Effect of Mode Amplitude on Power Consumption in Vibrating Mixer

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Abstract. A paper deals with a study of the influence of dynamic parameters for a vibrating apparatus and physicomechanical properties of treated material on its power consumption. The most reliable expression for calculating the power consumption is presented, from which the value of the power is proportional to the amplitude in the first degree and the vibration frequency in the third degree. In order to verify this theoretical formula for different materials, a test setup was developed. A description of the design and operating principle of the experimental setup is reported. Bulk materials (cement and potassium chloride with 5% additives) and fusible material (80% potassium chloride and 20% epoxide resin) have been the subject of the investigation. The experiments of influence of the vibration amplitude on the power consumption during the mixing were performed at a constant vibration frequency of 60 Hz and amplitudes of 0.64; 1.03; 1.44; 1.83 mm. It was concluded that the theoretical formulation of the linear dependence of power consumption on vibration amplitude is matched to the results of experiments. The simple interrelationships of initial, maximum, and final power consumption on amplitude are obtained. It was found that under optimal vibration parameters specified by the mixing kinetics, the approximate time of the constant temperature setting can be determined at the point in time at which constant power is fixed.

Keywords: Vibration · Mixing · Bulk material · Fusible material

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1 Introduction

Vibrating mixers have a wide distribution in the chemical, petrochemical, and food industries [1–4]. An exposure of vibration on mixed material and end-effectors of the apparatus significantly reduces power consumption and increases the rate of productivity, as well as the quality of the mixture. Moreover, in some cases, vibration only intensifies the main process (e.g., screw vibrating in the screw mixer), in others, it induces specific vibration effects that are used for mixing (e.g., circulation motion of the mixture inside the cylindrical or toroidal vessel) [5–7]. Vibration pulses cause the following processes: chaotic collisions of material particles and their separation by shape, density, and size; destruction of the formed conglomerates; reduction of friction between particles. Although mixing occurs in almost any process where vibration is used, good homogeneity of the derived mixture is obtained only in certain apparatuses with directed vibration [8–10].

The circulation of the load as an auxiliary factor in vibration mixing contributes to the renewal of the diffusion surface by moving volumes of particles lengthwise and crosswise of the mixer body. This fact results in uniformity throughout the mixture. According to [11], the absence of load circulation significantly slows down the mixing process even with high-intensity vibrations. Therefore, in order to reach maximum mixing velocity, it is important to select the operating parameters of the mixer, providing intense vibration and load circulation [12–14]. Thus, the basis of technological calculations of vibration mixers is to determine the power consumption of the load circulation, depending on the physicomechanical properties of bulk and fusible materials, as well as design and dynamic parameters [15–18]. In addition, the value of power consumed by the vibrating apparatus is the initial data for designing the drive and strength analysis of the components.

The purpose of this paper is to study the influence of the vibration amplitude of the apparatus on power consumption when mixing fusible and bulk materials.

2 Study Objects and Methods

According to the report [19], the power consumption is substantially determined by the vibration of the mixer body with loading. Therefore, taking into account the dynamic parameters of the vibrating apparatus and physicomechanical properties of the treated material, the most reliable expression for calculating the shaft power N (kW) has the form:

$$N = \frac{4qr^2 m\omega^5 \sin 2\gamma}{204\left(p^2 - \omega^2\right)} + \frac{m\omega^3 (r - A) f_{mp} d}{204}, \quad (1)$$

where $q = m\big/(m + M)$; m is the debalance weight, kg · s^2/m; M is the loaded mixer weight; r is the eccentricity of debalance, m; p is the natural frequency, 1/s; ω is the angular velocity of vibrating shaft rotation, 1/s; γ is the phase-shift angle between forced vibrations and driving force; A is the vibration amplitude of the apparatus body, m;f_{mp} is the reduced coefficient of friction in a rolling bearing; d is the bore diameter of bearing cup, m.

It can be seen from the formula (1) that the power is proportional to the amplitude in the first degree and the frequency in the third degree. For purposes of clarity, in the first term of Eq. (1), one can introduce the amplitude (m) for the case of forced vibrations as

$$A = \frac{qr\omega^2}{p^2 - \omega^2} \quad (2)$$

For the practical application of the formula (1), it is necessary to verify it in terms of the constituent parameters using an experimental approach. So, to study the effect of the operating mode on the power consumption of the vibrating apparatus for different materials, a test setup was developed (Fig. 1).

