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Developing Archetypal Machines for a Sequence of Food-Slurry Processing Operations: An Overview *(Pp 122-136)*

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Abstract

The importance of cereal gruel as a highly nutritious food for infants in many countries in Africa cannot be overstated. Conventional methods of producing these food-slurries prior to their consumption as food cannot meet up with the high demand for these gruels. This current work is targeted at developing various archetypal machines for the improvement of the production of these food slurries. Three prototype machines have been developed and discussed in this paper, namely, the suction sieving machine, the vibration sieving machine and the continuous flow multi-stage milling machine. The results of performance analyses on these archetypal machines are presented and compared to ascertain their efficiencies and their appropriateness for different operations respectively. The results show that the machines have increased the sieving rate of steeped grain and in extension the production of these food-slurries by over 50%. Design considerations for a dual-processing machine-assembly that combines the sieving and milling processes into a single operation is herein presented as the focus for future works. Conclusively, this work presents a remarkable contribution to research on the improvement of the production of various cereals gruels in Nigeria and many developing nations through the introduction of new processing technologies.

Key words: - Archetypal-Design; Performance-analysis; Sieving; Milling; food-slurry

Introduction

Maize gruel is the most popular form of cereal consumption in West Africa. This gruel can be made from slurry of maize, millet and sorghum. It is a popular weaning food for infants and breakfast cereal for adults when cooked. Traditional method of maize-slurry manufacture involves three unit operations of steeping to soften and ferment the kernels, wet-milling and wet-sieving to effect the separation of the over tails from the thorough. The quality of maize-slurry, especially the rheological properties, is dependent on such factors as type and variety of cereal grains, milling technique and particle size (influenced by sieving operation) , steeping and souring period.

The traditional maize-slurry sieving procedure leaves much to be desired. Traditional sieving operation is labour intensive, time consuming, and constitute a point of contamination and loss of nutrient. Moreover, the operation is not standardized, as sieves of different apertures are utilized. Shown in Fig. 1 is a diagrammatic representation of the traditional methods and newly developed technologies of processing maize-slurry. Presently, little or no information exist on the use of mechanical means or machine in the sieving of maize-slurry. In the aspect of wet milling, the conventional machines used also need to be improved for better efficiency. Thus, the development of appropriate technologies for the sequence of operations involved in maize-slurry processing becomes important. This procedure when fully developed will minimize excessive use of water, nutrient losses, contamination and time-cycle of maize-slurry production.

Researches have been conducted by the author over the years (Simolowo and Ndukwe, 2002; Simolowo and Adeniji, 2009) on the design of different prototype machines for processing maize-slurry. In this paper an overview of existing design innovations and newly conceptualized technologies will be presented. An outlook of a dual machine-assembly that forms an integral part of a prospective maize-slurry processing plant concludes this paper. Basically this paper focuses on the sieving and milling processes of maize-slurry which are part of the processes shown in Fig. 1. Two prototype machines have been developed for the sieving of ground corn slurry namely, the suction and the vibration sieving machines. An improvement of the conventional milling machine is achieved by designing a continuous-flow, multi-sage milling machine. The stages involved in the development of these prototype machines and their effect on the processing of "Ogi are also discussed in this paper.

Prototype machines for grain-slurry processing

Two types of machines for sieving ground corn-slurry and a multi-stage grinder for milling steeped corn or other grains for making grain-slurry are discussed in this section. The basis for designing these prototype machines, configuration of components, parts description, design considerations and review of work-stages leading to final development of these machines are presented. The advantages and disadvantages of using the developed machines over the traditional methods are also mentioned in this section. Comparative performance analysis of the two sieving machines and the improvement of the existing milling process using the multi-stage grinder are also presented in this section.

Suction grain-slurry sieving machine

The first prototype machine built for sieving grain-slurry was developed based on the principle of suction. The configuration of the machine and the fluid/air-flow directions are depicted in Fig.2. The four compartments that make up the equipment namely, *the slurry container, the mixing unit, the sieving unit and the reservoir* are tightly fitted together to create an air tight flow line for the fluid and air. The suction pump is connected to electric power source and is linked via an air hose to the sieving unit to create the sucking force in the fluid when switched on. Three stages are involved in the full development of the suction-sieving machine. They are *(i) general equipment specifications, kinematics and incorporation of a vacuum cleaner pump (ii) Vacuum Pump substitution with centrifugal blower (iii) improvement of blower efficiency and material specification.* The design information presented in Table 1 summarizes important issues entailed in the three stages of developing the suction sieving machine.

