Journal of Applied Sciences Research, 3(11): 1275-1278, 2007

Roll Press Prototype Design for Fine Powders Agglomeration

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Abstract: Large scale roll presses are used in industry to obtain agglomerated; dust free, particles from fine powders. In a roll press agglomeration takes place mainly due applied pressure. To obtain the design parameters of such machines extensive experimental work is usually required. To overcome this problem a prototype roll press is designed and manufactured to be used in compaction of powders to obtain agglomerated products. The outline of the prototype design is described. The mechanical capability of the press is given in terms of the available power and chosen speeds. It is also explained how such prototype could be used to reach the design of large scale roll presses. Some of the limitations and precautions are elaborated.

Keywords: Powder compaction, Roll press design, Agglomeration, Prototype.

INTRODUCTION

Agglomeration is the process of size enlargement known in areas where fine powder products and/or constituents are dealt with. Several industries like food, chemical, pharmaceutical industries as well as powder metallurgy industry are typical examples of areas where the problem due to dealing with powders does exist. Agglomeration is the process of size enlargement known in such areas used to obtain larger sized dust free particles. The formation of dust during transport, handling, storage or processing is considered one of the major problems[1] which results when dealing with such products. This dust may be valuable, or dangerous; as being toxic for example, or even explosive in some cases. Obtaining dust free forms of such materials is thus highly desirable.

The formation of larger size granules from less particle size powders can be physically attributed to one or more bonding mechanisms[2,3]. Solid bridges, chemical bonds, electrostatic forces……etc.; when exist between fine particles, larger size agglomerates are obtained. Many techniques which involve addition of binders, chemical reactions, heat, and pressure application are used to obtain agglomerates. The mechanical and physical properties of the agglomerates obtained[3] can give indication to what extent further dust formation will or will not take place during handling, transport, …etc. of such materials after being agglomerated. Several methods of agglomeration act differently on fine particles of several powders ending with various properties. In other words each method of agglomeration is affected by many factors which govern the process and affect the final properties. To obtain agglomerates of desired properties factors affecting each agglomeration process has to be carefully understood.

The roller press fig.(1), is a machine used for pressure agglomeration; where agglomeration mainly occurs due to pressure application between two counter-rotating rolls. As the rolls rotate the granular material is derived into the gap between the two rolls, as the material rotates with the rolls it approaches the smallest gap where it is pressed into agglomerates.

These machines were known very long while ago in the 1870s[2], however theoretical analysis of the operation of roll-type pressing machines has first been proposed by Johanson in 1965[4].

The Roller Press Machine: The roller press machine fig. (1), consists mainly of two cylindrical rollers, equal in diameter, rolling against each other with their axes parallel and generally in a horizontal position. The direction of rotation of the two rolls being one opposite to the other such that the feed is withdrawn from the upper side and the output emerges from the lower side of the two rolls fig. (1). The two rolls are arranged such that there is a small gap, b_o, on the line of centres of the two rolls, fig.(2). Compaction is obtained as the powder is withdrawn through the two rolls until it is forced to pass through the narrowest gap, b_o. Using smooth surface rolls the machine output is a sheet having thickness b_o, and width, W, as shown in fig. (2), which is the width of the two rollers and its length represents the output of the machine. The sheet obtained; of the compacted material, when crushed and

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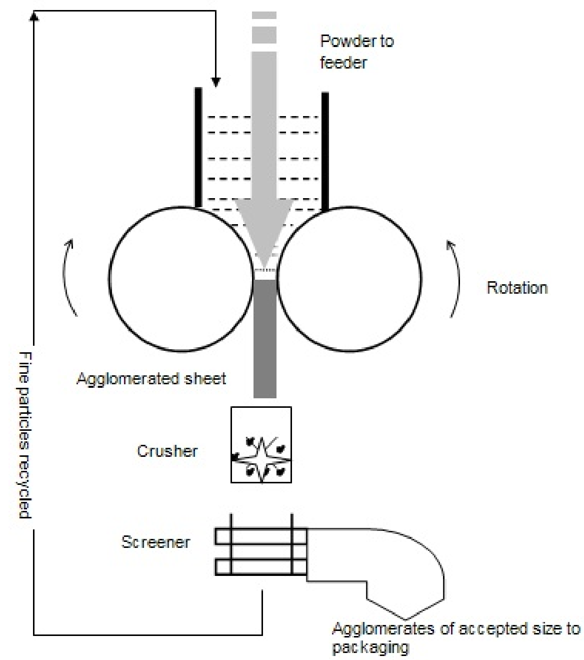

