AGGLOMERATION AND PREREDUCTION OF ORES

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1.0 INTRODUCTION

The success of metallurgical processes greatly depends on the particle size of raw materials used. The size requirements differ from process to process and the desired sizes may range from tenths of millimeters to tens of centimeters. The desired size can be obtained by crushing or grinding if the input material is too coarse, or agglomeration if the input material is much finer. Agglomeration is a process of size enlargement; briquetteing, sintering and pelletising being the three common processes used in the metallurgical industries. The requirement of particle size for sintering is much coarser (generally upto 10 mm) against that of pelletising which is generally below 0.1 mm. The briquetting process can accommodate the size range of both sintering and pelletising.

With development of beneficiation process to treat low grade ores, the particle size of concentrate had consistently reduced. Thus it becomes necessary to agglomerate the fine concentrates to make them suitable for subsequent metallurgical operations. Agglomeration plays more important role in ferro alloy industry as the costly basic raw material is mostly obtained in the form of fines generated during mining operation or obtained after beneficiation. The closer size range and higher strength of raw materials obtained during agglomeration improves the performance of arc furnace to a great extent. Further the ore feed is partly reduced outside the arc furnace, so that the power requirement in the arc furnace is much lower and overall economics of the operation is improved.

2.0 PELLETISING

For pelletising, the fines are properly moisturised and made to rotate in a drum or disc with or without the use of a binder to produce spherical balls. The moist balls (green pellets) are hardened to impart strength by firing at temperatures above 1000^{0}C. The advantage of pelletising over sintering is that the pellets have much higher strength and more uniform size. The size and strength requirement of the final pellets depends on their subsequent use, which generally varies from 5-25 mm and 50-200 kg respectively.

2.1 MECHANISM OF GREEN PELLET FORMATION

Two phenomena are responsible for the formation of green pellets, and which of the two is more predominant depends on the location and method of material feed and water addition. One way of forming pellets can be designated as "rolling of shells" or "snowball effect", in which the wetted ore particles are rolled up to form a pellet shell by shell (Fig. 1).

When pellet formation takes place by the second phenomena, the water filled pore system of a pellet acts like a water filled capillary tube, i.e. the surface tension of the water produces attractive force which operates on the ore particles and thus holds the wetted particles together in the form of pellets. In the beginning the initial bonding between the particles is due to water bridge or meniscus which does not have sufficient strength (Fig. 2a). When more liquid (water) is added , the liquid film on the particle surface begins to coalesce, but closed air filled cavities remain between the particles (Fig. 2b). The coherence of the particles is affected by surface forces from the meniscus travelling between individual particles. The ball grows as more moistened particles are coated on to the nucleus. Mechanical forces which are produced by bumping balls against each other and against walls of the rotating device in which they are enclosed, expel the air enveloped in the balls and the full capillary stage sets in (Fig.2c). At this stage the liquid fills the free space between the particles and the capillary forces result in the particle coherence throughout the ball.

Both phenomena exist in the formation of large pellets. The initial nucleus is formed due to the water surface tension, and the nucleus grows into size with the addition of subsequent layers on it. Uneven or excessive moistening of particle results in the production of large, irregular entities (Fig. 3).

2.2 LAYOUT OF PELLETISING PLANTS

General layout of pelletising plants using wet grinding system is shown in Fig. 4. It consists of (a) Preparation of raw materials which include grinding, classification, dewatering, mixing, etc., (b) hardening and strengthening.

Preparation of Raw materials

For pelletising, the ore is ground to very fine size, generally of the order of 70% fraction below 75 micron (200 mesh). The proportioning of various constituents in the mix and the control of the feed to the pelletiser is achieved by incorporating metering devices like table feeder, screw feeder, belt feeder, etc., to the raw material / ground material bins.

Green Pellet Formation

Drum and disc pelletisers are the two basic types of balling devices. Other devices like conical disc, cone attached to balling drum, disc pelletiser with reroll lip and multi level disc pelletiser, are only the modifications of disc and drum pelletisers.

Drum Pelletiser

It is a rotating inclined drum having its axis about 2 to 10 degrees to the horizontal and water sprays are provided inside the drum for ball formation. The schematic diagram indicating the flow pattern of the material inside the balling drum is shown in Fig. 5. The process consists of the ball formation having large size range inside the drum, screening of undersize pellets for recirculation, and collection of desired pellets for induration. The pellets can be screened at the exit end of the drum where a screen is installed, or a vibrating screen can be used as a separate unit. Water is sprayed by push-in lances installed on the feed side. The depth, the lances "pushed in" and the spray rate, are controlled independently.

