Full Length Research Paper

Design and Construction of a Magnetic Separator for Dry Beneficiation of Magnetic Minerals

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The work is focused on the design, construction and testing of a laboratory size magnetic separator for the dry beneficiation of magnetic minerals, which are considered useful for separating and recovering of magnetic particles (iron fillings) from the sand mixtures used in foundries for casting of aluminum alloys. The machine design incorporates the hopper assembly, framework, electrically powered belt conveyor, speed regulator and magnetic drum. The design takes care of the feed discharge rate which is usually directed from the hopper, with respect to speed of the belt. The weight-bearing conveyor is regulated and operated at the minimum speed for improved separation efficiency. The fabrication was tested on batches of samples which involves eroded sand containing a certain percentage of magnetic particles twenty to forty percent (20-40\%), from which about forty three percent (43\%) separation efficiency was obtained. The machine is relatively cheap and simple to operate as it allows easy material handling.

Keywords: Magnetic separator, magnetic minerals, casting, magnetic particles

INTRODUCTION

Mineral processing begins with beneficiation which describes any process any process that improves (benefits) the economic value of the ore by removing the gangue minerals, which result in a higher-grade product (concentrate) and a waste stream (tailings). It involves initially breaking down the ore to required sizes depending on the concentration process to be followed, by crushing, grinding, sieving etc. thereafter, the ore is physically separated from any unwanted impurity, depending on the form of occurrence and/or further process involved, separation processes take advantage of physical properties of the materials (Berry et al., 2001). There physical properties can include density, particle size and shape, electrical and magnetic properties, and surface properties. Major physical and chemical methods include magnetic separation, froth floatation, leaching etc., whereby the impurities and unwanted materials are removed from the ore and the base ore of the metal is concentrated, and meaning the percentage of metal in the ore is increased (Aylmore, 2019). This concentrate is then either processed to remove moisture or else used as is for extraction of the metal or made into shapes and forms that can undergo further processing, with ease of handling. Magnetic separation is a process in which magnetically susceptible materials is extracted from a mixture using a magnetic force. This separation technique can be useful in mining magnetic minerals such as iron as it is attracted to a magnet. Minerals fall into one of three magnetic properties: Ferromagnetic minerals; paramagnetic minerals; diamagnetic minerals. The aim of the project is to develop a 150W magnetic separator for the dry beneficiation of magnetic minerals. The main objectives include to: increase the metal content of the ore; reduce the gangue content so as to lower the slag formed in extraction of metal and decrease the thermal energy to separate liquid metal form mineral. The use of magnets for removing ferrous contaminants in an industrial environment first began in the 1940s when Orange F. Merwin developed a flat magnetic product to help farmers trap and remove metal contaminants from

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their grain chutes and some other crops. At the time, unwanted or “tramp” metal in the grain flow often created a spark that would ignite the explosive dust casing fires. Sometimes with catastrophic results. But with the advent of technology, its demand has continued to increase.

Now, it has a wide range of applications. These are mostly used for industrial purposes that are for mineral processing, manufacturing and recycling. Scientific laboratories also require this to prevent cross contamination between two different substances. So, with the rise in demand of different materials, there is also a hike in such equipment. This device is also used in separating different types of scraps from plastic, rubber and other materials. Magnetite is also known as a mineral oxide with iron is equally valuable with extraordinary magnetic properties (Clout and Manuel, 2015). The property of magnetite associated with its magnetic nature make relevant with the ore obtainable at separation of magnetic low-intensity. They are equally known to contain high level of iron (Yellishetty et al., 2012, Baawuah et al., 2020a, Baawuah et al., 2020b). Processing fine magnetite ores require efficient processes (Xiong et al., 2001). In the raw state, they are known to have low value economically and impurities must be removed to bring them to a finely acceptable state (Xiong et al., 2001). They are also available in raw form in countries like China (Torii, et al., 2001). In some industries, they are known for removal of vagrant metals (Elder and Sherrell, 2011) and the bristly or rough state of the ores (Aubrey, 1958, Connelly and Yan, 2009).