The general equipment specification stage of the suction-sieving machine entailed the kinematics or skeletal arrangement of the equipment and component by component specification following the design guidelines by Allen et al, (1982). At this stage a centrifugal pump (obtained from a vacuum cleaner) of 1KW rating was used to provide the required pressure drop. The sieving rate calculated herein was high because it was derived from the power of the suction pump dismantled from an existing vacuum cleaner and coupled to the sieving machine to make up its suction unit.

The design substitution stage involved the design and fabrication of an appropriate suction unit for the sieving machine. The newly designed centrifugal blower was used in place of the vacuum pump employed in the first stage of design. This substitution stage was characterized by reduction in efficiency and sieving rate of the machine. The reduction resulted from the fact that the newly fabricated and tested centrifugal blower was not as effective as the pump obtained from the vacuum cleaner.

At *the improvement and material specification stage,* works done by Gbolagade and Adeleke (2000) focused on the improvement of the blowers' efficiency and choosing appropriate materials for the machine units. Steel and other anti-corrosive alloys were used to replace other materials in the machine parts, while the size of the whole machine was also reduced to increase the pressure drop in the equipment. The complexity associated with fabricating the required centrifugal blower for the suction unit of the sieving machine and the quick clogging of the sieving gauze made it necessary to develop an archetypal vibration sieving machine**.**

Vibration grain-slurry sieving machine

The vibration sieving machine as shown in Fig.3 is made up of four sub-assemblies namely, *(i) the supporting frame structure (ii) the sieving/mixing unit (iii) the water reservoir unit (iv) the vibration assembly.* The supporting frame is the structural part that provides the kinematic rigidity for the equipment while supporting the weight of the machine.

The frame structure is made up of two frame units, namely, the *base frame* that withstands the weight of the whole machine and the *vertically attached frame* that supports the weight of 2 hp electric motor. The electric motor via a rod connected to a disc plate produces the needed vibration for the sieving process. The vibrating disc plate which carries the sieving/mixing unit at its center is suspended and held in place by four springs. The springs are located in spring houses attached to the top of the base frame.

The sieving/mixing unit is made up of the sieving container and sieving mesh. The sieving container which is made of stainless steel is cylindrical in shape and tapered at the exit end. Towards the tapered end is the sieving mesh, bolted on a circular flat ring in the sieving container. Attached externally on the sieving container is the vibrating disc plate. The sieving container has an average volume of 5340cm^3. A cover for the sieving container is also of stainless steel and centrally opened. The opening on the sieving cover accommodates the mechanical stirrer during the agitation. A stainless steel spout cylindrical in shape with a tapered end is attached to the base frame beneath the sieving compartment. The spout conveys the "Ogi" filtrate out of the sieving unit.

The water reservoir is a separate unit mounted on a stand made of iron. The water reservoir unit comprises: a water container, water stand and water hose. The water container (average volume 10618mm^3) made of plastic material has a lid and a tap attached to its base. A water hose connecting the tap and the sieving container supplies water that is mixed with the thick slurry within the sieving compartment so as to ease the sieving process. *The vibration assembly* provides the agitating mechanism that produces the required vibration torque for the whole system. It comprises the arrangement of electric motor, driver pulley, driven pulley, belt, agitator bearing, stirrer bearing, vibrator bearing and offset driver shaft for eccentric movement. The electric motor, (2hp, 220v, 50 Hz) which runs at a speed of 1450rpm is mounted vertically on the electric motor frame, and coupled onto the driver shaft. The driver shaft is connected off-center to the vibrator bearing on the vibrating disc plate.

