

## VISCOSITY OF Cu-Zn ALLOYS

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One of the basic parameters that characterize a liquid phase is its viscosity. In the paper, the results of viscosity measurements for copper, copper-zinc alloys with 5 %wt. Zn and 10 %wt. Zn as well as Cu-Zn alloys with small additions of antimony, selenium and sulfur are presented. The viscosity measurements were conducted by means of a viscometer using the phenomenon of damping rotational vibrations of the crucible by filling the liquid metal. It was observed that the additions of zinc, antimony and selenium resulted in the viscosity reduction while the addition of sulfur led to its increase.

*Key words:* viscosity, viscometer, copper alloys, Arrhenius Equation, Frenkel Equation

**Viskoznost Cu-Zn legura.** Jedan od osnovnih parametara koji karakteriziraju tekuću fazu je njena viskoznost. U radu su prezentirani rezultati mjerenja viskoznosti za Cu, Cu-Zn leguru sa 5 % Zn i 10 % Zn, kao i za Cu-Zn leguru sa malim dodatkom antimona, selena i sumpora. Mjerenje viskoznosti je provedeno pomoću viskozometra korištenjem fenomena prigušenja rotacijske vibracije lonca za taljenje kod ispunjavanja tekućim metalom. Primjećeno je da dodatak cinka, antimona i selena rezultira smanjenjem viskoznosti, dok kod dodavanja sumpora povećava se viskoznost.

*Ključne riječi:* viskoznost, viskozimetar, legura bakra, Arrhenius jednadžba, Frenkel jednadžba

### INTRODUCTION

Viscosity, also called internal friction, is one of the basic parameters of liquids. There are two kinds of viscosity: dynamic viscosity with a unit of Pa·s or P (poise) and kinematic viscosity expressed in m<sup>2</sup>/s or St (stokes). The kinematic viscosity is a ratio of dynamic viscosity of given liquid and its density at the same temperature. In case of liquid metals and alloys, mainly due to experimental difficulties at high temperature (comparable to those encountered during surface tension [1] or density measurements [2]), viscosity reference data concerning those materials are rare. In the paper, the results of viscosity measurements for copper, copper-zinc alloys with 5 %wt. Zn and 10 %wt. Zn as well as Cu-Zn alloys with small additions of antimony, selenium and sulfur are presented. The viscosity measurements were performed by means of a viscometer utilizing the phenomenon of damping of the crucible rotational vibrations by the filling liquid metal.

### METHODS AND RESULTS

Viscosity measurements were performed with the use of a viscometer described in references [3, 4]. In case of a viscometer whose theory's author is Shvidkovskii [5], the phenomenon of damping of the crucible rotational vibrations by the filling liquid metal is ap-

plied. A mirror and a ceramic tube with a crucible fixed to its end are attached to a molybdenum filament. A light beam is directed at the mirror. During the system movements, the light reflected by the mirror fell onto a scale which allow the vibration period and amplitude measurements. The crucible is placed inside a graphite heater. The temperature of liquid metal is measured by means of a thermoelement situated directly below the crucible bottom. Movement of the suspension system is achieved with the use of a stator which generated a magnetic field affecting the molten metal inside the crucible. Through a feeder, antimony, selenium and sulfur additions are introduced into the crucible. During the measurements, helium is used as a protective gas. A schematic diagram of the measuring apparatus is presented in Figure 1.

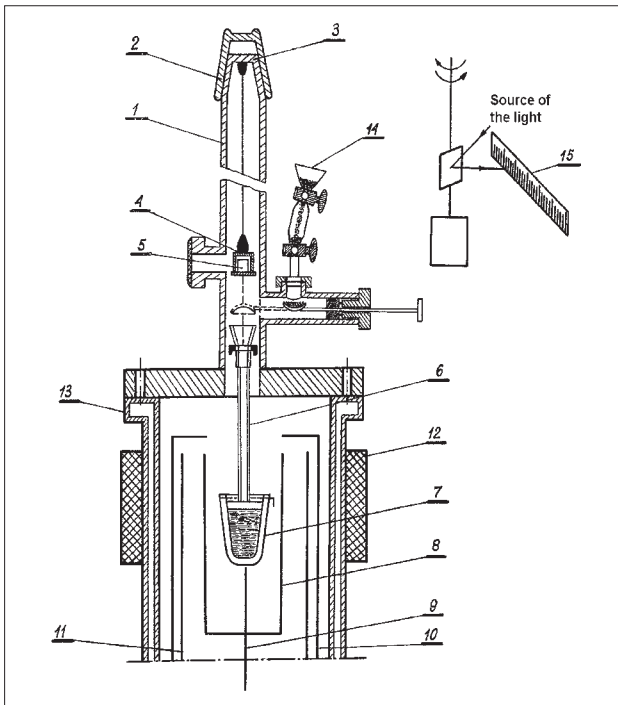
Viscosity is deduced by means of the equation [5-7]:

$$\nu = \frac{1}{\pi} \left( \frac{K}{mr} \right)^2 \frac{\left( \delta - \delta_0 \frac{\tau}{\tau_0} \right)^2}{\tau \gamma^2} \quad (1)$$

where:

- $\nu$  - coefficient of kinematic viscosity,
- $K$  - moment of inertia of the moving system,
- $m$  - specimen mass,
- $r$  - internal radius of the crucible,
- $\delta$  - logarithmic decrement of vibration damping of the system with the specimen,

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**Figure 1** A schematic diagram of the viscometer (1 – housing, 2 – cap, 3 – mount ring of the suspension system, 4 – frame, 5 – mirror, 6 – ceramic tube, 7 – crucible, 8 – heater, 9 – thermoelement, 10 – metal screen, 11 – ceramic shield, 12 – stator, 13 – water jacket, 14 – feeder, 15 – scale).