Fig. 1: Agglomeration process using roll press machine

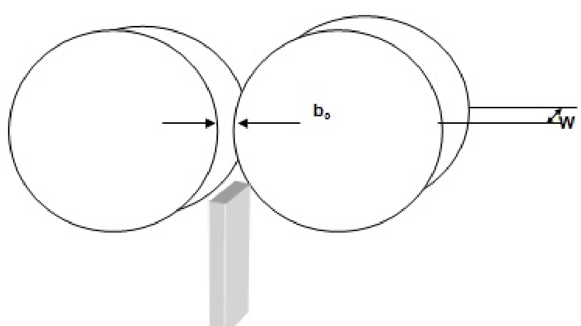

Fig. 2: A sheet of width W and thickness bo is produced according to the minimum gap and rolls' width respectively

screened agglomerates at random shape are obtained, fig. (1). Other forms of the roll surface can change the shape of the agglomerates obtained. As mentioned above, agglomeration takes place depending on many factors such as the properties of the constituents, binders added, heat, moisture content, pressure, chemical reaction…etc. The roller press machine is concerned with obtaining agglomerates mainly due to the effect of the pressure applied by the machine on the material.

The theoretical analysis of roll press machines was based on understanding the behaviour of granular solids within a roll-press which involves the interaction between the particles of the materiel itself as well as the interaction between the material and the machine (roller-surface). The understanding of this behaviour was considered necessary to develop more accurate designs of machines required to deal with certain powders giving certain output properties. It is also understood[1,5] that within a roller press there exists two distinguished regions. The slip region where the powder starts to move but is still slower than the roll, that is, slip occurs and hence; the name "slip". As the powder accelerates its speed builds up until it catches with the roll speed. From this point the material is trapped between the two rolls as it travels with the same speed as that of the rolls until it leaves the machine. Consequently it is compressed as it proceeds towards the narrower space.

The design parameters are mainly the roll radius, R, the minimum gap, b_o, the starting angular position of the nip region and the roll force. Extensive experimental work has to be done to obtain, according to Johanson's rolling theory[4], relations describing the friction between the granular material particles as well as the friction between the granular material and the machine surface, the compressibility constant, k, of the powder, which is a material property that relates the pressure applied on the granular material to the change in its bulk density, ….etc.

It was proposed by the author, in a previous study[6], that obtaining the compaction ability of the machine; expressed as the bulk density ratio, the design parameters of the machine can be obtained without knowing the friction parameters of the material and material-machine interaction parameters. Where another njp region can be assumed based on the input bulk density. Thus avoid a lot of experimental work that is considered to be not required. This is achieved by performing a single test where the granular solid is actually rolled within a small; prototype press, where the compaction ratio obtained by the machine determines the bulk density ratio, leading to the design parameters of the machine. In this paper the details of a proposed prototype roll press are given and it is described how this will affect the design of roller press machines.

The Prototype Roll-press:

The Prototype Description: A design of a prototype roll press fig (3) is proposed. The proposed design incorporates two cylindrical rolls of 150 mm diameter and 50 mm width. Each of the two rolls is fixed using three screws to a holding shaft. A gear is mounted to each shaft and the two gears are meshing together. The assembly allows the attachment through an adjustment mechanism which allows the gap, b_o, between the two rolls to vary from zero (touching position) to 5 mm on the line of c entres which is in a horizontal

Fig. 3: The roll press prototype, general view

position. The two gears on the cylinders are driven by the output shaft from a gear box and a pulley system arrangement. A 3 kW motor drives the machine. The normal speed of the motor shaft is 1400 rpm. The used gear box steps the speed down to 140 rpm, further reduction is obtained through the set of pulleys, 3 speeds are available 60, 20, and 12 rpm. The system of pulleys can be replaced to allow different speed ratios. A more expensive alternative can offer a variable speed gear box to be used where an open choice with no limitation on the speed can be obtained.