The dimensions of commercial drums vary depending on the output required. The drum diameter varies between 1 and 3.5 meters, its length between 5 and 9.5 meters. Average capacity of a drum pelletiser is around 50-60 tph.

Disc Pelletiser

The disc pelletiser is a machine widely used at present in several industries. In contrast to the balling drum, the disc pelletiser can combine balling and screening in one operation, since the pellets of larger size only can be made to discharge out of the disc, whereas the finer pellets will be keeping on rolling till the size grows. Furthermore the quality of the product can be controlled by simple operations such as varying the disc inclination, speed, the adjustment of scraper blades, location of feed point and water sprays. The material in the disc is worked in a manner similar to that encountered in the balling drum, the particles to be balled being subjected to the action of practically the same forces in both instances. The schematic diagram of disc pelletiser showing the path of raw material is shown in Fig. 6.

Immediately after the disc pelletiser, vibrating screen or roller screens are installed to collect the desired size pellets (generally 6-20 mm) and feed them to hardening unit. The oversize and undersize pellets are recirculated for balling operation. The roller screens have advantage of forming more rounded pellets with further improvement in the strength of green pellets due to additional rolling.

2.3 IMPORTANT PROPERTIES OF GREEN PELLETS

Drop Strength

It is the most important and also guideline for other properties. High drop strength indicates its resistance to breakage during transport of the pellets between disc pelletiser and hardening unit.

Drop strength is given by the number of drops undergone by a green pellet when it is dropped from a height of 450 mm on a steel plate. Generally the drop strength over 7 is sufficient in commercial operation.

Compression Strength

The green pellets as well dried pellets should have minimum compression strength so that pellet can sustain the load of pellet over it, during drying operation.

Moisture Content

Minimum moisture content is essential for pellet strength. Low moisture makes the pellets brittle and higher moisture make them highly plastic which get easily deformed during subsequent operation.

2.4 FACTORS INFLUENCING GREEN PELLETS FORMATION

Granulometric Properties

The term covers all properties in connection with the ore grain size, grain shape and size distribution. The required properties depend on the type of ore and the quality requirement of pellets. The fineness is reported normally in terms of percent below 0.2, 0.075, 0.04 mm as well as its blaine number. The blaine number is a measure of specific surface area and reported as cm^2/g, and hence depends on the particle size distribution and the shape of grains (Fig. 7). In general for production of high strength pellets it is desired that no particle should be above 0.2 mm and proportion of -0.04 mm should be between 60-90%. This corresponds to generally the blaine number 1800-2400. Finer material produces pellets with high strength but low porosity. Hence too fine grinding is avoided to prevent the bursting of pellets during drying stage. Increase in proportion of -0.075 mm from 75 to 95% resulted in improvement of drop strength by 100% for chrome ore[(2)].

Moisture Content

Water acts as a binder during green pellet formation. The optimum moisture content depends on type of the ore, its fineness and additives used. The optimum moisture content for different ores is given below :

Magnetite : 7-9%
Hematite/Chromite : 8-11%
Limonite :10-14%
Nickel ore :16-24%

Addition of Binders

For most ores addition of a binder, besides water, is necessary. The role of binder is to

i) Improve the ballability of the material
ii) Improve drop and compression strength of green pellets
iii) Adjust mineralogical and chemical consistency and quality of fired pellets

The common binders include bentonite, lime, soluble glass, cement, sulphite waste liquor and organic compounds like dextrine, tar, molasses, etc.

Water Spraying System

The water pressure generally varies between 0.5 and 1.5 atmosphere. If the pressure is low, coarse size pellets are formed and high pressure produces smaller pellets.

Fine spraying is necessary for production of small pellets and coarse spraying for large pellets.

Disc Inclination And Height of The Border

The disc angle is determined by the dynamic angle of repose of specified material. The tilt angle of disc surface should be more than the dynamic angle of repose (Fig. 8). If it is smaller or equal, the material remains in a position of rest on the surface of the disc. If the tilt angle is too high, the charge will not be lifted up. .

The height of boarder is also determined by the tilt angle: The filling volume is dependent on both factors. The lowest tilt angle requires lowest height of boarder: The flatter the disc and higher the border, the longer the pellets will be retained in the disc. However, the disc capacity, the size and strength of green pellets depend upon the time of retention.

Disc Rotating speed

The disc speed should be such that the material is entrained upto the highest point in the disc and then rolls down. This means that a flat disc rotates at lower speed than a steep one.

With insufficient speed, the charge remains in a relative position of rest and no rolling of material occurs. At an excessive speed, the material moves upwards without rolling down. Due to centrifugal force on it the material slung against the disc rim, and hence no rolling takes place. This phenomenon occurs at the critical speed of the drum, which makes the maximum utilisation of disc surface for rolling action of the material. In commercial plant the disc speed is generally of the order of 6-20 rpm for the diameters ranging from 3 to 6 meters.