The continuous flow multi-stage grinder

The conventional milling process using the existing burr mills requires re-pouring of ground slurry several times into the mills to obtain the expected texture of paste. This procedure is tedious and time-consuming, hence, the need for a continuous multi-stage grinder that eliminates the re-pouring of milled slurry into the grinder. The prototype smulti-stage grinder with its parts shown in Fig.4 is the modification of the conventional burr mill grinder used in Nigeria presently. This archetypal design comprises a combination of three (3) burr mill grinders arranged serially, for the purpose of getting ultra fine product at a single grinding flow. Each of the three burr mill housing of the grinder contains two sets of grinding plates, in which the outer plate is connected to the driven shaft and the other inner plate is fixed to the machine frame.

When the outer plate rotates over the inner plates, the grooves of both plates will cross each other at acute angles. The point of intersection of such grooves begins near the center of the plates and moves outward the circumference as the plates rotate. This grinding action of the machine is achieved by shear action as compare to other machines that make use rubbing action. The fineness of the product coming out of the system can be regulated by adjusting the screw connected to the driven shaft. The main components of the multi-stage grinder that distinguishes it from the existing grinders are here in described

Three Pairs of Fixed Plate and Rotating Plate: These are the plates that bring about the grinding or milling operation in the machine. They are made of mild steel with rough surfaces to give the desire crushing. The assembly is coupled in such a way that they can be easily dismantled for proper cleaning. This procedure is difficult to achieve in existing machines, since the hoppers are fixed permanently.

Three Mill Housings: These house the fixed and rotating plates and are held in position by fastening screws and fly nuts at the back of the mill plate. The other ends of the housings carry the gap adjusters which accommodate the anti friction bearings. The transmission shafts of the conveyor extend on both ends of the mill housings to receive and deliver the torque required by the machine operation.

Transmission Shafts: These are the major operating devices and are three in number. They are made of mild steel and have worm gears welded at one end of the shafts to bring about the forward and backward movement of the grinding plate which perform the grinding operation. The other ends extended to the side of the machine where the sprockets are fitted on the shafts.

Sprocket and Chain: Sprocket and chains have been selected to transmit power to the second and third shaft based on the following facts (i) they are adjustable (ii) they are the most suitable for the working distance (iii) they eliminate slip caused by vibration (iv) perfect velocity ratio is ensured thereby transmitting adequate power from the upper (first shaft) to the lower shaft (v) they are maintain high efficiency with minimal power loss, as they give fewer loads on the shaft. The second and the third sprockets are the driving and driven sprockets respectively. The sprockets on the first and third transmission shafts are simplex in design while that on the second shaft is duplex. This is to enable it carry the chains from the first and the third shafts simultaneously.

Performance analysis of archetypal machines

In this section the performance analyses are discussed for the designed prototype machines namely, the suction and vibration sieving machines and the multi-stage grinder. The performance analysis of the suction and vibration sieving machines were accomplished by comparing their sieving rates with those obtained by manual sieving process. Milled corn and millet mixed together was used in conducting the performance tests. The objectives of the performance tests for the sieving machines (Simolowo and Adeniji, 2009) were: (i) to obtain the average sieving rate of the machine and compare it with the manual process (ii) to compare the volumes of filtrates and mass of chaff obtained by the manual and mechanical methods so as to obtain the optimum performance of the machine (iii) to estimate the amount of water utilized during both sieving processes within the time of sieving.

Experimentation and performance results of suction sieving machine

The objective of performance analysis stated in section 3.0 (i) was attained for the suction sieving machine based on the two specified conditions namely; manual (without pump attached) and mechanical (with centrifugal suction pump connected to machine). In the manual sieving process, grain-slurry mixture and sprinkled water were simply allowed to pass through the sieve cloth under natural gravitational force while for the mechanical process, the pump was connected to the suction line of the sieving unit and switched on. Both tests as described were repeated four times for each process and the sieving flow rates were determined by recording the time different volumes of grain-slurry mixture pass through the sieve unit (Simolowo and Ndukwe 2002). Presented in tables (2) are the results of the performance tests.

Experimentation and performance results of vibration machine

The three objectives stated in section 3.0 were considered in the performance test of the vibration sieving machine (Siomolowo and Adeniji 2009). The manual sieving and the mechanical sieving using the vibration sieving machine were compared. Performance index parameters calculated for both manual and mechanical processes included; (i) sieving rate (ii) volume of water used in sieving (iii) weight of filtrate obtained (iv) weight of chaff collected after sieving. The results obtained from the experimental assessments of both manual and vibration methods are presented in Table 2. The overall improvement of the vibration method over the manual process was calculated as 82% (Siomolowo and Adeniji 2009). Tables 2 shows further that for the same average volume $1.00 \times 10^{-3} m^3$ of slurry mix the average sieving time for the manual and mechanical methods were 135s and 63.8s respectively bringing about 47% time reduction with the application of the sieving machine.

