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Operational conditions of a screw-feeder-equipped high-pressure roller mill

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Abstract

The throughput characteristic of a screw feeder and of a high-pressure roller mill equipped with it are investigated with four quartz materials 100/400 μm, −400 μm, −100 μm, −20 μm. The feeder throughput is proportional to the screw speed and does not depend on the counter-pressure created by varying the outlet resistance. The mill throughputs at different roller velocities line up to a proportionality to the screw speed. The screw speed has to exceed a lower limit to ensure a proper mill operation. This limit depends on the feed fineness. A screw feeder can increase the throughput by a factor 2 at the same roller velocity. The additional power draft can be kept smaller than 10% of the total power as the screw speed is adjusted properly.

Résumé

Les caractéristiques du débit d'une vis sans fin, et celles d'un broyeur à cylindre à haute-pression comportant une vis sans fin, sont déterminées à l'aide de quatre granulations de quartz: 100/400 μm, −400 μm, −100 μm, −20 μm. Le débit de la vis est proportionnel à sa vitesse de rotation et indépendant de la contre-pression produite par l'étranglement à la sortie de la vis. Le débit du broyeur, pour les différentes vitesses du cylindre, est proportionnel à la vitesse de rotation de la vis. Afin que le broyeur fonctionne silencieusement, la vitesse de rotation de la vis doit dépasser une limite basse qui dépend de la finesse de la mouture. La puissance supplémentaire nécessitée par la vis, après un bon réglage de sa vitesse de rotation, est inférieure à 10% de la puissance totale.

Keywords: High-pressure roller mill; Screw feeder; Fine grinding

1. Introduction

High-pressure roller mills are advantageously equipped with screw feeders if a fine material is fed containing a high fraction below 100 μm [1,2]. A screw feeder creates an additional pressure upon the material entering the mill and improves by that the material introduction, which is disturbed by the air squeezed from the voids as the particle bed is compacted. The air velocity rises proportionally to the roller speed [3]; however, the drag force reduces with decreasing particle size; the roller speed, therefore, is limited depending on the feed fineness. The application of a screw feeder is well known for briquetting rollers, see, e.g., Refs. [4–6].

The mill and the screw feeder are two devices with different throughput characteristics and connected to each other without any buffer in-between. Therefore, the individual characteristic of each should be known to adjust properly the operational parameters, particularly those of the screw feeder so that its power draft remains moderately.

The volumetric mill throughput is usually expressed by the equation

$$\dot{V}_M = \delta_s(1-\zeta_s)\, sLu \qquad (1)$$

with the relative bulk density δ_s and the slip factor ζ_s both in the axial plane, the gap width s, the roller length L and the circumferential speed u. The slip is unknown and usually assumed to be zero. The value of δ_s and s cannot be predicted easily even for coarse materials. The vertical pressure caused by the material column in the feeder shaft or by a screw feeder is not included directly in Eq. (1);

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however, it affects δ_s and s, and with fine materials, that pressure determines mainly the mill performance.

The volumetric throughput of a screw feeder is expressed according to Ref. [7] as:

$$\dot{V}_S = \kappa \delta_{SF} a_S v_{ax}$$
$$A_S = (\pi/4)(D_{ST}^2 - D_{SS}^2) = k_A (\pi/4) D_{ST}^2$$
$$k_A = 1 - (D_{SS}/D_{ST})^2 \qquad (2)$$
$$v_{ax} = \pi D_S n_S G(\phi, \psi)$$
$$G(\phi,\psi) = \tan\phi \tan\psi / (\tan\phi + \tan\psi) \quad \tan\phi = S_S / \pi D_S$$

where κ: filling ratio of the screw, δ_{SF}: relative bulk density at the outlet, D_{ST}: screw tube diameter, D_S: screw diameter, D_{SS}: screw shaft diameter, n_S: number of screw revolution, ϕ: screw inclination angle, S_S: screw pitch and ψ: transportation angle.

In Eq. (2) κ, δ_{SF} and ψ are unknown and have to be determined experimentally.