**Basic Operating Principle of a Magnetic Separator**

It is important to know the five basic magnetic separation component types: Magnetic grates, plate magnets, magnetic traps, magnetic drum and magnetic pulleys. Magnetic separation is a filtration process in which ferromagnetic or paramagnetic particles are removed from a process line. The process is achieved by applying an electrical current to a wire mesh or matrix, thereby inducing a magnetic field. When a solution or gas is passed through the mesh, any magnetic particles are attracted to the focus of the magnetic field and are filtered out of the flow. A magnetic separator consists of a powerful magnet that is either laid down or suspended from a ceiling or device. Materials can be passed over a table top magnetic separator while suspended magnetic separators often dangle above a material in order to extract its impurities. Magnetic separators can also be cylinders that objects are passed through. The material that a magnetic separator purifies can be in the form of parts, a finished product, or even liquid metal. Materials with different magnetic movement experience different magnetic force. The magnetic separator basically separates materials by applying the laws of magnetism. Magnetism is a force that is created when attracted or repelled by one another. A magnetic field is the area around a magnet. The larger the magnet and the closer an object is to the magnet, the greater the force of the magnetic field.

**Mathematical Formulations and Equations**

**Length of Belt**

\[
L = \pi(R_1+R_2)+2x+(R_1-R_2)
\]

**Angle of Contact of Pulley**

\[
\theta = 180^\circ - 2\alpha
\]

\[
\sin \alpha = \frac{(D_1 + D_2)/2}{x}
\]

\[
\theta = \text{angle of contact}
\]

**Torque**

\[
T = \frac{(P\times 60)}{2\pi N}
\]

Where:

- \( T \) = Torque
- \( N \) = Speed of rotation

For torque transmitted by the belt on driven pulley:

\[
T = (T_1 - T_2) \times R
\]

**Ratio of Driving Tensions**

For ratio of driving tensions

\[
\mu \cot \Theta \cosec \beta = 2.3 \log \left( \frac{T_1}{T_2} \right)
\]

\[
P = \text{Power output of electric motor}
\]

\[
T = \text{Torque}
\]

\[
T_1 = \text{Tension on tight side}
\]

\[
T_2 = \text{Tension on slack side}
\]

\[
\mu = \text{Coefficient of friction for leather belt}
\]

\[
\Theta = \text{Angle of contact in rads}
\]

\[
2\beta = \text{Groove Angle}
\]

**Power Equation**

\[
P_e = v T_e
\]

\[
V = \frac{\pi DN}{6}
\]

\[
T_e = \left( T_1 - T_2 \right)
\]

Where

- \( P_e \) = Power output on driven pulley
\[ V = \text{Velocity of belt in m/s} \]
\[ T_e = \text{Effective Tension} \]

**Ratio**

\[ \pi DN_1 = \pi DN_2 \tag{10} \]
\[ \frac{D_1}{D_2} = \frac{N_1}{N_2} \tag{11} \]

\[ N_1 = \text{Speed of driver pulley} \]
\[ N_2 = \text{Speed of driven pulley} \]

**Mass**

\[ W = mg \tag{12} \]
\[ m = \varphi v \tag{13} \]

**Load Acting on Bearing**

\[ K_I = \frac{(19.1 \times 10^6 \times H)}{(D_p \times n)} \tag{14} \]
\[ K_r = f_b \times K_{sv} \tag{15} \]

Where,

\[ K_I = \text{Tangential load} \]
\[ K_r = \text{Radial Load} \]
\[ H = \text{Transmitted Power} \]

**Design and Construction Procedure**

The design and construction of the magnetic separator includes conceptual design, material selection, and basic fabrication. Basic fabrications include measurement, marking out, cutting, preparation and joining. The design below shows each component member of the magnetic separator; their configuration and geometry. The various lengths and features are reflected and the diagram is properly labelled and dimension. Also, an assembly of all part is shown. The major components of the separator include: The main frame, hopper and bin, conveyor belt, the drums (magnetic and rotating), power drive, speed (voltage) regulator, guard plates, bearings.

**Design Specifications**

**Main Frame**

This was made of Ø50cm and Ø30cm galvanized steel pipe. The pipes were cut and welded to form rectangular table holding the drums at and height of 50cm above the ground level.

**Hopper and Bin**

Flat sheet was cut into fulrum of 4.0cm x 4.0cm base area with 15.0cm height, while an open-right cylindrical bin of Ø 30cm x 40cm height is formed from flat steel plate. The base of the bin is cut and fixed with the top end of the fulcrum (hopper) by welding. The feed discharging end of the hopper is controlled by the welded Ø30 mm galvanized pipe inclined at angle 45° against the moving conveyor.