Method of Operation: In this manner for a powder that will be compacted at a gap of 5mm, for example, the output bulk density can be given by weighing the quantity output during time t, and dividing this by the volume, V, given by

$$V = b_o W w R t \qquad (1)$$

Knowing that, for rotational speed N, in rpm:

$$w = 2pN/60 \text{ rad/s} \qquad (2)$$

(Substituting for length dimensions in cm, time in seconds, speed of rotation, N, in rpm)

$$V = 1.96\ Nt\ \ cm^3 \qquad (3)$$

Knowing the input bulk density, or determining it [7,8] for example, the bulk density ratio; or the compaction is obtained as:

$$\rho_{out} = x\rho_{in} \qquad \text{where } x>1 \qquad (4)$$

Certain compaction takes place within the machine to obtain the required output bulk density. This implies the required increase in pressure through the material compressibility property,k,[4], given by

$$\left[\frac{P_2}{P_1}\right] = X^1 \qquad (5)$$

the bulk density at position 1, the start of the nip region according to Johanson[4], when calculated based on input to the machine rather than being the start of the nip region, will end with a better prediction for the mechanical design[6]. It can be shown that the variation of the pressure through the machine can be obtained as a function of the angular position. This will be in terms of the minimum gap to roll radius ratio, b_o/R, as being related to the variation of the bulk density. Thus the roll force and torque can be determined using those parameters. Therefore for a full scale roll press, for the compaction of the same powder material, the required torque can be obtained, using the same roll surface material for the large rolls.

Values and Limitations: For the given dimensions of the prototype and using the power relation[9] stating that the power equals the product of the torque and the angular velocity, given by:

$$P = T\omega \qquad (6)$$

Where w is the angular velocity rad/s and if the speed of rotation N, rpm, therefore, using equation (2), the following table can be obtained,

The torque values, T in the above table are the theoretical values that can be obtained for 3 Kw power at the given values for the speed of rotation, N in rpm, and F_t is the corresponding tangential force in each case, at the surface of each of the two rolls. It can be shown that these values delivered by the machine's mechanical system; i.e. motor, gear box, pulleys, can be considered an upper bound, for torque and force values, for the given parameters of power, roll radius and speed of rotation.

As the powder travels through the machine, at a certain speed with the minimum gap b_o set to a certain value the bulk density increases to reach the value prescribed by the minimum gap at the output. This implies the increase in pressure through the compressibility property given by equation (5). Therefore as the material is forced through narrower and narrower gap its density increases (or its specific volume decreases) and as a result due to the compressibility property an increase in pressure is developed progressively with its travel.

Table 1: Torque and tangential force values for rotational speed choices.

N, rpm	T, Nm	F_t, kN
12	2387	16
20	1432	9.55
60	477	3.2

This pressure reacts on the rollers' surface. The motor and the mechanical system should be capable of developing the required torque and force (i.e. pressing action) that is able to overcome this reaction. Otherwise the powder will block the machine and will stop it from rotation due to the increase in pressure developed while travelling toward narrower passage. This describes the limit on the ability of the machine to continue to operate.

Scale up Guidelines: For large scale machine the bulk density ratio is kept the same to obtain the same product compaction starting with the same properties of the constituents. As the bulk density ratio is related to the geometrical parameters [4,11], the large machine dimensions' can be deduced. Relating the obtained dimensions to those of the prototype, knowing the pressure, through compressibility property, and the geometrical parameters (i.e. area of contact for full scale machine) force in the latter case and torque (through ratio of radii) can be obtained. It should be noted that the surface material of the large scale rolls is the same as that of the prototype roll press and the powder properties; grain size, moisture content, binding constituent, …….etc., are also the same for both cases. This will ensure that the friction properties[6] are not necessary to be known.

RESULTS AND DISCUSSIONS

- A prototype roll press can be used to obtain the outlines of the design of large scale roll presses.
- The assumption to locate the start of the nip region based on inlet conditions to the machine will over estimate the power and mechanical requirements, thus on the safe side for mechanical design.
- Previous work[5] has been performed to study the effect of feeders on compaction, where the output of the machine was obtained for different feeding speeds and roll speed variations. However the effect of feeders on the starting of the nip region was not recorded. The study in this manner relates to the output properties of the powder rather than the ability to estimate the design of the machine.
- The minimum gap, b_o, for large scale machine, if cannot exceed a certain limit, this will be a limitation on the scale up ratio, however, obviously, there is no limitation on W, the width of the rollers. The effect of the width to thickness ratio on the rigidity of the compacted sheet has not been studied.
- Effect of forces on machine members are not mentioned here, however, studies to ensure structural integrity has been performed. The shafts carrying the rollers are hanging in form of canti-lever beams which is accepted for a small size prototype[5], however, the knowledge of the forces can be used to perform necessary stress analysis for other supporting configurations where boundary conditions will be known.
- Further it is assumed that the rollers are rigid enough to remain purely of circular sections.

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