Disc Diameter

Due to simplicity of operation, the pelletising discs have large variations in its diameter. The smaller discs for laboratory purpose have the diameter of around 0.8-1.0 meter, whereas the commercial units have their diameters upto 7 meters. It has been established that size of disc area has no influence on the pellet quality apart from the fact that the porosity decreases slightly with increasing diameter. However, the diameter and disc area are deciding factors for the quality of pellets produced.

Location Of Feed And Water Sprays

The place where the ore is fed and water added, is of great influence on the properties of the pellets. No universal rules are applicable, but in general for production of smaller pellets material is fed at the top portion of the disc surface, and for production of large pellets at the lower portion of disc surface.

2.5 HARDENING OF PELLETS

The green strength of pellets is hardly adequate and may be increased by subjecting them to various treatments which depend on the starting material for the pellets, and further processing. Drying may prove sometimes sufficient, possibly in combination with use of binders, or chemical hardening or heat hardening can be applied.

Heat hardening is most common method employed. The mechanism of hardening is governed by the initial chemical constituents of the input material. Hematite and magnetite concentrates low in gangue, are strengthened by recrystallisation of hematite particles. A different mode of hardening occurs if ores higher in gangue or ores containing basic additives are processed. In this case the pellets are hardened due to gangue fusion and formation of slag binder between ore particles. Slag bonding generally produces lower strength compared with the strength imparted by recrystallisation. Higher temperature and time of induration produce pellets with higher compression strength.

Pellet Hardening Units

There are three basic types of hardening units :

i) Vertical Shaft type :

In this system the charge moves continuously through the shaft and the gas passes counter-currently. There is variation of temperature from top to bottom. The top portion acts as a drier, the second part as firing unit and the third as cooler.

ii) Horizontal Travelling Grates :

This consists of three parts, the first part acts as a drier,the second part as firing unit and the third as cooler.

iii) Grate Kiln System :

This system consists of three basic units, i.e travelling grate, rotary kiln and grate cooler. The drying and prestrengthening is performed in the grate, firing in the rotary kiln and the cooling in a grate type cooler. The treatment carried out in three different units gives the best compliance of the technology with the nature of the feed material.

The TATA STEEL charge chrome plant at Bamnipal (Orissa), uses chrome ore fines to make green pellets in a disc pelletiser, fired in a vertical shaft furnace, preheated in a rotary kiln and finally made into charge chrome (60% Cr) in submerged arc furnace.

3.0 SINTERING

In sintering the agglomeration of ore particles is achieved by surface fusion as a result of burning of a solid fuel (Coke fines) added to the charge mix. Sintering is likely to be more economical as it does not require any binder or fine grinding of raw materials.

3.1 GENERAL PLANT LAYOUT

The general layout of a sinter plant may conveniently be divided into the following sections :

Proportioning of raw materials
Mixing
Loading of mix on to strand
Ignition
Sintering
Sinter treatment
Waste gas system

Proportioning of raw materials

The raw materials used are as follows:

- Ore fines, normally -12 mm. It is undesirable to have larger lumps and it is also undesirable to have an unduly high proportion of -150 microns material.
- Fuel, normally 3 mm coke breeze; fine anthracite is sometimes used.
- Furnace flue dust and fines produced in sintering.
- Flux, limestone and/or dolomite of -3mm.

The raw materials may be blended by laying them down and reclaiming them from beds outside the sinter plant proper, or the individual components may be stored separately and conveyed to separate bunkers in the sinter plant. From these bunkers the various materials are withdrawn via feeders, and collected on a gathering belt.

Mixing

The proportioned raw materials are next mixed and moistened. This is usually done by passing them through a drum fitted with paddles, water being added to impart permeability to the mixed materials. After this initial mixing, the moist mix may be rolled in a drum to give increased permeability.

Loading and mixing on to the strand

The mix is now ready to be loaded on to the strand. The aim is to lay down the material evenly across the width of the strand with the minimum compacting. This can be achieved by using devises like swinging spout, a roll feeder, vibrating-tray feeder etc. In some cases a thin layer of inert material, such as sized sinter, is first laid on the grate bars and the sinter mix is loaded on top of this hearth layer. Immediately after loading, the surface of the mix is levelled by passing it under a plate, the 'cut-off plate', which is set so as to give the desired thickness of mix on the strand. Normally this is between 100-450 mm.

Igniting

The mix is ignited by means of gas or oil burners. Normally the burners are set in a brick-lined hood which covers a length of strand, but vertical burners which impinge directly on to the mix are sometimes used.