**The Conveyor Belt**

The conveyor belt (220cm long) is made of two layers of cotton material. Cut into 7cm width, and folded around the two drums (100cm) apart with an overlap of 8cm. The overlap was firmly sewn together. The extra-which allows compensation for the conveyor shrinkage when the machine/drums operate at high speed. The cotton material also allows the passage of magnetic flux from across the magnetic drum to the ore, and the strength is sufficient to carry the weight of the feed.

**The Drums**

There are two types of drum incorporated into the machine: Magnetic Drum: This unit is made by packing four pieces of round bar permanent magnet in a galvanized steel housing Ø20cm x Ø10cm closed ends cylinder. Rotating drum is made of Ø20cm x Ø10cm closed ends steel cylinder on which the conveyor belt rotates.

**The Power drive**

The electric motor single-phase 0.15kw, 1,420 rev/min supplies the energy for rotating the drums which carry the weight bearing conveyor belt. The electric motor is connected to the rotating drum by using pulley and A35 size v-belt network. The electric motor is located at the base end of the rotating drum, guarded by aluminum sheet cover against the sand mixtures dropping from the conveyor belt. The rotating speed of the electric motor also provides small vibration that is transmitted to the hopper and bin stand, thereby making the ore to come out of the hopper discharge orifice with more ease. The electric motor is connected to 220V AC mains supply and switched on or off by the regulating Switch.

**Speed Regulator**

This is incorporated into the machine by making use of voltage regulator connected to the motor, hence controlling the speed of rotation when the switch is uttered from high to low speed.

**The Guard Plates**

There are three guard plates made of aluminum sheets
cut into desired shape and fitted into three important parts of the machine. These guards include: Electric motor housing/guard; which protects the motor from dust; Conveyor belt housing: Controlling the sliding movement of the belt on the drums when rotating at high speed and it also controls the level of the feed fed on the conveyor belt. The half piece of the conveyor housing also serves as a base support for the weight-bearing belt; the magnetic drum guard: This controls the movement (throwing) of sand at high working speeds. It acts as a collector to the non-magnetic minerals.

**Design Considerations**

The magnetic separator is to be powered with a 0.15kw electric motor with a maximum speed of 1420rpm. The following factors were also considered in determining the sizes of the various major components of the machine. Stress induced on the shaft when subjected to torsion; strength and rigidity when the shaft transmits power under various operating and loading condition; amount of power to be transmitted to the shaft through the electric motor; reliability of the machine, its safety during use and its durability type of manufacturing processes to be employed at low cost of production, versatility, portability and ease of maintenance. All the aforementioned were the guiding factors of this design.

Under this section, components shall be treated with respect to the type of load acting on them and the relevant equation that relates the load and the component material. Also the component parameter shall be determined.

**Design Calculations**

**Calculation for torque on driven pulley**

From Equation (4) Where Power = 150W; N = 90rpm, T = 15.92Nm

**Calculation for angle of contact of belts**

Using Equation (3) Let angle of groove be 30°, \( \mu = 0.3 \) and \( \beta = 15°, \theta = 1.41 \)rads

**Calculation for flat tension**

Using equation (5), \( T_2 = 8.54N \) and \( T_1 = 43.91N \)

**Calculation for effective power**

Using equation (9), \( T_e = 35.37N \)

Using Equation (8), \( V = 2.12m/s \)

Using Equation (9), \( P_e = 75W \)

**Drum speed**

Therefore, with 90rpm, Using equation (2.11), \( N_2 = 20 \)rpm

**Conveyor speed**

Using equation (8), \( Vc = 471mm/s \)

**Calculation for length of best**

Using equation 1, Length of innovat= 334.5mm

**Calculations for forces acting on drum shaft**

The drum shaft will be subjected to forces due to:

1. Tension from belt
2. Weight of drum
3. Torque exerted on shaft.

Where;

\[ \Phi: \text{density of mild steel} = 7850 \text{kg/m}^3 \]
\[ g: \text{acceleration due to gravity} = 9.8 \text{m/s}^2 \]

Using Equation 13

\[ \Phi: \text{density of aluminum} = 270 \text{kg/m}^3 \]

Volume of drum = volume of steel + volume of aluminum plates

Diameter of Drum = 500mm

Drum length = 198mm

Volume of steel sheet = \( 3.142 \times 0.5 \times 0.0005 \times 0.198 \)

