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THE INFLUENCE OF THE COMPLEX ELECTRIC PERMITTIVITY AND GRAIN SIZE ON MICROWAVE DRYING OF THE GRAINED MINERALS

The character of interactions of microwaves with selected minerals at their drying was investigated by means of components of complex permittivity and the parameters of penetration and absorption determined from them. The course of microwave drying assumed on the basis of these parameters corresponds to experimental results. A positive influence of lower grain size of minerals on their microwave drying has been proved.

INTRODUCTION

Microwaves represent high frequency electromagnetic radiation the wavelength of which is in the interval 1–300 mm. Technical practice makes use of their thermal effect on an irradiated substance which has volumetric character (Metaxas A.C., Meredith R.J. 1983). The microwave heating can be used for treatment purposes particularly for drying of minerals, modification of their physical and chemical properties, improvement of effectiveness of flotation and leaching processes in ores or for desulphurization of coal (Metaxas A.C., Meredith R.J. 1983; Florek I., Lovas M. 1994; Haque K.E. 1987; Florek I., Murova I. 1994).

The microwave drying of solid substances depends on their electrical properties and technical parameters of the radiation source. With regard to current wide possibilities of selection of a suitable source the electric properties of the dried substance represent a factor which decides about the use of microwave drying. These properties are best expressed by complex permittivity (ε^*), improperly termed complex dielectric constant, which characterizes the behaviour of the relevant substance in a time dependent electric field by means of its real (ε') and imaginary components (ε''). The effect of microwave irradiation on a substance is routinely evaluated according to the size of its loss angle calculated from the ratio $\varepsilon''/\varepsilon'$ as $\tan \delta$.

The evaluation of microwave drying of substances by means of the loss angle is ambiguous. This parameter fails to express sufficiently the interaction of the

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substance with microwaves which can acquire the character of reflection, absorbance or transmission. In majority of substances, including minerals, these types of interactions are take place in varying ratios which affect the rate of drying. The course of microwave drying depends not only on the interaction with the dried substance but also on the direct effect of microwaves on water which is also involved in this process. It is, in fact, this particular phenomenon which extends considerably the possibilities of utilization of the mentioned way of drying.

Available references (Walkiewicz J.W., McGill S.L., Moyer L.A. 1988; Chen T.T., Dutrizac J.E., Haque K.E., Wyslouzil W., Kashyap S. 1984) show that the suitability of microwave drying of minerals has been evaluated only empirically according to the rate of their heating. This paper presents an investigation of the mentioned process in selected minerals by means of components of their ε^*, parameters dependent on them as well as by means of experimentally determined drying rates. At the same time, the influence of grain size of these minerals on their microwave drying was investigated.

EXPERIMENTAL PART

Microwave drying and evaluation of its rate was carried out on minerals in which various interactions with microwave radiation were presumed. Their list, together with their characteristics, is shown in Table 1.

The components of complex permittivity of the mentioned minerals were measured at the Millitary College of Aeronautics in Košice applying a method of a short-circuited waveguide. This method belongs among simple waveguide methods and enables rapid measurements (Florek I., Domaracky V. 1993; von Hippel A. 1954). The values of ε' and ε'' measured at the frequency of 9.3 of GHz are summarized in Table 2.

Table 1. Characteristics of selected minerals

Mineral	Chemical formula	Site*	Grade of sample
Chalkopyrite	$CuFeS_2$	Slovinky	27,1 % Cu , 31,5% Fe
Galena	PbS	Banská Štiavnica	83,6% Pb
Magnetite**	Fe_3O_4	Nižná Slaná	53,9% Fe
Siderite	$FeCO_3$	Rudňany	43,1% Fe
Quartz	SiO_2	Švedlar	99,8% SiO_2

*All mentioned sites are located in Slovak Republic

**Produced by roasting of siderite

The microwave drying of samples of selected minerals was carried out in a furnace Panasonic NN-5251 B, with the maximum output of 900 W at frequency of 2.45 GHz. Samples were placed on a rotating plate in the working space. To compare the microwave drying with the conditions of conventional drying an electric dryer STE 39 with an output of 2200 W, made by CHIRANA (Slovakia), was used.

The measurements and evaluation of moisture content of samples corresponded to the requirements of the standard ČSN 721012.

DISCUSSION

The influence of ε* of selected minerals on the process of their microwave drying was investigated by means of measured values of ε' and ε'' as well as of the loss angle tan δ calculated from them (Tab. 2).