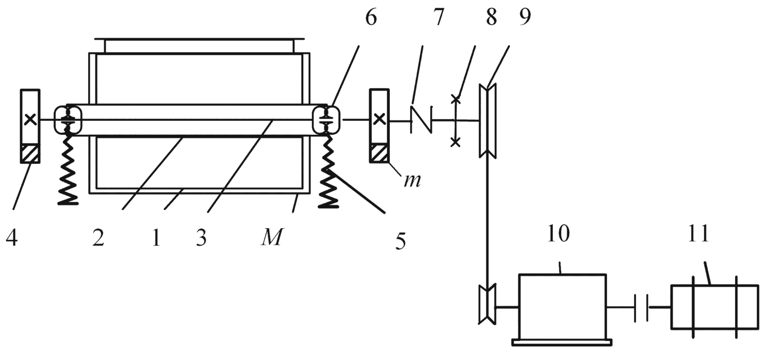

Fig. 1. Scheme of experimental set-up. 1—mixer body; 2—central pipe; 3—vibrator shaft; 4—debalance; 5—flexible support; 6—bearing support; 7—flexible connector; 8—intermediate support; 9—V-belt transmission; 10—variator; 11—motor

The vibrating mixer has a horizontal body with an inner central pipe. The mixer installed on flexible supports, being an end-effector with mass M. A vibrator shaft is placed inside the central pipe on bearing supports. Plates with debalances (*m*) and eccentricity (*r*) are fixed at both ends of the shaft. Shaft rotation is driven by an electric motor (4.5 kW and 2880 rpm) through a system of a flexible connector, a V-belt transmission, and a speed variator. The vibration amplitude of the apparatus body depends on the number of the withdrawable debalances. The amplitude value is measured by the VR-1 vibrograph (Vibropribor, Russia). The study of the influence of the vibration amplitude on the power consumption during the process was performed at a constant vibration frequency $\nu = 60$ Hz and amplitudes of 0.64; 1.03; 1.44; 1.83 mm. The frequency of vibrations is determined by the number of vibrator shaft turns and is recorded using the ST-5 stroboscopic tachometer (Analypribor, Georgia). It should be mentioned that the value of vibration amplitudes was specified in the experimental work [20] in accordance with the patterns of vibration mixing. To measure the power consumption, the laboratory setup is equipped with a CL8516 wattmeter (Mir, Russia).

The body of the vibrating apparatus has a heating jacket with hot water, which comes from the boiler with a built-in thermostat (Ariston, Italy) using the circulation pump (WILO, Germany). The temperature mode is controlled by the IT-17-S digital thermometer (Eksis, Russia) with the TSP-100 thermocouple mounted inside the apparatus.

Bulk materials, such as cement and potassium chloride with various additives, have been the subject of investigation. Additives (5%) in the dissolved state were applied to potassium chloride powder. Then the solvent was removed and the composition was sieved. As fusible material, a composition of 80% potassium chloride and 20% epoxide resin ED-5 was used. The physical properties of the test components are shown in Tables 1 and 2.

Table 1. Properties of bulk materials

Composition	Bulk density (kg/m^3)	Particle size distribution (μm)	Temperature (°C)
KCl (95%) + glycerin (5%)	980	125–360	18–20
KCl (95%) + paraffin (5%)	903	125–360	18–20
Cement	1707	90 and less	18–20

Table 2. Properties of fusible material

Liquid phase	Temperature (°C)	Density (kg/m^3)	Dynamic viscosity (Pa•s)
Epoxide resin ED-5	20	1165	25
Epoxide resin ED-5	80	1135	0.2

3 Results and Discussion

Figure 2 presents experimental data of change in the power from different amplitudes in case of the fusible material. It should be noted that there are no temperature curves of the composition during vibration mixing in this figure. Therefore, the power plot shows the characteristic temperature dots at the initiation and termination of the epoxide resin fusing, as well as the dot at which constant set temperature is reached.

It has been found that with an increase in the amplitude of vibration, the heating time of the mass load to the fusing temperature drops (dot “a” is closer to the ordinate axis). Furthermore, there are the reductions in fusing time (the distance “ab” decreases) and time of reaching the constant set temperature under this condition.

The reason for the temperature changes of the mass loading is the densification of the mass movement with increasing vibration amplitude. So, this fact leads to the improvement in the heat transfer between the apparatus body and the material, as well

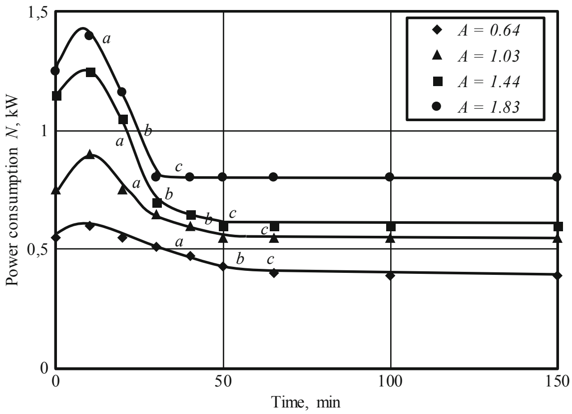

Fig. 2. The vibration amplitude *A* (mm) dependence of power consumption *N* (kW) for fusible material (80% potassium chloride + 20% epoxide resin) at a frequency of 50 Hz. Temperature dots: a—fusing initiation (80 °C); b—fusing termination; c—constant set temperature (~87 °C)

as greater heating of the mass due to friction. It is reasonable that intensification in the motion of the mass requires additional power consumption.