$\delta_o$  - logarithmic decrement of vibration damping of the empty system,

$\tau$  - vibration period of the system with the specimen,

$\tau_o$  - vibration period of the empty system,

$\gamma$  - unitless quantity [5-7].

The viscosity measurements were performed at 1 373 K, 1 423 K and 1 473 K and the results were 0,489 cSt, 0,461 cSt and 0,423 cSt, respectively. The measure-

**Table 1** The chemical compositions of alloys.

No.	Cu /%wt.	Zn /%wt.	Sb /%wt.	Se /%wt.	S /%wt.
1	95,0	5	-	-	-
2	94,9	5	0,1	-	-
3	94,6	5	0,4	-	-
4	94,9	5	-	0,1	-
5	94,6	5	-	0,4	-
6	94,9	5	-	-	0,1
7	94,6	5	-	-	0,4
8	90,0	10	-	-	-
9	89,9	10	0,1	-	-
10	89,6	10	0,4	-	-
11	89,9	10	-	0,1	-
12	89,6	10	-	0,4	-
13	89,9	10	-	-	0,1
14	89,4	10	-	-	0,4

**Table 2** The Arrhenius and Frenkel Equations used for alloy viscosity description.

No.	$\nu = A \exp \frac{B}{T}$ /cSt	$\nu = CT \exp \frac{D}{T}$ /cSt
1	$\nu = 0,187 \exp \frac{884}{T}$	$\nu = 4,98 \cdot 10^{-5} T \exp \frac{2260}{T}$
2	$\nu = 0,210 \exp \frac{685}{T}$	$\nu = 5,64 \cdot 10^{-5} T \exp \frac{2045}{T}$
3	$\nu = 0,178 \exp \frac{890}{T}$	$\nu = 4,86 \cdot 10^{-5} T \exp \frac{2230}{T}$
4	$\nu = 0,166 \exp \frac{1030}{T}$	$\nu = 4,45 \cdot 10^{-5} T \exp \frac{2400}{T}$
5	$\nu = 0,178 \exp \frac{916}{T}$	$\nu = 4,79 \cdot 10^{-5} T \exp \frac{2280}{T}$
6	$\nu = 0,196 \exp \frac{1020}{T}$	$\nu = 5,09 \cdot 10^{-5} T \exp \frac{2440}{T}$
7	$\nu = 0,224 \exp \frac{800}{T}$	$\nu = 5,85 \cdot 10^{-5} T \exp \frac{2210}{T}$
8	$\nu = 0,210 \exp \frac{730}{T}$	$\nu = 5,55 \cdot 10^{-5} T \exp \frac{2100}{T}$
9	$\nu = 0,222 \exp \frac{600}{T}$	$\nu = 6,09 \cdot 10^{-5} T \exp \frac{1940}{T}$
10	$\nu = 0,189 \exp \frac{800}{T}$	$\nu = 5,02 \cdot 10^{-5} T \exp \frac{2200}{T}$
11	$\nu = 0,207 \exp \frac{720}{T}$	$\nu = 5,60 \cdot 10^{-5} T \exp \frac{2070}{T}$
12	$\nu = 0,229 \exp \frac{550}{T}$	$\nu = 6,12 \cdot 10^{-5} T \exp \frac{1930}{T}$
13	$\nu = 0,207 \exp \frac{1120}{T}$	$\nu = 1,25 \cdot 10^{-5} T \exp \frac{4570}{T}$
14	$\nu = 0,164 \exp \frac{140}{T}$	$\nu = 4,25 \cdot 10^{-5} T \exp \frac{2820}{T}$

ments for the alloys were performed in the temperature range of 1 273 – 1 523 K.

The obtained viscosity values of copper-zinc alloys and Cu-Zn alloys with additions of antimony, selenium and sulfur are described by means of the most commonly applied Arrhenius Equation:

$$\nu = A \exp \frac{B}{T} \quad (2)$$

and Frenkel Equation:

$$\nu = CT \exp \frac{D}{T} \quad (3)$$

where:

A, B, C, D – constants,

T – temperature.

The chemical compositions of alloys used for viscosity measurements as well as the equations applied for its description are presented in Tables 1 and 2, respectively.

## SUMMARY

The viscosity measurements resulted in the observation that both for pure copper and all investigated alloys, viscosity decreases with the rise of temperature. Fur-

thermore, it was found that additions of zinc, selenium and antimony result in viscosity decrease, while the effect of sulfur addition is viscosity increase. The viscosity increase is probably associated with formation of sulfides whose influence is comparable to that of solid inclusions in liquid metals.

## REFERENCES

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