Sintering

Air being sucked through the bed into windboxes situated under the grate. The grate consists of a number of individual pallets. These pallets travel forward on wheels running on a track beside the strand, and the system is sealed as far as possible against leakage of air in at the grate edge, The strand moves forward at about 3 meters per minute so that the mix takes about 15 minutes to travel from the igniter to the end of the strand. During this time the combustion zone travels through the bed, the strand speed normally being adjusted so that combustion of the fuel at the bottom of the bed is complete just before the sinter reaches the end of the strand (Fig. 9).

Sinter treatment

At this point the finished sinter is tipped from the strand as the pallets turn for their journey back to the loading end. The sinter falls on to a crash deck and the large lumps are broken up by toothed wheels. The discharged sinter is hot, but varying in temperature according to its previous position in the bed; the sinter from the top of the bed has already been cooled to ambient temperature, whereas that from the bottom of the bed is over 1000^{0}C. From the crash deck the sinter moves to a vibrating screen, normally set at about 9 mm. The under size, the return fines goes back to join the stream of raw materials and the oversize goes forward to the sinter cooler.

A typical charge and operating conditions for the production of sinter from manganese ore fines is as follows :

Coke : 5.5% ;	Moisture : 7.0% ;	Suction : 150 mm W G
Return fines: 25.0% ;	Bed depth:125 mm ;	Sinter rate : 20mm/min.
Ore fines : 69.5% ;	Productivity :1.0 t/m^2/hr	
hearth layer : -10+6mm sinter		
Ignition time : 30 sec.;	Ignition Intensity : 10,000 kcal/min/m^2	

Waste gas system

Suction upto about 12 kN/m^2 is applied to the bottom of the sinter bed by means of a series of windboxes, which are connected by a series of downcomers to wind main. The clean gas after removing dust by counter weighted dust valves, mechanical means and electrostatic precipitators is finally discharged to the atmosphere through a stack.

4.0 BRIQUETTING

Where availability of binder is not a limitation, the briquetting is always preferred, since it does not call for fine grinding of raw materials as in case of pelletising and high temperature treatment as in case of sintering. In case of high pressure briquetting operation, even the binders are not used.

4.1 PROCESS

Basically, the process involves passing of finely divided material through the nip of the rolls under sufficient pressure to overcome the internal molecular forces and form a dense, cohesive compact. Agglomeration using double roll equipment is a compaction process, and terms "briquetting" and "compacting" are some what interchangeable. The term briquetting is normally used for predetermined shape of agglomerates (pillow shaped etc.). Compacting is most often used for the production of agglomerates in the form of flat or corrugated sheet.

4.2 EQUIPMENT

Roll type briquetting machines are capable of forming different sizes and shapes (pillow, egg, semi spherical and bar shaped). The shape of briquettes is obtained by the desired shape of grooves made on the periphery of rolls (Fig.10).

Many materials can be compacted by pressure alone. However, in some instances binders are used to lower the pressure required for compacting, thereby increasing production for economical operation. The most commonly used binder is water, although many other raw materials as well as heat may be used. The other common binder in case of ferro alloy industry are bentonite, dextrine, molasses, tamrind seed powder, etc.

The layout of a briquetting plant consists of bins or feeders, mixer for homogenising the raw materials, briquetting press and some times a drying unit.

5.0 PREREDUCTION

Prereduction, i.e reduction in solid state in ferro alloy industry is practiced to reduce the power consumption in the electric arc furnace which is the most costly commodity.

In the process of prereduction of chrome ores, the ore is partially reduced in the solid state before charged into an arc furnace in the hot condition. In the conventional method preheating, melting and reduction of chrome ores have all been dependent on electric energy, while in prereduction process expensive electrical energy can be partly replaced with cheaper energy sources and the productivity of the electric furnace can be greatly improved.

5.1 PROCESS

Before charging into electric furnace, the ore fines are ground and pelletised. The pellets are prereduced in a rotary kiln using coal fines or reducing gases from the arc furnace as reductant. The hot and partially reduced pellets are directly charged into the arc furnace. In case of lumpy ores, the pelletising is eliminated and the ore is directly fed into the reducing rotary kiln. The reduction achieved in the rotary kiln is to the extent of 60% and it has been made possible to produce high carbon ferro chrome containing 57-60% Cr, 8% C and 3% Si. The power consumption was of the order of 2000-2100 kWh/tonne ferro chrome. It has been made possible to use cheaper coke fines in place of costly coke lumps, by adding the coke fines during pelletising operation.

6.0 CONCLUSIONS

The success of metallurgical processes depends on the particle size and uniformity of the raw materials used. In the light of beneficiation of low grade ores, the particle size of the concentrates had consistently reduced and hence not suitable directly for metallurgical operations. Thus it become necessary to agglomerate the fine concentrates to make them suitable for subsequent metallurgical operations. The type of agglomeration process depends on the quality of raw materials used and the quality of agglomerate needed for subsequent operation.

