate partial pressures of vapours of the gaseous phase components, the following chemical reactions were taken into consideration:



The basic dependencies used in the calculations were those describing changes of enthalpy of free evaporation processes [5].

In order to calculate the equilibrium pressure of the gaseous phase monomers, dependencies (3) and (4) were used, however, the equilibrium pressures over pure bath p_i^o were calculated based on the data applicable to standard free evaporation enthalpy of the individual components.

$$p_i = p_i^o \cdot a_i = p_i^o \cdot \gamma_i \cdot X_i = \left[\exp\left(-\frac{\Delta_p G_i^o(T)}{RT}\right) \right] \cdot \gamma_i \cdot X_i \quad (3)$$

and

$$K_j = \exp\left(-\frac{\Delta_p G_j^o(T)}{RT}\right) \quad (4)$$

where:

p_i and p_i^o – pressures of the i^{th} component over the solution and pure bath correspondingly / Pa,
 γ_i – activity coefficient for component “i” in the alloy,
 X_i – mole fraction of component “i” in the alloy,
 R – gas constant / $\text{J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$,
 T – absolute temperature / K,
 K_j – equilibrium constant for the j^{th} reaction involving participation of the gaseous phase components,
 $\Delta_p G_i^o(T)$ – standard free enthalpy of the evaporation processes and chemical reactions involving participation of the gaseous phase correspondingly / $\text{J} \cdot \text{mol}^{-1}$.

For the sake of the calculations, the free enthalpy values for the Fe-Cu system were extracted from the thermodynamic database of the HSC Chemistry 6 computer programme [6] (Table 1).

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Table 1 Enthalpy of free reactions in Fe-Cu system in the temperature 1 873 – 2 048 K.

Temp. / K	Reactions occurring in the Fe-Cu system	
	$\Delta_p G_i^o(T) / \text{kJ} \cdot \text{mol}^{-1}$	
	$\text{Cu}_{(l)} = \text{Cu}_{(g)}$	$\text{Fe}_{(l)} = \text{Fe}_{(g)}$
1 873	105,12	146,57
1 898	102,37	143,51
1 923	99,63	140,45
1 948	96,89	137,40
1 973	94,15	134,35
1 998	91,42	131,31
2 023	88,69	128,28
2 048	85,97	125,26

For the sake of the calculations, the iron activity value was assumed to equal one. In order to calculate the activity coefficient for copper in liquid alloy, dependence (7) was applied:

$$\ln \gamma_{Cu} = \ln(\gamma_{Cu}^{\infty}) + \varepsilon_{Cu}^{Cu} \cdot X_{Cu} \quad (5)$$

where:

$$\ln(\gamma_{Cu}^{\infty}) = 4\,370 / T \quad (6)$$

It was also assumed that:

$$\varepsilon_{Cu}^{Cu} = -8\,740 / T \quad (7)$$

Figure 1 depicts the equilibrium pressures of vapours for pure components of iron and copper, whereas Figure 2 shows the changes of the copper vapours pressure obtained based on the calculations conducted and depending on the temperature and the copper content in liquid iron.

The analysis of the equilibrium composition of the gaseous phase over the liquid solution of Fe-Cu has implied that the equilibrium pressure value for copper practically exceeds the pressure of iron vapours within the whole range of pressures and temperatures applied, except for the pressure value for the copper mass concentration of 0,1 % above the temperature of 1 923 K.