These parameters differ considerably for individual minerals, however, they correspond to the data on the rate of their microwave heating (see Tab. 2). According to them the influence of microwaves on chalcopyrite and galena is manifested by their intensive warming up while the thermal influence on quartz and siderite is mild. The character of interactions of these minerals with microwaves, in particular the extent of their absorption and reflection, was evaluated according to the depth of penetration (γ) and coefficient of absorption of this radiation. There is a relationship between the mentioned parameters and components of ε*. The parameter γ was calculated using an equation obtained from the wave equation

$$\gamma = \frac{c}{2f\pi}\sqrt{\frac{2}{\sqrt{\varepsilon'^2 + \varepsilon''^2} - \varepsilon'}} \qquad (1)$$

Table 2 Parameters of microwave heating of selected minerals

Mineral	Complex imaginary component ε''	permittivity real component ε'	Loss angle tan δ	Depth of penetration γ[m]	Coefficient of absorption $A \cdot 10^9$	Heating rate [°C·min^{-1}]
Chalcopyrite	2,28	10,30	0,22	0,055	8,00	920*
Galena	1,41	11,10	0,12	0,097	4,96	137*
Siderite	0,36	6,66	0,05	0,275	1,23	69
Quartz	0,02	2,82	0,02	3,274	0,06	11*

*From the literature (Walkiewicz J.W., McGill S.L., Moyer L.A. 1988)

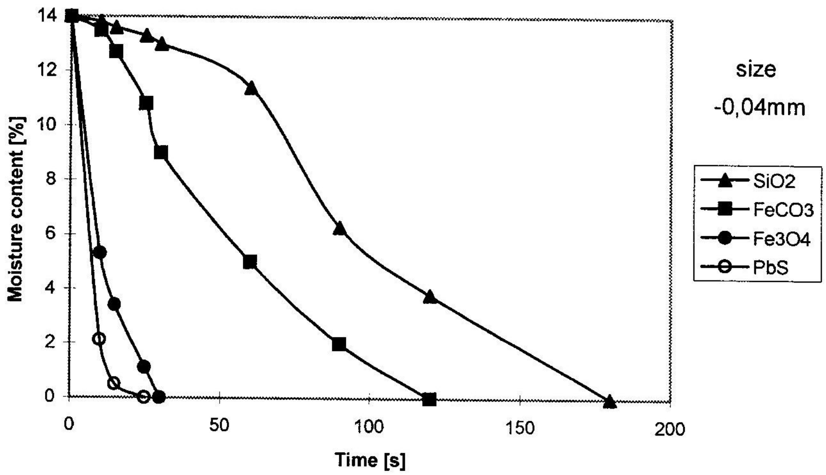

Fig.1 Course of microwave drying of selected minerals

where c – light velocity ($m \cdot s^{-1}$), f – radiation frequency (Hz). Values γ of selected minerals indicate that microwaves penetrate only through a thin surface layer in chalcopyrite and galena while they pass readily through quartz and siderite. However, the microwave drying is subject to the absorption of microwaves by the mineral which determines the magnitude of the induced thermal effect. Its evaluation is possible by means of the coefficient of absorption (A) calculated from the equation

$$A = \frac{f \cdot \varepsilon''_{ef} \cdot E^2_{loc}}{E^2_0} \qquad (2)$$

where E_{loc} – intensity of local electric field which exists inside the irradiated mineral ($V \cdot m^{-1}$)

E_0 – intensity of an external electric field ($V \cdot m^{-1}$).

Values γ and A, presented in Table 2, allow us to assess the course of microwave drying of selected minerals. With regard to low penetration and high absorption of microwaves in chalcopyrite and galena an intensive heating of their surface layer is observed which speeds up considerably the process of their drying. The absorption of microwaves by siderite and most of all by quartz is very low while the microwave transmittance of these minerals is very high, therefore the preconditions for their microwave drying are inferior to those in the previously mentioned minerals.

The preconditions for microwave drying of selected minerals, determined on the basis of parameters γ and A, correspond to experimentally determined course of the drying process (see Fig.1). Very rapid drying of galena and magnetite, which