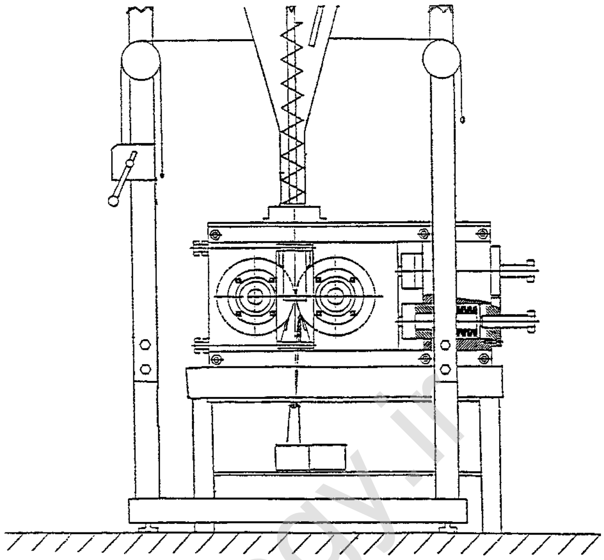

Fig. 2. Sketch of the high-pressure roller mill with screw feeder.

2. Experimental devices and materials

The screw feeder device is shown in Fig. 1. Its special design allows to mount it above the lab-scale mill (see Fig. 2). The design parameters are as follows: tube diameter $D_{ST} = 105$ mm, screw diameter $D_S = 104$ mm, tube length = 300 mm, screw shaft diameter $D_{SS} = 40$ mm, screw pitch = 63.8 or 104.7 mm, screw inclination angle $\phi = 11.0°$ or $17.8°$, speed 20 to 220 rpm, throughput 100 to 3000 kg/h. Both screws are be called as the 60-screw and the 100-screw.

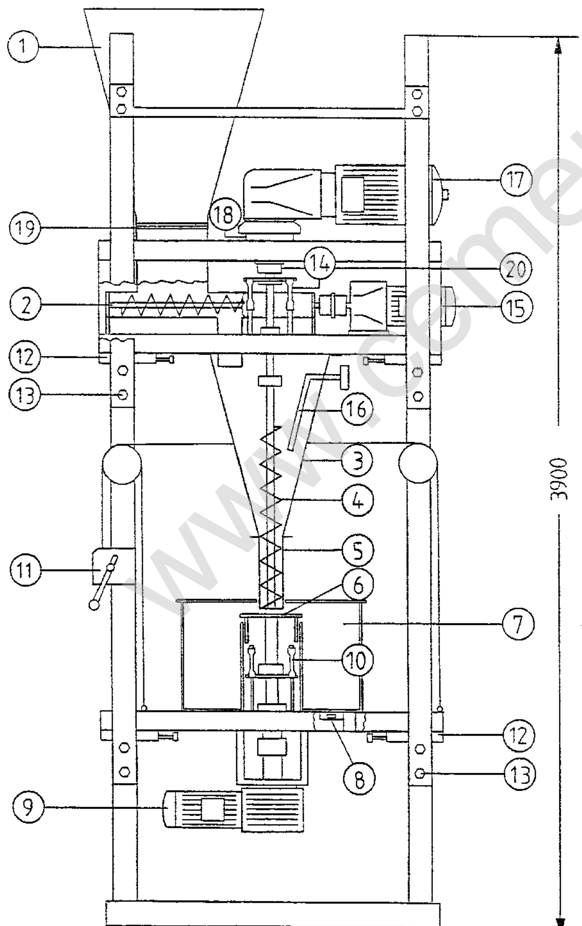

Fig. 1. Sketch of the screw feeder device.

The feed material is loaded into the hopper 1 and transported with the auxiliary screw 2 to the screw funnel 3. The sensor 16 controls the filling level. The feeding screw 4 transports downward the material against the rotating disc 6, which distributes it in the container 7. The distance d_D between the screw tube 5 and the disc and also the disc speed can be adjusted within a certain range, in order to vary the resistance against the material flow and by that the resulting pressure. The following parame-

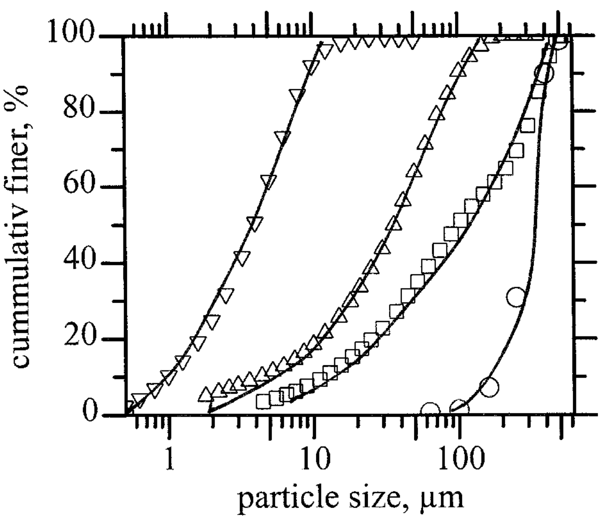

Fig. 3. Particle size distribution of the test materials.