The average mass of chaff obtained by manual and mechanical procedures were given as 103×10^{-3} kg and 58×10^{-3} kg respectively (Siomolowo and

Adeniji, 2009) resulting in 56% reduction with the application of the developed equipment. An average volume of 2.00 x $10^{-3}m^3$ was used with the vibration sieving machine as compared with an average volume of 4.00 x $10^{-3}m^3$ used in the manual process, thus, bringing about an economical advantage of about 50% reduction in water usage (Siomolowo and Adeniji, 2009).

Experimentation and performance results of multi-Stage grinder

The parameters of focus in testing the grinder comprise (i) performance (ii) durability (iii) reliability (iv) safety of operation. The test operation involves feeding moist grains into the hopper and switching on the prime mover, that is, the A.C. motor (or petrol engine), which transmits motion to the machine through the transmission shafts, pulley-belt and chain-sprocket systems described in section 2.3. Through the use of force of gravity and machine vibration the moist grains in the hopper fall through the inlet port into the groove of the screw conveyor. The grains follow the spiral path of the conveyor until it impinges on the surface of the rotating grinding plates. The grains are flung round the circumference of the grinding plates into the inner surface of the cover and finally to the outlet. Sequentially the operation takes place at the two other stages to produce the expected fine smooth grain-slurry.

Further works

Improvements on existing archetypal machines

There is need for further works to improve the operations of the multi-stage grinder considering (i) the transmission arrangement (ii) the general kinematics (iii) ease of operation (iv) multiple application of machine (vi) performance of machine. Future works are also focused on improving the performance of the vibration sieving machine. The vibration sieving machine is more suitable for sieving operations. This is because of the complexity and intricacy involved in designing an appropriate centrifugal pump for the suction sieving machine.

Developing a dual-purpose food-slurry processing assembly

Further works are also going on the design of a Food-slurry processing assembly (Tugbiyele, 2009) The single corm-mix or grain processing assembly is to handle two critical operations in grain-slurry processing, namely, the grinding and sieving processes at the same time. The processing assembly consists of a combination of the operations of the multi-stage grinder and the vibration sieving machine. The assembly unit is being designed based on the following considerations.

(i) *To increase production efficiency:* The combined efficiency is increased by increasing the ratio of useful work done by the assembly in comparison to the efficiencies of the separate machines.

(ii) *To reduce cost of production:* This design is to reduce the high cost of food-slurry production which comes from the manual work or the use of the milling and sieving machines separately. The use the separate machines involve the transport the grain-slurry from one place to another and this in turn affects the cost of production. More so, this burden of transporting ground slurry from one point to another is reduced by using the processing assembly.

(iii) *To Design for safety:* This consideration makes safety paramount. The use of materials that can cause less damage to operator are put into consideration.

(iv) *To Design for durability:* Materials that can withstand excessive vibration, abrasion, heat and corrosion are put to use.

(v) *To design for more hygienic purposes:* The grain-slurry processing assembly reduces the human contact with the slurry during processing and hence the germs and impurities that comes in contact with the grain-slurry and thereby making it more hygienic for consumption.

(vi) *To merge the food-slurry preparation into a unified whole:* The tedious nature of grain-slurry preparation is merged into a unified whole by designing an grain-slurry processing assembly. The cumbersome nature of producing the slurry filtrate is minimized because the assembly processes the corn-mix with little human effort.

Conclusion

In the years past, the conventional methods of processing slurry grains prior to their consumption as cereal gruel in many undeveloped nations have always been slow, tedious, boring, time consuming and in some cases unhygienic. This paper reveals a new trend of on-going works in automation of operations involved in grain slurry processing. The primary objective of designing prototype machines that improves the conventional processing of various highly-nutritional slurry foods in Nigeria and many African countries has been achieved in this work. The developed archetypal machines have reduced considerably the tedium and boredom associated with conventional sieving methods. Tests have shown that the newly developed machines increased the sieving rate by about 50%. The mechanical methods also produce high quality filtrate based on the hygienic conditions put into consideration in the design and fabrication of the machines. The new milling approach is also geared towards removing the tedium encountered at the milling stage due to repeated grinding of the steeped grains to attain the required texture.

