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Energy utilization in a fluid energy mill

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A "Gem" fluid energy mill was built into an assembly which allowed the temperature, pressure and quantity of air flowing through it to be measured. The feed rate of powder to be ground was also controlled. The increase in surface area of sodium chloride was determined as a function of air pressure and feed rate in order to establish the conditions for optimum performance.

THE history of fluid energy milling may be traced from approximately 1880, through a range of devices designed to accelerate particles to high velocities in fluid jets, particle reduction being achieved either by impact with fixed objects (Auger, 1936), or by attrition in opposing streams (Rowley & McCabe, 1948) or by mutual attrition in converging streams and turbulent flow as in the "Microniser" (Andrews, 1936) or "Jetomiser" (Stephanoff, 1946).

As fluid energy mills became commercially available the suggestion arose that their energy consumption is excessive, and this was examined by Stephanoff (1949) and by Pendleton (1963). Dotson (1962) determined the energy requirements of both fluid energy and ball mills. All three authors found that for similar degrees of particle size reduction, the energy requirements were comparable. Dotson, however, tested three sizes of fluid energy mill on silicon metal powder and obtained results which indicated that smaller mills were less efficient, in terms of surface area produced per unit of power expended, than larger ones. The present work was started in order to determine whether this was in fact the case.

Experimental

The mill used was a research model "Gem" fluid energy mill (George W. Helme Inc., Trost Jet Mill Division). Its construction is shown in Fig. 1, together with details of how probes were inserted to measure conditions inside it. The probes could be inserted at various positions, the holes not in use being closed off by means of Duralumin plugs. Piezometric and total heads were measured by tubes flush with the wall and by a small pitot tube respectively. The pitot tube carried a copper-constantan thermocouple within it.

The mill was clamped during measurements to the end of a 6 inch diameter brass cylinder as shown in Fig. 2. All the air leaving the mill through the filter bag which accumulated the milled product, was thus collected and made to pass through the rotameter.

To obtain a constant controllable rate of powder feeding, a feed apparatus was devised as shown in Fig. 3. The principle is that of a rotary tabletting machine. A rotating circular upper plate with a ring of holes near its outer edge was driven by a geared-down electric motor. The motor speed was set and maintained constant by a Pye smooth speed controller. A polythene funnel acted as a feed hopper, filling the holes

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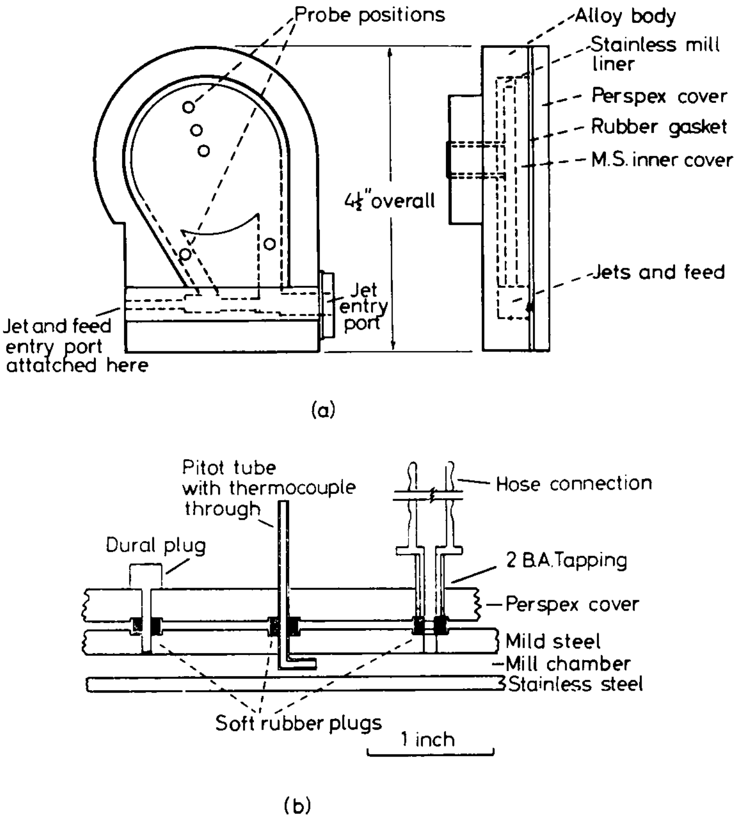

FIG. 1. (a) The fluid energy mill and (b) detail of the attachment of the probes to the mill face.