Table 1
Properties of the test materials, quartz, $\rho = 2650\ kg/m^3$

No.	Size range (μm)	Relative bulk density		x_{50} (μm)	Eff. friction angle (deg)	Wall friction angle (deg)
		Loose (%)	Vibrated (%)			
1	100/400	51	60	300	36	22
2	−400	52	67	90	37	24
3	−100	44	57	36	37	26
4	−20	26	34	4	38	26

ters are measured: material mass in the container, the screw speed and torque, the screw shaft force and the force acting upon the disc.

The mill has rollers with 200 mm diameter and 100 mm length. The fixed roller (left) is equipped with dam rings to prevent bypassing of material. More details on the devices and the test procedure can be found in Ref. [8]. The experiments were performed with four materials of quartz (see Fig. 3 and Table 1).

3. Screw feeder throughput

In discussing the screw feeder characteristics, typical results of material 2 (−400 μm) with the 60-screw should be considered first. Fig. 4 shows the disc force F_D over the screw speed n_S for two disc gaps $d_D = 8$ and 12 mm and three disc speeds $n_D = 49$ and 94 or 95 rpm. Both these parameters determine the resistance which the material flow has to overcome at the outlet. It can also be seen that F_D depends strongly on it. With the smallest gap of 8 mm and the lowest disc speed of 49 rpm, the force rises steeply up to 3500 N. As n_D is increased to 95 rpm or d_D opened to 12 mm, the maximum force drops down to only 300 N. The measured force range corresponds to average screw pressures according to $p_S = 4F_D/\pi(D_{ST}^2 - D_{SS}^2) = F_D/7402\ mm^2$ between 13 and 470 kPa, which is comparable with results from briquetting rolls [5]. However, it can be seen in Fig. 5 that the outlet resistance affects only slightly the throughput which is mainly controlled by the screw speed and can be approximated quite well with a linear function. The small influence of the screw pressure simplifies the following considerations; however, one has to be aware that this simplification cannot not be applied under all conditions.

In Figs. 6 and 7, the disc force F_D and the wall friction $F_F = F_S - F_D$ are plotted over the shaft force F_S. Both F_D and F_F can be considered being approximately proportional to the shaft force F_S. This result allows to estimate the screw pressure p_S from shaft force F_S if the screw feeder is mounted on the mill, then it follows with the slope $k_F = (F_D/F_S)$:

$$p_S = k_F F_S / A_S \tag{3}$$

The slope k_F depends mainly on the fineness and is 0.32 for material 1, 0.55 of material 2, and 0.63 for material 3.

Fig. 8 gives an overview on the throughput characteristics of the 60-screw for all four materials and proves again that an approximation with a proportionality is reasonable. According to Eq. (2), the relation $\dot{M}_S = k_S n_S$

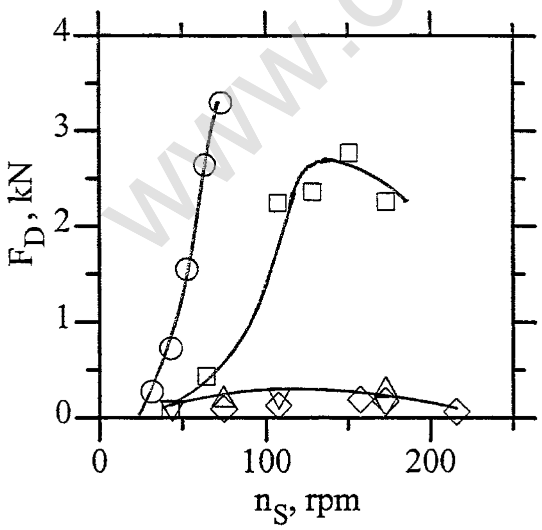

Fig. 4. Disc force F_D and screw speed n_S, material 2, 60-screw, $d_D = 8$ and 12 mm, $n_D = 47$ and 95 rpm, ○ 8 mm/47 rpm, □ 8/71, Δ 8/95, ▽ 12/47, ◇ 12/94.