Further works presented in this paper are on the design of a machine assembly that combines the operations of the multi-stage grinder and the vibration sieving machine into a single continuous operation. Other future works relating to the existing prototypes are (i) multi-grain slurry processing and simplified operational units (ii) lower optimal operating speed for vibration sieving machine for improved efficiency (iii) automation of all food-slurry production processes .

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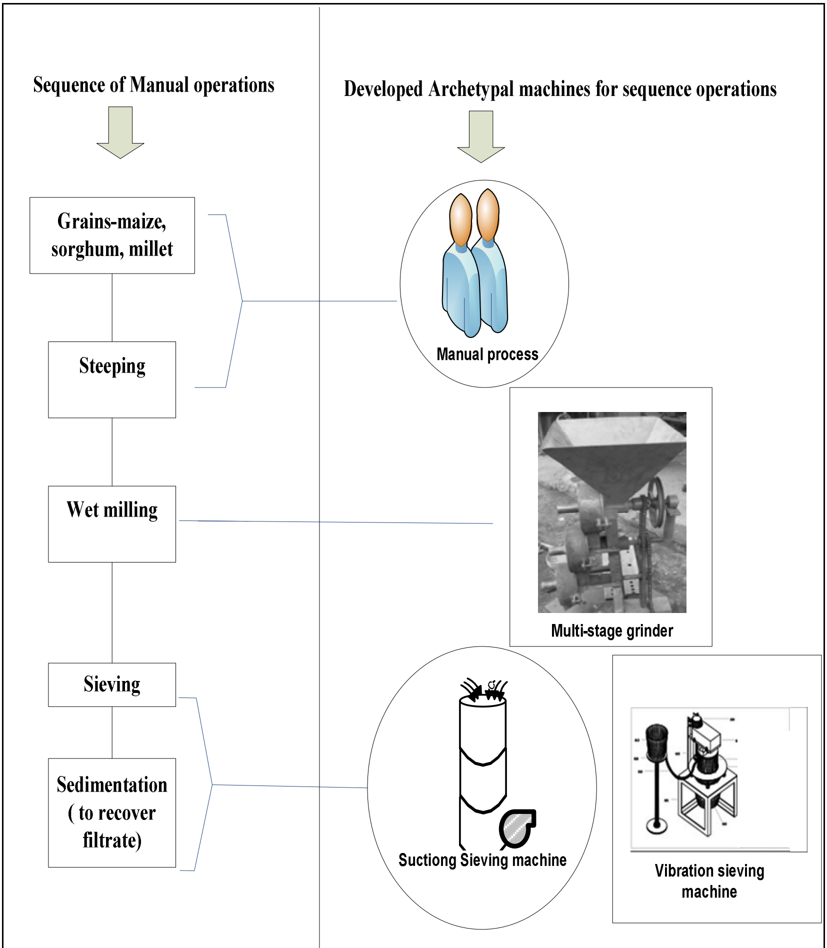