Agglomeration plays an important role in industrial applications as is the case with ferro alloy industry. Since the power consumption in the electric furnace is a major contributor for the cost of ferro alloy production, prereduction before the ore is charged into the electric furnace reduces the cost of net product made, by lowering of the power consumption in the arc furnace.

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1. Srb, J and Ruzickova, J., Pelletisation of Fines, Vol.7, page 15, 1977.
2. Bruce Mc, Rae L and Selmer-Olsen, S.S., Proceedings of 2nd Int. Symp. on Agglomeration, Atlanta, March, page 363, 1977.

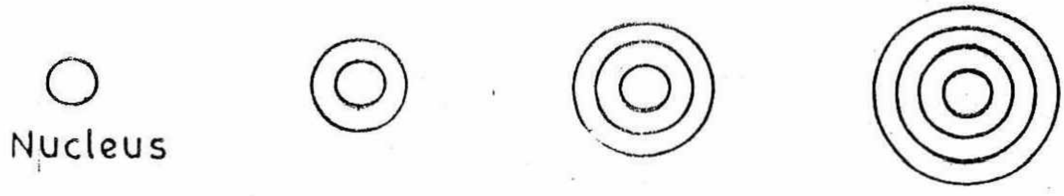


FIG. 1 : GREEN PELLET FORMATION DUE TO "SNOW BALL EFFECT"