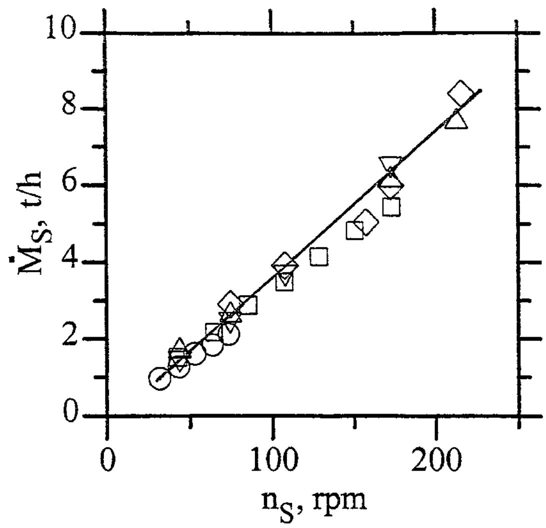

Fig. 5. Throughput and screw speed n_S, parameters as in Fig. 4.

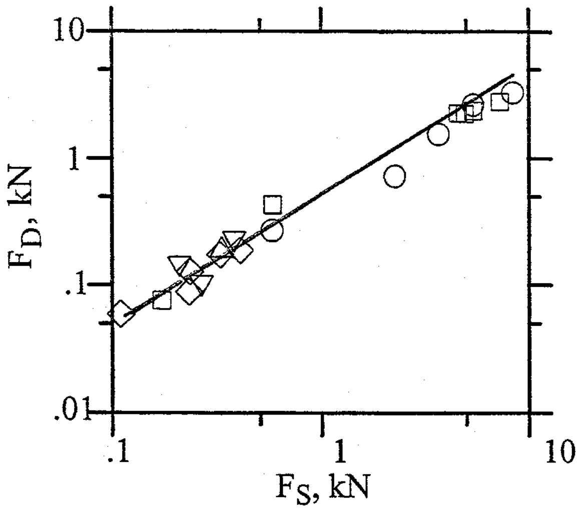

Fig. 6. Disc force F_D and shaft force F_S, parameters as in Fig. 4.

requests that the term $\{\kappa \delta_{SF} G(\phi, \psi)\}$ has to be constant and it follows

$$G(\phi,\psi) = (4/\pi^2 k_A \kappa \delta_{SF})(k_S/\rho D_{ST}^2 D_S) = B$$

$$\tan\psi = B \tan\phi/(\tan\phi - B) \quad (4)$$

The transportation angle ψ could be calculated if the filling ratio κ and the relative bulk density δ_{SF} were be known. In principle $(\kappa\delta_{SF})$ increases as the screw works against a pressure; therefore, it should be assumed that κ is unity and δ_{SF} is equal to the relative bulk density after vibration; Table 2 gives calculated ψ-values between 15° and 23°. The effective friction angles and the wall friction angles of the four materials do not differ much (s. Table 1); therefore, the transportation angle calculated with the introduced assumption, cannot be correlated to them. The 60- and 100-screw were tested with the feed materials 1 and 3. In both cases, the transportation angle increases somewhat, indicating that the throughput rises a little bit

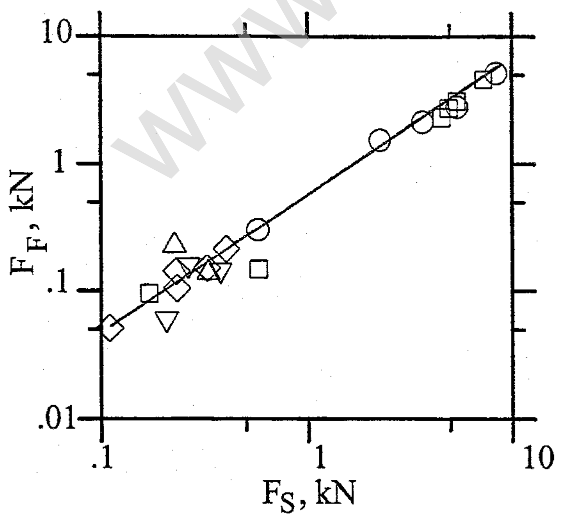

Fig. 7. Wall friction F_F and shaft force F_S, parameters as in Fig. 4.