Figure.1. A sequence of grain-slurry processing operations from cereals

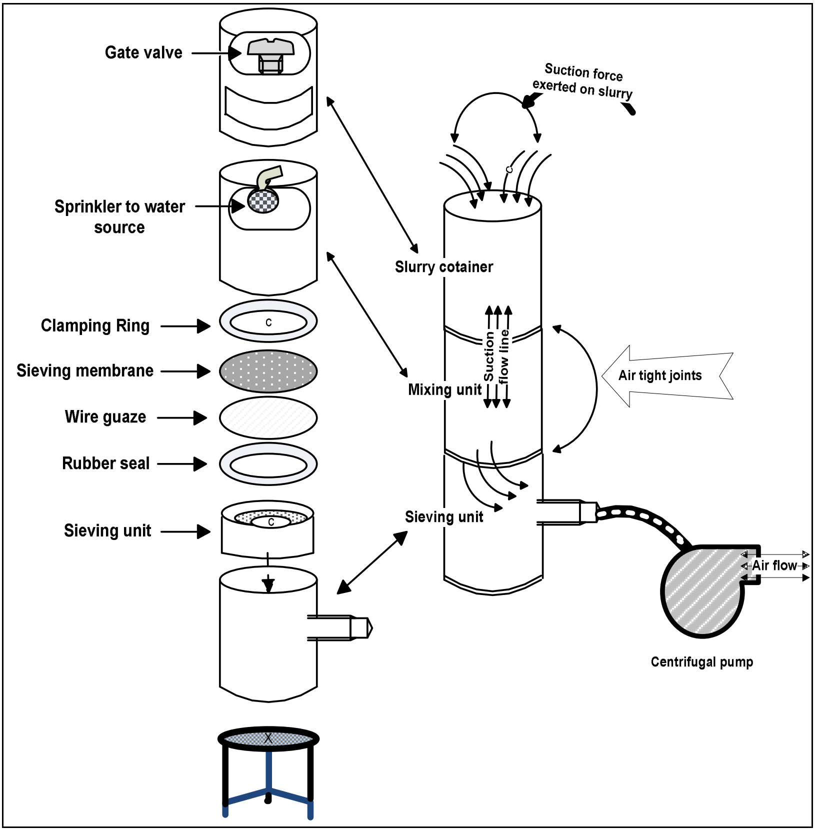

Figure 2: The fluid and air flow in suction sieving

Table 1: Work-Stages and Design Consideration in developing the suction sieving machine

Work-stage	**Critical design considerations**	**Capacity and operating parameters of Machine**	**References**	**Improvement over previous archetypal design**	**Shortcoming**
(1) Equipment specification and incorporation of the suction pump of a vacuum cleaner	Suction Power to produce the required pressure drop	Sieving rate was $8.09x10^{-3} m^3/s$	Ndukwe, (1998)	First archetypal machine.	(i) Dependence on vacuum cleaners for suction pumps (ii) quick clogging of sieving gauze
(2) Vacuum Pump substitution with a designed centrifugal blower	(i) Power needed for sieving operation (ii)Impeller blades design (iii) Head developed by centrifugal blower (iv) maximum deflection of sieving gauze	(i) Sieving rate was $2.8x10^{-5} m^3/s$ (ii) Pressure of $106.34KN/m^2$ acting on the sieving surface. (iii) developed actual head of 11.54m	Agbonson 1999; Adeleke & Gbolalade, (2000)	General improvement on design configuration of previous machine.	(i) Reduction in efficiency and sieving rate. (ii) clogging of sieving gauze (iii) Complexity of centrifugal blower design and fabrication
(3) Improvement of blower efficiency and appropriate material selection	(i) Impeller blades design (ii) selection of anti-corrosive alloys	Sieving rate was $11.10x10^{-5} m^3/s$	Simolowo & Nduka, (2002)	Increase in efficiency and sieving rate.	(i) Complexity of centrifugal blower design and fabrication (ii) quick clogging of sieving gauze