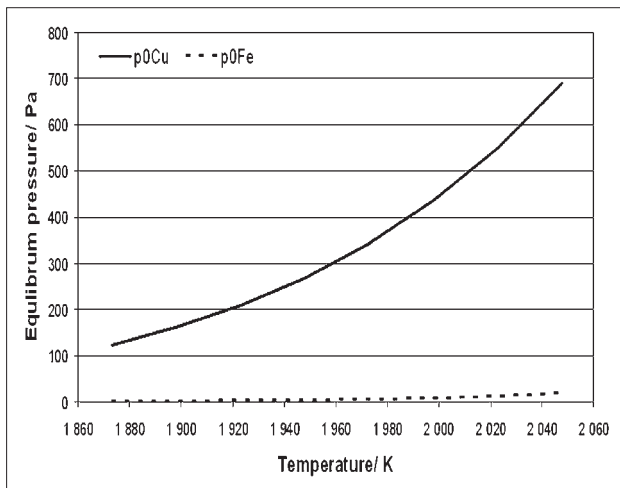


Figure 1 Change of iron and copper equilibrium pressure for pure components

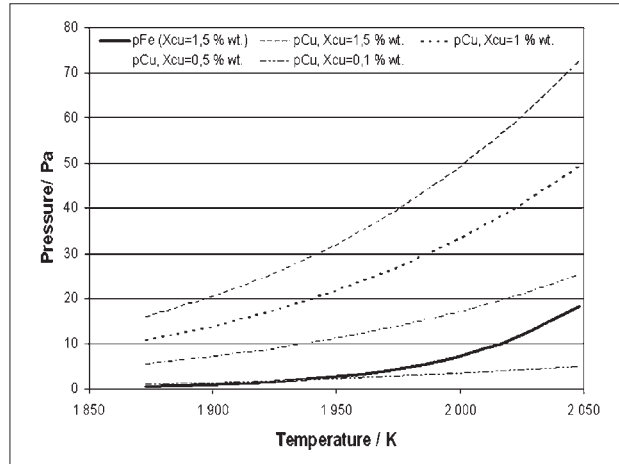


Figure 2 Change of copper pressure depending on its content in liquid iron and sample iron pressure over the Fe-Cu solution on the Cu mass content of 1,5 %.

RATIO COEFFICIENT

According to Ollette [8], the quantity conditioning the possibility of evaporating a component from a liquid metallic alloy under the conditions of reduced pressure is the so-called coefficient ratio, also referred to as the evaporation ratio. For a two-component alloy and the metallic vapours in the atomic form, the ratio coefficient is determined based on the following dependence:

$$\Phi_i = \left(\gamma_i \cdot \frac{P_i^0}{P_A^0} \right) \cdot \left(\frac{M_A}{M_i} \right)^{0.5} \quad (8)$$

where:

- Φ_i – ratio coefficient,
- M_A – molar mass of the primary alloy component,
- M_i – molar mass of the evaporating component.

According to Ollette, the process of evaporation of a component in a metallic form is possible if the following condition is satisfied:

$$\Phi_{i(j)} > 1 \quad (9)$$

The volatility ratio change for copper vapours within the range of temperature from 1 873 to 2 048 K has been depicted in Figure 3.

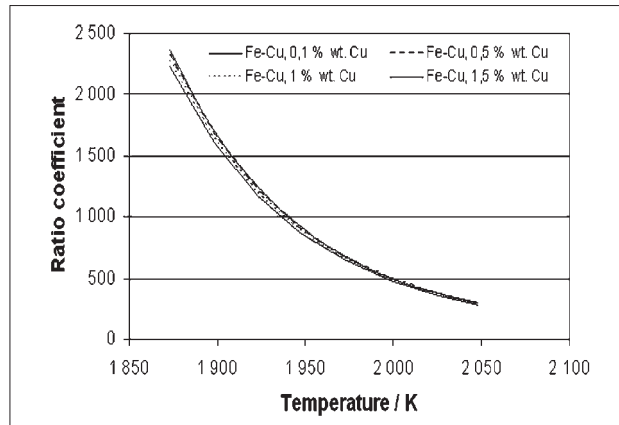


Figure 3 Change of ratio coefficient for copper vapours depending on its content in the liquid iron and temperature.

The data provided in Figure 3 imply that for liquid Fe-Cu alloys within the range of temperatures being analysed, Ollette's condition is satisfied which shows the possibility of removing copper by evaporation in the process of remelting under the conditions of reduced pressure.

CONCLUSIONS

Based on the analysis of the equilibrium composition of the gaseous phase over the liquid Fe-Cu solutions, it can be concluded that the increase of the copper content in the liquid alloy causes a considerable increase of the copper vapour pressure as compared with the iron vapour. The foregoing means that the processes of removing copper from the liquid iron can be conducted through evaporation of the metallic admixture. Having determined Ollette's volatility ratios, the possibility of removing copper by evaporation was confirmed.

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Note: P. Nowak is responsible for English language, Katowice, Poland.