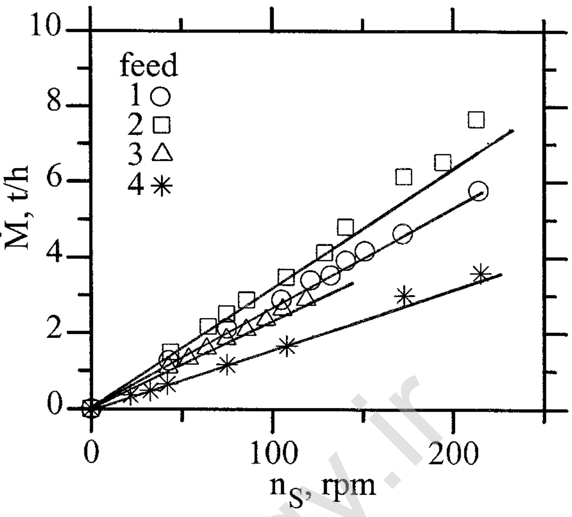

Fig. 8. Throughput $\dot{M}_S$ and screw speed n_S, 60-screw, ○ 100/400 μm, □ −100 μm, △ −100 μm*, * −20 μm.

more (about 8%) than what is due to the increase of the screw pitch. If the average transportation angle of 19° is used for all materials, then the throughput can be predicted with an accuracy of ±8%.

All these considerations lead to the conclusion that within the tested range, the influence of the feed fineness is mainly correlated to the bulk density. However, two limitations of this statement should not be forgotten: (1) the tested materials are not cohesive and (2) the introduction of the materials into the screw was ensured, which may not be satisfied if the screw speed increases further.

4. Mill throughput with screw feeder

The throughput of a high-pressure roller mill equipped with a screw feeder depends on the roller velocity u and the screw speed n_S. Figs. 9 and 10 show results with the materials 2 and 3, respectively, those with the materials 1 and 4 are given in Ref. [8]. The dashed line represents the screw throughput. The full symbols indicate a proper operation of the mill, the open ones a rattling operation [9].

Table 2
Transportation angles

Screw	Material	Relative bulk density vibrated (%)	k_S (kg)	B	Transportation angle ψ (deg)
60	1	60	0.460	0.124	18.9
100	1	60	0.641	0.173	20.6
60	2	67	0.533	0.129	20.9
60	3	57	0.392	0.111	14.5
100	3	57	0.530	0.150	15.7
60	4	34	0.280	0.133	22.8

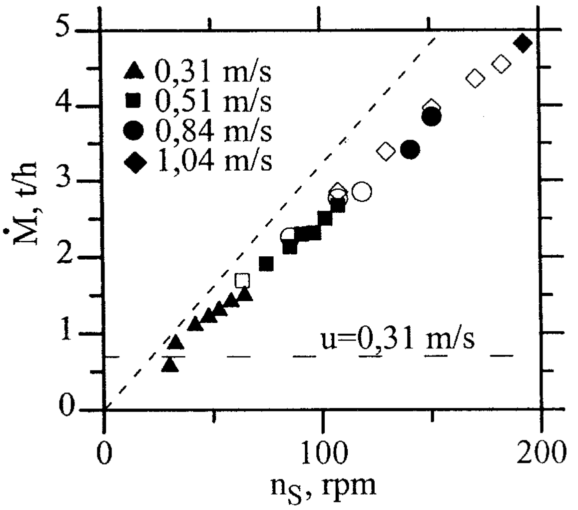

Fig. 9. Throughput $\dot{M}$ and screw speed n_S, material 2, 60-screw, roller velocities indicated in the diagramme.

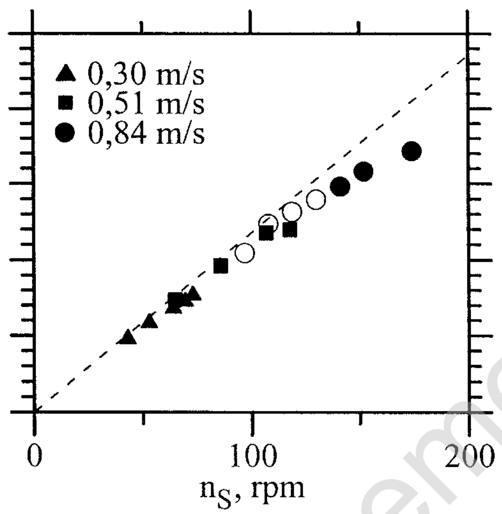

Fig. 10. Throughput $\dot{M}$ and screw speed n_S, material 3, 60-screw, roller velocities indicated in the diagramme.