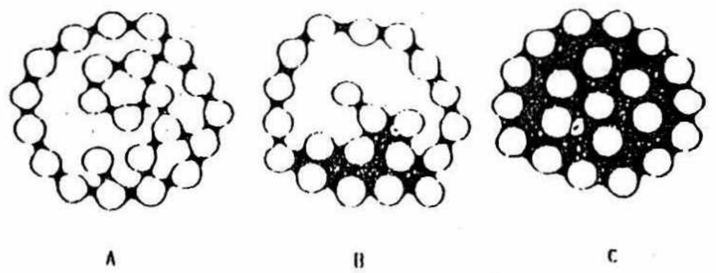


FIG. 2 : MECHANISM OF BALL FORMATION

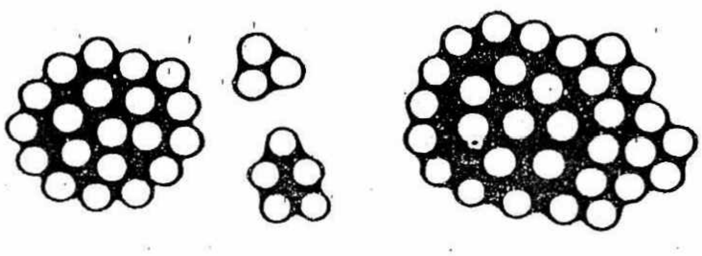


FIG. 3 : FORMATION OF FLOODED BALLS

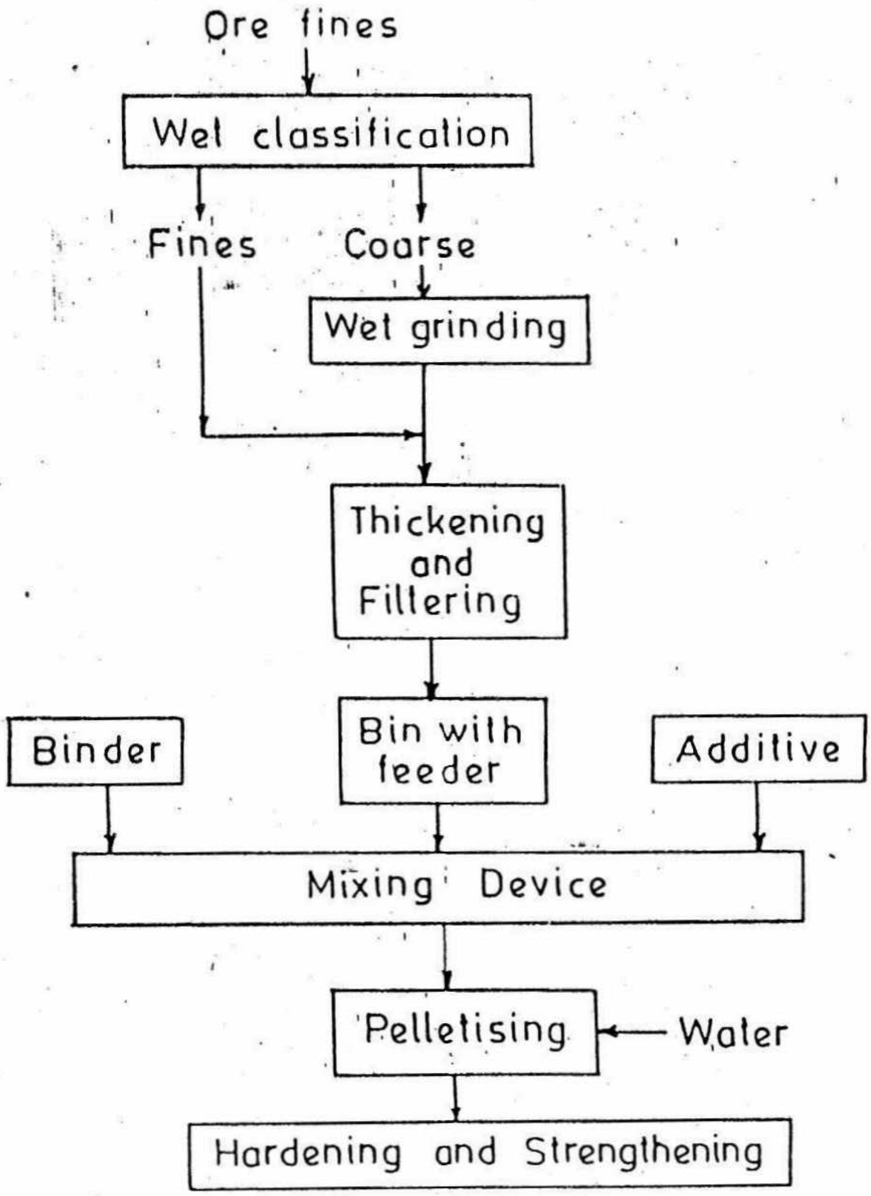


FIG. 4 : FLOW SHEET OF PELLETISING PLANT WITH WET GRINDING

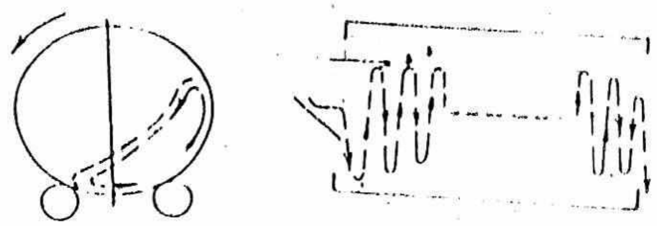