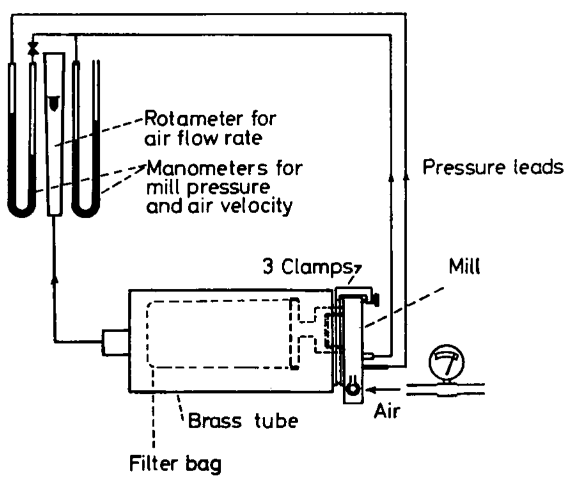

FIG. 2. The mill clamped to the air flow measuring assembly.

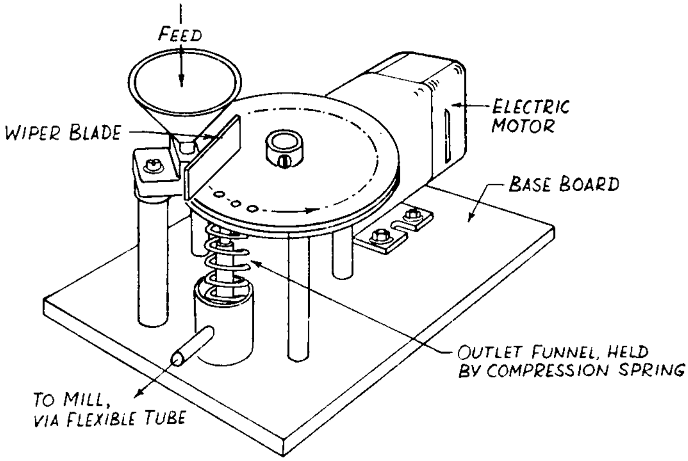

FIG. 3. The constant-rate powder feed apparatus.

as they passed beneath it. The powder was carried round over the stationary lower plate until the hole passed over a hole in the lower plate, to which the mill feed suction pipe was attached. The powder was then drawn into the mill by the feed Venturi.

The feed to the mill was Analar sodium chloride. 2 kg of this material was coned and quartered to 2 g and a sample of this examined microscopically. 300 particles were measured by a calibrated eyepiece vernier indicator. The mean particle size by area was 330μ. The milled product was examined by a Fisher sub-sieve sizer to obtain surface area and hence mean particle size.

A typical run was carried out as follows: the mill bag was weighed, attached to the mill and the mill apparatus assembled. The feed device was switched on and its delivery rate determined by collecting and weighing over a few minutes. Compressed air was then fed to the mill with the powder feed tube closed and after settling down, the air flow-rate, mill pressure, velocity head thermocouple readings were taken. These readings were taken again with the feed tube open, and then powder supply was commenced and continued for 20 min, measuring all parameters at intervals. After shutdown, the bag was reweighed. 10 g of the product was dried at 150° for 1 hr and examined on the Fisher sub-sieve sizer. All the data for the evaluation of mill performance are thus easily available, with the exception of the energy supplied by the air.