So, under optimal vibration parameters specified by the mixing kinetics, the approximate time of the constant temperature setting can be determined at the point in time at which constant power is fixed. Based on the curves in Fig. 2, the interrelationships of initial, maximum and final power on amplitude are obtained (Fig. 3).

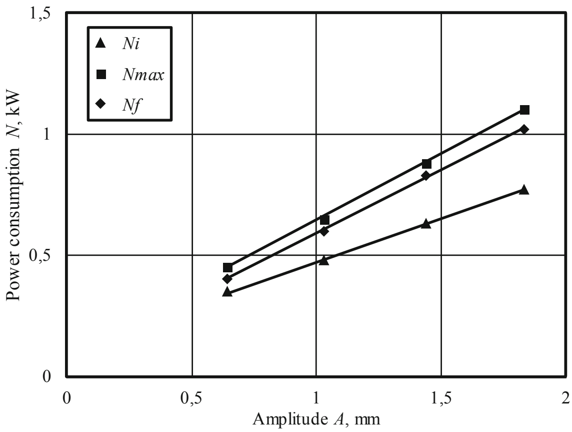

Fig. 3. Change in values of initial, maximum, and final power consumption from vibration amplitude at a frequency of 50 Hz

These graphics can be closely approximated by simple expressions:

$$N_i = 0.159A + 0.243,$$

$$N_{\max} = 0.592A + 0.223,$$
$$N_f = 0.356A + 0.185, \quad (3)$$

where N_i and N_f are initial and final power (kW), respectively; $N_{\max}$ is maximum power (kW).

The experimental value of power consumption in the loaded vibrating mixer may be considered under two parts. The first one is the power transmitted directly to the load to overcome the resistance caused by the material, and the second one is the power consumed to vibrate the empty mixer. The value of power transmitted to the load can be considered useful, going directly to the intensification of mixing, since this part of power goes to the circulating motion and vibrations of the load in the mixer. The power for vibrating the empty mixer at the different vibration modes is obtained by the experimental approach.

The linear dependence of power consumption on vibration amplitude is confirmed by the results of the experiments carried out on different bulk materials (Fig. 4).

The experimental results for materials with different physicomechanical properties verified the linear dependence of the function $N = f(A)$ and hence are in full agreement with the theoretical expression (1).

The power consumption when mixing the fusible composition (80% potassium chloride + 20% epoxide resin) is obtained by subtracting the values for unloaded mixer from the experimental values N_i, $N_{\max}$, N_f at the same vibration modes. The maximum power is transmitted the load at the optimum amplitude $A = 1.44$ mm so that the desired water content of the material is achieved in the shortest time.

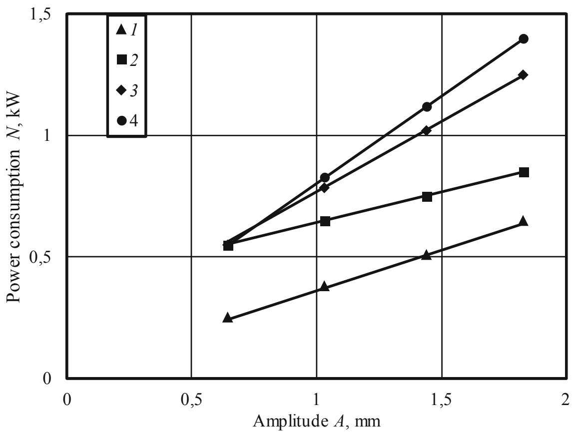

Fig. 4. $N = f(A)$ dependence for various bulk materials: 1—unloaded apparatus; 2—cement; 3—KCl (95%) + glycerin (5%); 4—KCl (95%) + paraffin (5%)

4 Conclusion

It has been stated that the theoretical formulation of the linear dependence of the power consumption on the vibration amplitude is matched to the results of the experiments carried out on fusible and bulk materials. The simple interrelationships of initial, maximum, and final power consumption on amplitude are obtained.

Furthermore, it was found that with an increase in the amplitude of vibration, the heating time of the load to the fusing temperature drops, as well as the fusing time and time of reaching the constant set temperature. This fact leads to an improvement in the heat transfer between the apparatus body and the material, as well as greater heating of the mass due to friction. Thus, under optimal vibration parameters specified by the mixing kinetics, the approximate time of the constant temperature setting can be determined at the point in time at which constant power is fixed.

The advantages of the vibrating mixers are considerable simple design, high weight load factor, providing a high rate of productivity, good homogeneity of the derived mixture, and high-level of industrial safety.

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