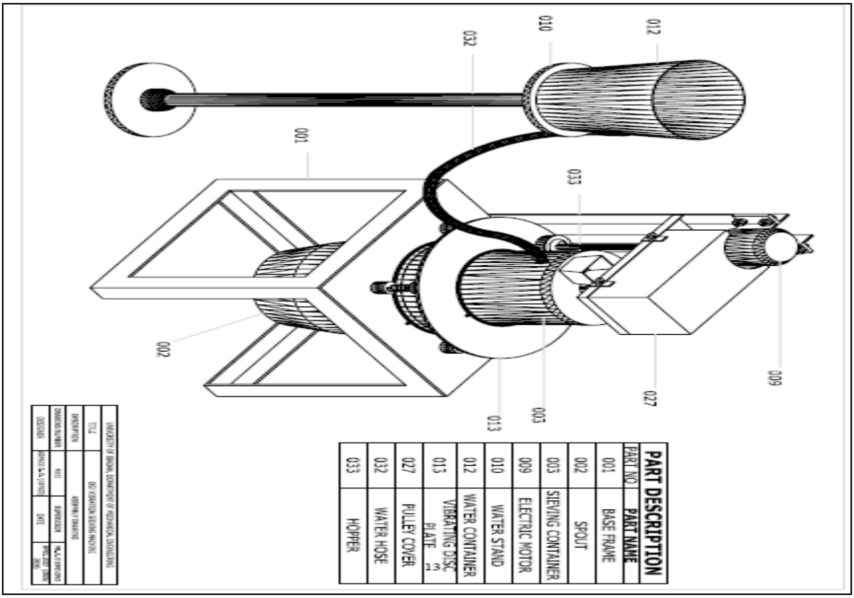

Figure 3: Isometric view of the Vibration Sieving machine

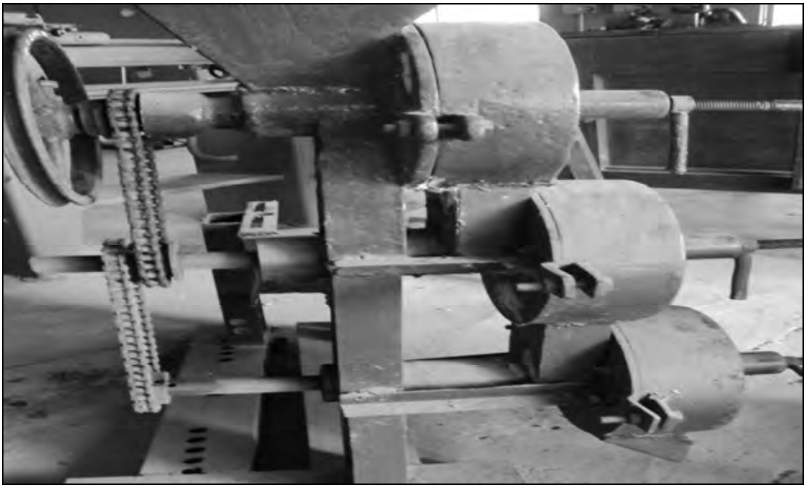

Figure 4: The Multi-stage Grinder

Table 2: Performance Test Results for prototype sieving machines

Method of Sieving	Volume (m^3)	Time (s)	Sieving Rate (m^3/s)
Manual	1.00×10^{-3}	120	8.3×10^{-6}
	1.00×10^{-3}	180	5.6×10^{-6}
	1.00×10^{-3}	120	8.3×10^{-6}
	1.00×10^{-3}	120	8.3×10^{-6}
			Average $=7.6 \times 10^{-6}$ m^3/s
Suction Pump Assisted	9.52×10^{-3}	82	11.6×10^{-5}
	9.34×10^{-3}	85	11.0×10^{-5}
	9.52×10^{-3}	87	10.9×10^{-5}
	9.34×10^{-3}	84	11.0×10^{-5}
			Average $=11.1 \times 10^{-5}$ m^3/s
Using Vibration sieving Machine	1.00×10^{-3}	60	1.6×10^{-5}
	1.00×10^{-3}	75	1.3×10^{-5}
	1.00×10^{-3}	75	1.3×10^{-5}
	0.90×10^{-3}	45	2.2×10^{-5}
			Average $= 1.6 \times 10^{-5}$ m^3/s

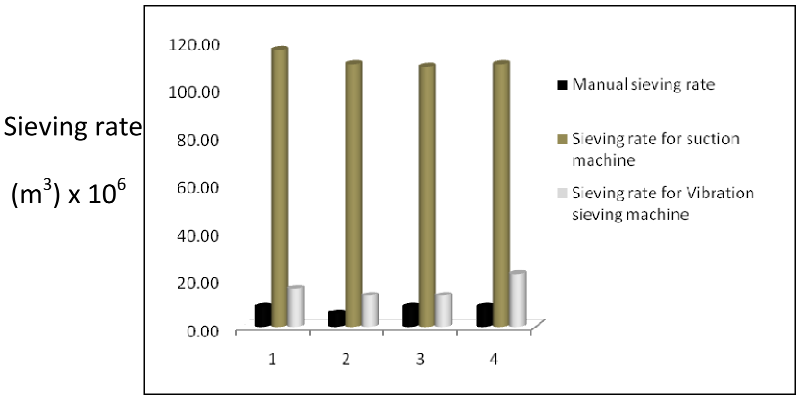

Figure 5 Sieving Rates for Manual and Mechanical processes