Volume of steel sheet = 0.000311m³

Mass of steel sheet = 0.0001555 \times 7850

Mass of steel sheet = 1.22kg

Volume of aluminum plates = \( 2 \times 3.142 \times (0.4 - 0.08)^2 \times 0.0005 \)

Volume of aluminum plates = 0.00032m³

0.00032 \times 2700 = 0.87kg

Mass of drum = 1.22kg + 0.87kg

\( M = 2.09kg \)

Using equation 2

\( W = 2.09 \times 9.8 \)

\( W = 20.47N \)

\( F_1 = 35.38N \) is the torque exerted on the shaft

**Assembly and Operations**

The above-mentioned parts described above were assembled into a unique rigid body with the aid of bolts and nuts, and welding. The lower units of the frame were held down with bolt and nuts and supported by the weight of the electric motor. The hopper and bin are supported at the top and bottom to the body of the machine to give more firmness to the structure when it is operated at high
Figure 1: Orthographical Sketch of the Magnetic separator

Figure 2. Computer aided design Isometric view and pictorial view of the Magnetic separator

speed and for easy transportation. Provision of a slot was made to control flow rate of the discharge orifice by opening and closing the small slot on the neck of the hopper discharge pipe. It is very easy to change any part during servicing or maintenance. As presented in Figure 1 and 2 are the orthographic sketch of the machine and
RESULT AND DISCUSSION

Test procedures

The performance evaluation of the machine was carried out on a mixture of eroded sand and iron filling with a 0.15kw electric motor. This was done by taking the samples from different separation stages and determining the efficiency on weight separation bases.

Efficiency = \( \frac{\text{output weight}}{\text{input weight}} \) x 100%

2000g of sample was measured as the bases of the charge fed into the hopper in the first stage separation, while the concentrate recovered is charged in the subsequent 2nd and 3rd stages.

TEST RESULT

<table>
<thead>
<tr>
<th>Weight Measured (g)</th>
<th>Feed</th>
<th>1st separation</th>
<th>2nd separation</th>
<th>3rd separation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C0</td>
<td>T0</td>
<td>C1</td>
<td>T1</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>T2</td>
<td>C3</td>
<td>T3</td>
</tr>
<tr>
<td>Weight Measured (g)</td>
<td>2000</td>
<td>319</td>
<td>1681</td>
<td>252</td>
</tr>
<tr>
<td>Stage Sep. Eff. (%)</td>
<td>15.97</td>
<td>78.99</td>
<td>83.99</td>
<td>40</td>
</tr>
</tbody>
</table>

DISCUSSION

It can be inferred that the separation efficiency improves at every stage for the sample tested. About 42.38% out of the 256 of concentrate present in the ore was recovered. Although the method adopted for the operation of the magnetic separator was found to be theoretically sound, the magnetic separator did not function optimally during testing due to varying operational speeds as a against the desired theoretical speed which would enable optimal performance. Some operational procedures adopted include: Checking all the parts to ensure they in good order, connecting the cable to the electric device while the discharge orifice remains closed, starting the machine at the lowest speed and feed the bin with the quantity of ore feed required; during rotation of machine belt, it is important to open the slot to allow the ore to the conveyor belt; the speed of the machine is better regulated from high to low by changing from 1 up to 5 on the speed regulator. Finally, it is important to allow the separator sufficient time for complete discharge. The bin holds small quantity of the feed, which may be scrapped into the hopper by hand.

CONCLUSION

The design and construction of a magnetic separating machine; purposely designed for the beneficiation of dry magnetic materials and was tested on the mixture of eroded sand and iron filling. The machine was assessed to have performed excellently and could be used for small scale experimentation. However as can be seen from the construction, the service and method applied is functionally satisfactory. It is worthwhile to mention here that this project has broadened our knowledge in mechanical engineering field especially in the area of design. There are too numerous opportunities to be exploited and changes to make for more impact of the engineers to be felt in Nigeria. This we believe can come through the joint efforts of engineering research making and in the development of the little technology we have acquired. With the design and construction of this project, we hope that our local miners will also be able to practically tackle difficulties in the beneficiation of Iron Ore and other magnetic minerals. It is recommended to expand the project in future research while improving the efficiency of the machine and the cost of production of the machine.

REFERENCES


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