The horizontal line in Fig. 9 marks the mill throughput without a screw feeder at the roller velocity of 0.31 m/s which is the upper limit for a proper operation with material 2. The materials 3 and 4 cannot be compacted without a screw feeder. The essential results of these test series are as follows.

(1) The results of the different test series at a constant roller velocity line up on one curve which can be approximated by a proportionality to the screw speed, $\dot{M} = Kn_S$, the slope of which depends on the feed fineness (K/kg): 0.620 (1), 0.421 (2), 0.350 (3), 0.219 (4).

(2) The throughput is always somewhat less than the screw throughput without mill; therefore, the screw builds up a pressure. Its calculation from the screw shaft force gives values between 10 to 60 kPa; p_S rises with n_S and increasing feed fineness [8].

(3) Within the tested range, the screw feeder can increase the throughput by a factor of two as the same roller velocity.

(4) The screw speed has to exceed a lower limit to avoid a rattling operation. This limit increases with the roller velocity and depends on the feed fineness, because the screw pressure has to be high enough to prevent the disturbance of the material introduction caused by the air squeezed from the particle bed voids as it is compacted.

5. Energy considerations

Fig. 11 shows the specific energy consumption of the mill together with the screw feeder (E_M) and of the screw feeder alone ($E_{M,S}$) for the materials 1 (left) and 3 (right). Besides some exceptions, all E_M values are grouped within a slightly increasing narrow band, and the screw energy can be kept smaller than 10% of E_M, if the screw speed is adjusted properly. The exceptions in Fig. 11 (left) with

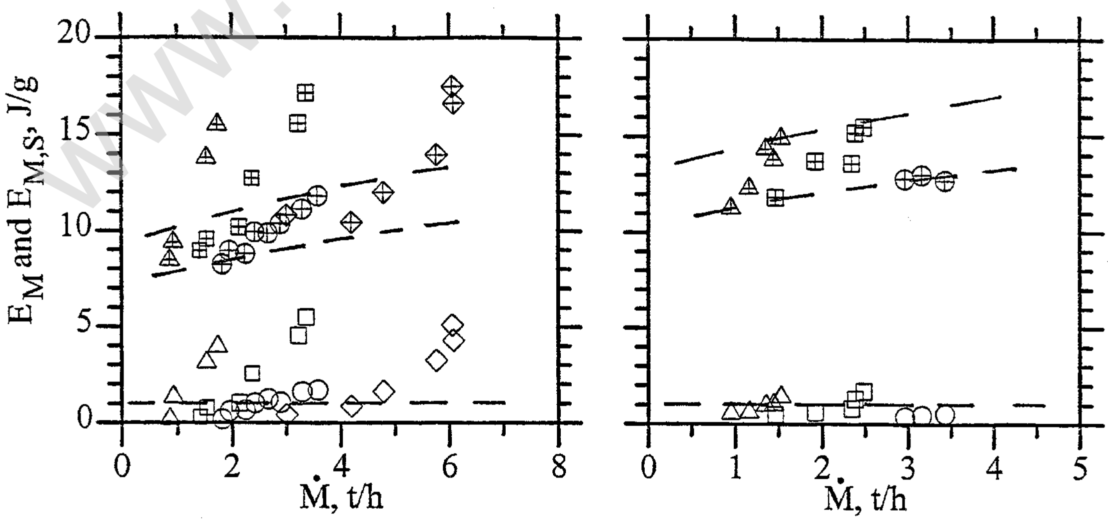

Fig. 11. Specific energy consumption of mill together with the screw feeder, E_M (symbols with +) and that one of the screw feeder alone, $E_{M,S}$ (empty symbols) left: material 1, 60-screw, △ 0,30 m/s, □ 0.51, ○ 0.84, ◇ 1.05, right: material 3, 60-screw, △ 0.30 m/s, □ 0.51, ○ 0.84.

higher E_M and $E_{M,S}$ values are all caused by a very high screw speed.

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