FIG. 5: BALLING DRUM

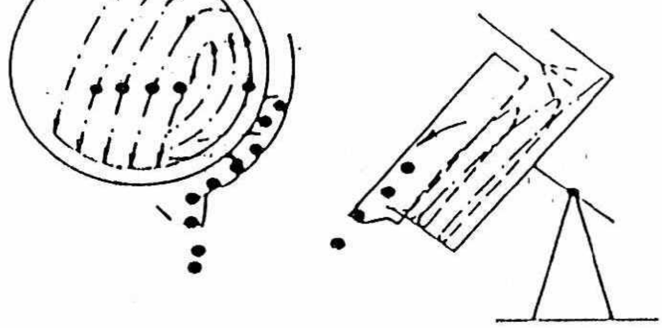
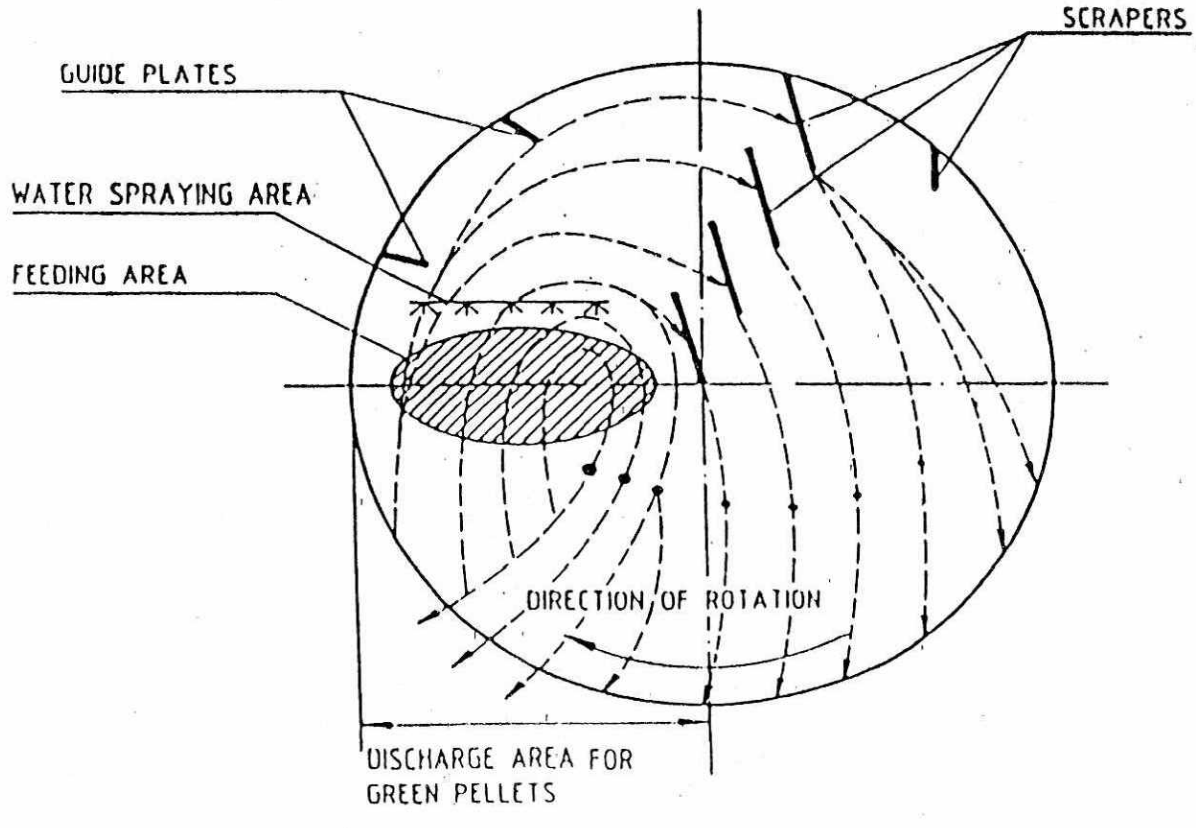
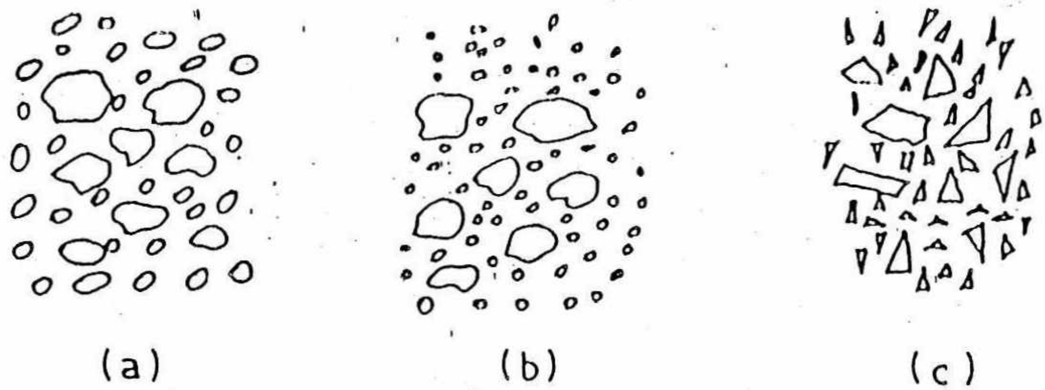


FIG. 6: DISC PELLETISER





	(a)	(b)	(c)
% below 0.075mm	80	80	80
Shape	Rounded	Rounded	Angular
Blaine No.	1800	2200	2200