The energy supplied by unit mass of gas in expanding from pressure p_2 to pressure p_1 and specific volume V_1 is given by

$$W = \frac{k}{k-1} p_1 V_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right]$$

where k varies from the ratio of specific heats (= 1·403 for air) for an adiabatic expansion to unity for isothermal conditions. The ideal maximum energy would be that obtained by adiabatic expansion, and it is this value which has been used to calculate the energy required to create unit surface area in Table 1. Although the expansion of the compressed air through the jet must be almost adiabatic, the measured mill temperatures show no great divergence from ambient. The temperature given by the mill thermocouple must be corrected for the effect of the approach velocity of the gas, since this velocity is high, by the method of Hottel & Kalitinsky (1945). Velocities in the mill of 6–12,000 cm/sec were obtained, and the temperature corrections involved are from 2–10°. Because of the complex and repetitive nature of the calculations, a program was written for the calculation of results, which was run on the London University Atlas computer.

TABLE 1. DEGREE OF COMMINUTION OF SODIUM CHLORIDE AT FEED RATES BETWEEN 150–700 G/HR AS A FUNCTION OF THE APPLIED AIR PRESSURE OVER THE RANGE 40–80 PSIG

Feed rate g/hr	Product particle size, μ	Area created m^2/hr	Air supply pressures psig	Mill pressure cm Hg	Mill temp. °C	Air velocity m/sec	Energy supplied 10^5 joules/hr	Energy to create unit area 10^3 joules/m^2
170	5·0	93	40	82·9	18·2	83·5	4·80	5·17
155	1·7	248	60	93·2	17·6	94·7	10·50	4·22
159	1·7	266	70	97·5	16·6	84·5	11·97	4·50
180	1·5	331	80	101·9	20·5	108·6	14·93	4·51
248	7·6	88	40	83·1	21·3	84·0	4·82	5·47
226	2·0	308	60	90·1	14·1	93·7	9·81	3·18
267	2·8	262	70	94·9	15·0	120·9	12·30	4·70
247	1·5	443	80	102·9	15·6	102·0	14·51	3·28
346	12·0	77	40	82·2	20·9	79·3	4·91	6·37
328	3·2	281	60	88·1	15·0	92·1	9·50	3·54
380	2·3	454	70	94·1	23·8	91·9	12·78	2·81
337	2·1	442	80	101·6	15·2	102·3	14·76	3·32
443	9·0	133	40	81·8	25·6	80·1	5·01	3·78
420	3·6	320	60	87·3	18·0	66·1	10·14	3·17
432	2·8	432	70	91·1	29·1	82·3	13·27	3·07
450	2·9	427	80	97·5	14·4	105·1	15·33	3·60
527	24·2	56	40	82·0	32·0	63·5	5·11	9·12
545	10·0	144	60	86·0	28·8	79·8	10·71	7·44
537	12·0	120	70	87·9	31·7	90·7	14·14	11·82
561	6·4	283	80	93·6	26·9	90·2	16·70	7·01
701	11·5	163	60	87·1	26·6	73·9	10·48	6·43
698	4·8	397	70	89·0	23·6	103·3	13·59	3·42
711	9·1	211	80	93·3	23·0	102·6	16·55	7·86
381	24·6	40	40	82·2	26·8	82·6	4·99	12·58
388	4·8	218	60	86·3	24·7	85·0	10·54	4·83
381	3·9	264	70	92·1	22·5	114·4	13·03	4·94
378	3·8	277	80	94·3	23·1	126·0	16·37	5·92

Results and discussion

The degree of comminution achieved at feed rates between 150 and 700 g/hr is given in Table 1 as a function of the applied air pressure over the range 40–80 psig. If a graph is plotted of new surface area created against energy supplied, at constant feed rate, a straight line is obtained. One typical line is shown in Fig. 4 for a feed rate of about 170 g/hr. Similar lines may be obtained for other feed rates. The slope of any such line is a measure of the efficiency of utilization of the energy in the air supplied to the mill, since it represents the new surface area created per unit of energy input. Thus firstly it appears that Rittinger's law applies, since the energy required is proportional to the new surface area created. Secondly, the slope of the line varies with feed rate, at first