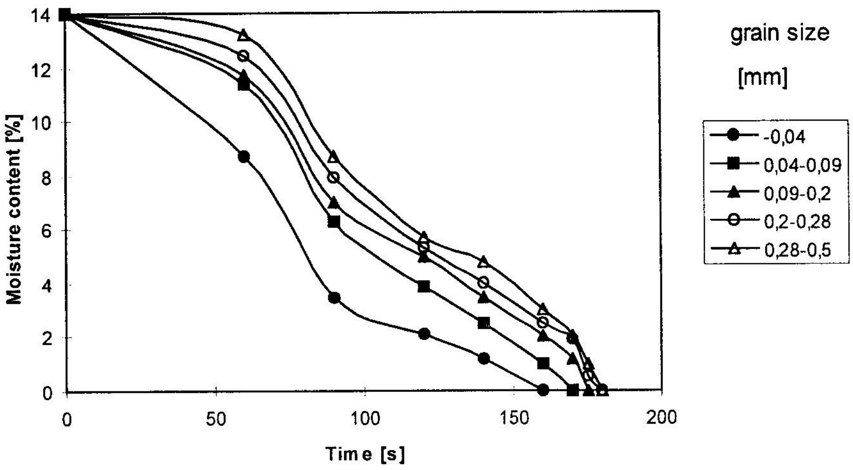

Fig. 2. The influence of grain size on microwave drying of quartz

were used as a replacement for highly flammable chalcopyrite, is related to their intensive heating. Less rapid, however sufficiently effective drying of siderite and in particular of quartz, despite the mild heating of these minerals, can be explained by interaction of microwaves with water. Distilled water, used for wetting the samples, exhibits values of $\varepsilon' = 76{,}7$ and $\varepsilon'' = 12{,}00$ at frequency of 3 GHz (Metaxas A.C., Meredith R.J. 1983). The comparison of components of ε^* with parameters γ and A, calculated with the help of these components for water, quartz and siderite, indicates that the microwave heating of water is most intensive and its evaporation has an essential influence on the course of drying. Based on this phenomenon the microwave drying can be used in all minerals regardless of their ε^* and the character of the interaction with microwaves. However, after the rapid drying, there is a danger of ignition of flammable minerals.

Although the microwave drying of minerals depends most of all on the components of their ε^*, the influence of their grain size on the rate of this process has also been experimentally proved in samples of quartz and galena (Figs. 2 and 3). In both minerals, each exhibiting different interaction with microwaves, the drying of samples of various grain size classes revealed a positive influence of decreased grain size on the rate of this process. This phenomenon is in contradiction with the conventional drying in an electric resistance dryer which provides better results in minerals of bigger grain size. More rapid microwave drying of fine-grained materials may be explained by the volumetric effect of microwaves. Their thermal effect, induced simultaneously throughout the sample volume, speeds up the drying process in comparison with the conventional method at which gradual heat propagation into the sample interior can be observed. The drying of the entire sample volume excludes, mainly in fine grained minerals, formation of a dried-up surface layer through which vapours may pass only with considerable difficulties. Such a

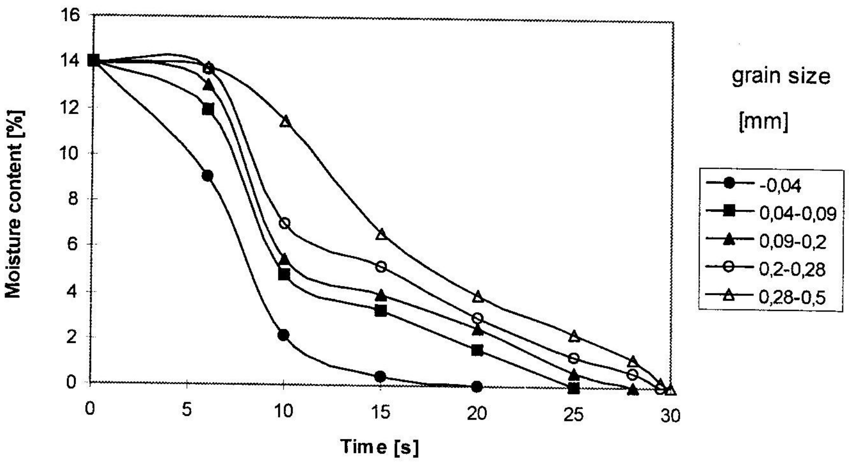

Fig. 3. The influence of grain size on microwave drying of galena

layer is usually produced applying a conventional way of drying. It hinders the escape of water vapours from the sample interior and results in considerable prolongation of the time of drying. Microwaves interact not only with minerals but also with water. Bigger specific surface of fine grained samples enables better evaporation of water and the smaller volume of a mineral grain affects positively the heat transfer to its surface. The comprehensive effect of the mentioned phenomena improves the microwave drying of fine grained samples.

CONCLUSION

Components of complex permittivity and the parameters of penetration and absorption of microwaves dependent on them express the character of their interactions with minerals subjected to drying. They allow evaluating the course and the rate of the drying process. This process may also be influenced by good absorption of microwaves by water. Therefore, it can also be used in minerals which exhibit only mild absorption of microwaves resulting in their insufficient heating. Grain size is another factor which affects the process of microwave drying of minerals. Experimentally proved positive influence of lower grain size of minerals on their drying is conditional upon the volumetric character of the effect exerted by microwaves on the dried sample .

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Florek I, Lovas M., (1995), Wpływ złożonej stałej przenikalności dielektrycznej i rozmiaru ziarn na mikrofalowe suszenie uziarnowych minerałów, *Fizykochemiczne Problemy Mineralurgii*, 29, 127–133 (English text)

Na podstawie składowych złożonej przenikalności dielektrycznej i parametrów penetracji oraz określonych na tej podstawie absorpcji badano charakter oddziaływań mikrofal z wybranymi minerałami podczas ich suszenia. Stwierdzono, że przewidywany na podstawie tych parametrów przebieg suszenia mikrofalowego odpowiada wynikom eksperymentalnym. Wykazano dodatni wływ drobnego uziarnienia minerałów na ich suszenie mikrofalowe.