FIG. 7: EFFECT OF PARTICLE SIZE AND SHAPE ON BLAIN NUMBER

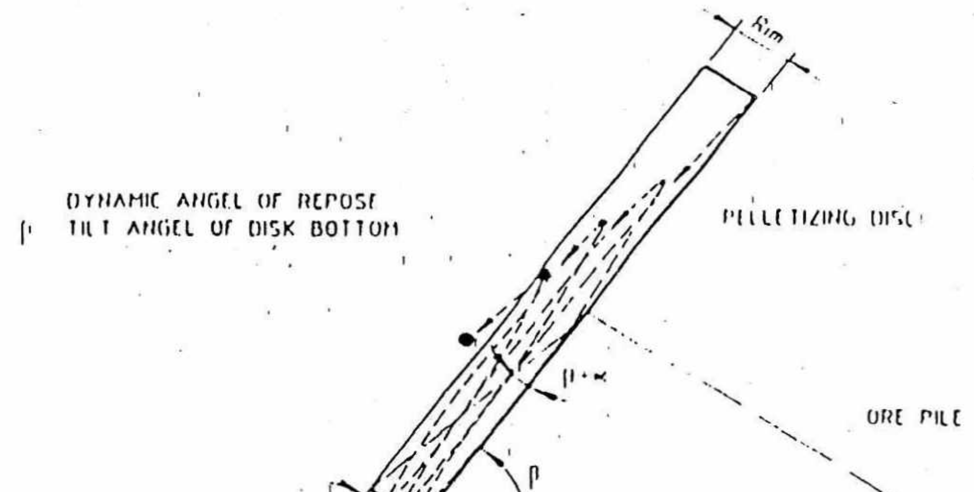


Figure. 8: Optimum Disc slope

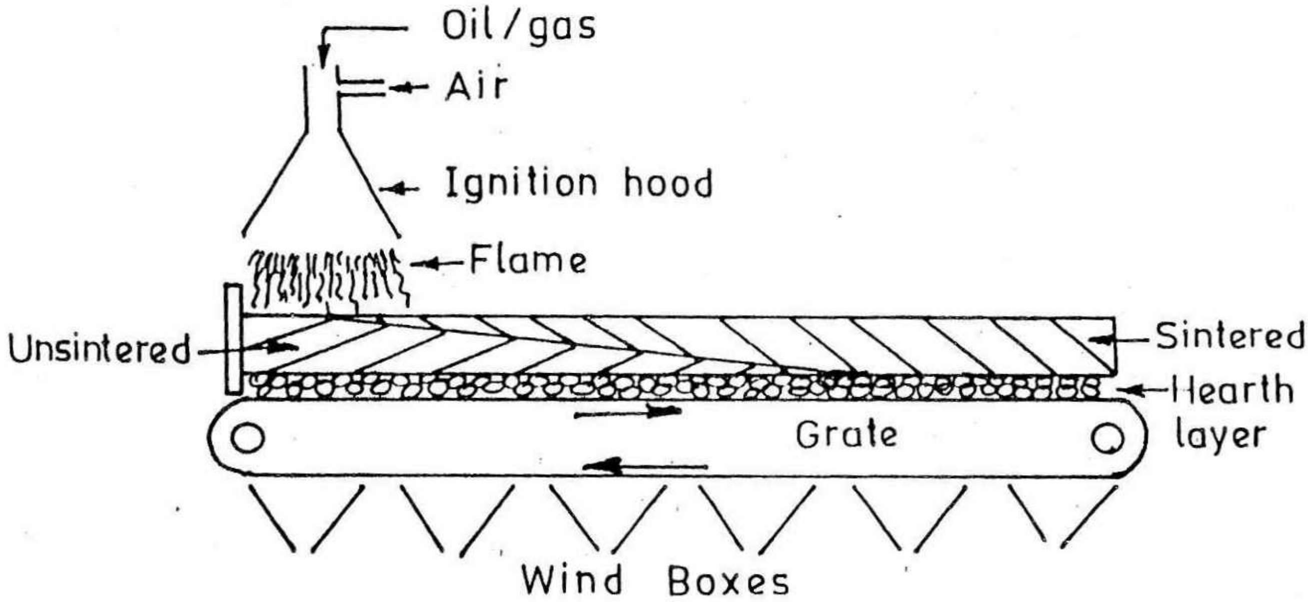


FIG. 9: ADVANCE OF SINTERING ZONE ON A GRATE TYPE SINTERING MACHINE

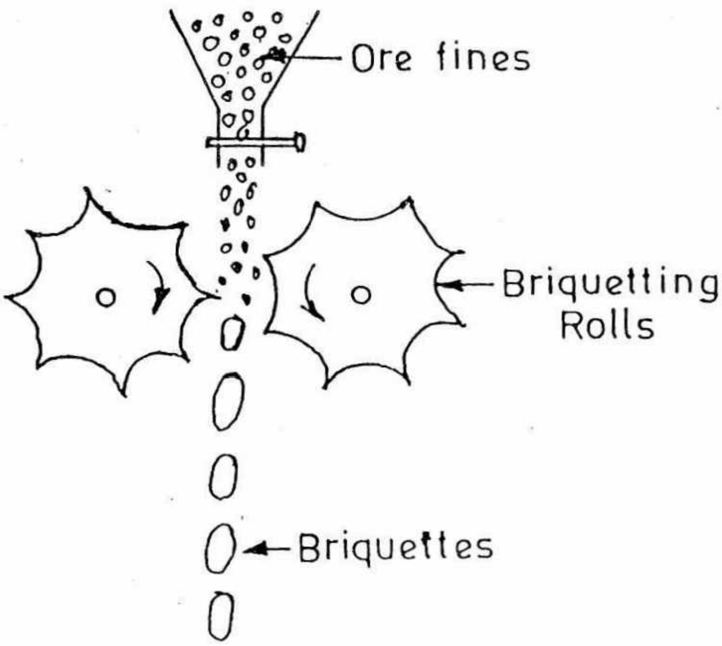


FIG.10: ROLL TYPE BRIQUETTING PRESS