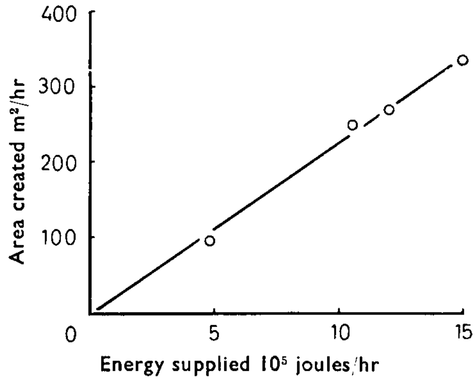

FIG. 4. New surface area created as a function of energy supplied. The feed rate for this plot is approximately 170 g/hr.

increasing and then decreasing sharply, so that there is an optimum feed rate at which the mill is operating at maximum efficiency. This is shown in Fig. 5, where the energy required to create unit area of new surface is plotted as a function of feed rate. The optimum, where this energy is a minimum, is the result of two opposing effects. At low feed rates the particle concentration is low in the grinding chamber, and there are relatively few inter-particle collisions. At high feed rates, the particle concentration is so high that particles have no time to accelerate up to a high enough velocity in between collisions to enable fracture to occur. Somewhere between these two extreme conditions there must be an optimum.

The scatter on the optimum plot is large. Some of this is due to there being no control over the degree of comminution achieved. Once the feed rate and air supply are set, the product size is not controllable. There must be a difference between creating the type of surface area needed to

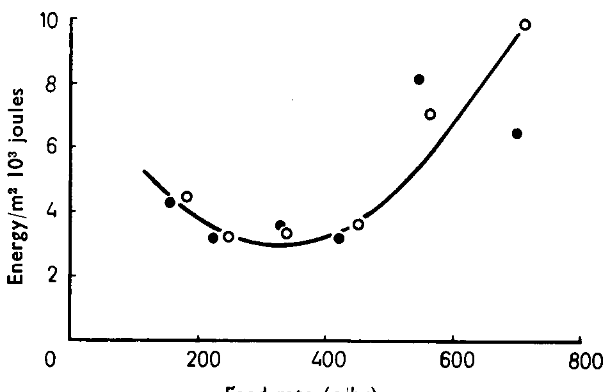

FIG. 5. Energy required to create unit surface area as a function of feed rate, showing the optimum operating conditions. ● 60 psig. ○ 80 psig.

reduce the particle size from the feed size, 330μ, down to say 15μ, and creating the area needed to go from 15 to 3μ.

The energy required for reduction of particle size in this small mill compares well with the crushing energy for sodium chloride quoted by Schellinger (1952) determined by calorimetric measurements using a ball mill, and as observed by Piret (1953) the required energy is far in excess of that predicted from surface energy considerations.

Comparing the performance of the mill, operating at or near its optimum, with Dotson's figures shows that the small size of the mill does not reduce its performance. For example, taking the fourth line of Table 1, 331 m^2/hr of surface are created by feeding air at 80 psig at a rate of almost 130 litres/min, measured at atmospheric pressure, to the mill. This represents an energy input rate of 0·42 h.p. Since 331 m^2 is approximately 3000 ft^2, the mill is creating surface at the rate of about 7,000 ft^2/h.p. hr, which may be compared with Dotson's figures of 2,000 ft^2/h.p. hr for a 2 inch elliptical mill, ranging up to 12,000 ft^2/h.p. hr for a ball mill. Part of the difference is probably due to Dotson's working with silicon, whereas the present authors have used the rather more easily-fractured sodium chloride, but some of the difference is likely to reflect a genuine improvement in efficiency. The improvement may be due to the double jet principle of the Gem mill, which causes direct impaction of the ingoing feed with oversize returning from the mill chamber to the opposing jet.

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