# Performance Evaluation of Sand Screening Machine: Effect of Sieve Size and Moisture Content

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**Abstract:** In construction industry, sand is a major raw material besides water, cement, gravel and steel. The quality of sand is vital in development of firm structures in construction. Thus, for construction industry to remain competitive, it is critical to develop efficient sand screening technologies that produce high quality sand while reducing labour cost. Therefore, the main objective of this research paper was to assess sand sieving technologies used in construction industry in Kenya and to design and evaluate performance operation of the sand screening machine that would help improve the efficiency and quality of sand while lowering the overall construction cost. The specific objectives were to design sand screening machine and to investigate the effect of moisture and sieve sizes on screening time. Experiments were conducted on semi-automatic machine driven by motor to determine fine sand produced at different moisture levels and time consumed. The machine designed consist a motor, sieve, shaft, steel hollow tubes, flat steel bars, sheet metal plates, hinges, eccentric sheaves, and angle bars. The study found that screening raw sand of 10 kg using a designed semi-automatic machine with a sieve of 3mm x 3mm and densities 1442 kg/m$^3$, 1602 kg/m$^3$, 1682 kg/m$^3$, 1922 kg/m$^3$ and 2082 kg/m$^3$ were found to produce 8.1kg, 6.8kg, 6.1kg, 4.1kg and 2.8kg respectively with sieving time of 24s, 26s, 27s, 30s and 32s respectively. Designed semi-automatic sand sieving machine displayed a labour reduction cost of 66% leading to savings of Ksh. 39,600 per month. In addition, the output of the machine screening dry sand (1442 kg/m$^3$) 8 hours per day was found to be 9,720 kg. In conclusion, low density sand and optimal sieve size results to high efficiency and significant labour cost savings. The study recommends the use of sand with low density (dry) and adoption of semi-automatic screening machine technologies in construction industry in order to attain Kenya's affordable housing programme.

**Key Words**: Sand, Sand Screening Machine, Eccentric Sieves, Motor, savings.

## I. Introduction

Sand is a crucial component in building construction. Sand is used throughout the building process, from the foundation to the finishing touches. Sand used in foundation (Leal Filho et al., 2021; Maillot, 2013) is somewhat coarser than sand used in plaster work, which is finer(Ngugi, Mutuku, Gariy, & Research, 2014). Beaches, rivers, dunes, mountains, deserts, sand pits, and quarries are the primary sources of sand. Most often, it is acquired in raw form while being combined with foreign substances. For this reason, it must be screened to eliminate impurities and stones before being utilized (Gutti and Musa, 2017). Conventionally, screening is typically done manually using fixed screens or machines, and using these techniques requires a lot of time and money(Badri et al., 2018; Vijaya & Research).

In Kenya, the majority of building sites mostly use the manual sand sieving technique. This approach is easy and reasonably priced. However, the operation requires a lot of human labor; there are considerable dangers to the health and safety of the operators; and there are delays in the work's completion that are not only detrimental but also wasteful from an economic standpoint. It is crucial to develop a small-scale semi-automatic sand separation system for Kenyan small-scale construction sites that eliminates the drawbacks of the manual method while also offering a quicker and more inexpensive service(Ogunwole & Management, 2012). However, there is no data on how sand moisture levels and sieve sizes affect the length of time spent sifting.

With close to 50 million citizens, Kenya is a large and developing nation(MAEDA, DIXON, KENYA, & REALL, 2023). As the country's economy grows, more Kenyans are moving from rural to urban areas in quest of better-paying jobs(Favilukis, Mabille, & Van Nieuwerburgh, 2023). In many places, including Nairobi, Mombasa, and Kisumu, this trend has increased demand for new homes that result in increase in construction activities which has been linked to a higher demand for sand. Within the following five years, 500,000 affordable homes are to be constructed. Kenya's yearly housing demand is 250,000 units, while its anticipated supply is 50,000 units, resulting in a 2 million unit, or 80%, housing shortage. With so many people unable to afford to buy or construct their own home, housing affordability is a major issue in Kenya. This will increase the sand usage for construction and therefore, understanding the factors affecting sand sieving is important(Kieti, 2020).

According to Bandgar's research, the sieving machine's screening capacity increases as the machine's reciprocation speed rises(Bandgar, Chate, Dongare, Mirpagar, & Education, 2018). Also, as a result, identical amounts of wet and dry sand would not weigh the same; the wet sand would weigh more as a result of having more mass due to the water's mass sandwiched between the sand and its own mass(Sulaiman, Aminu, & Shehu). The only components of dry sand are the mass of the sand and the space between its grains. This implies that dry sand has more grains per volume and hence greater mass than wet sand, which takes up less space per grain and hence, economical to procure dry sand than wet(Varley, Rutherford, Zhang, & Pellegrino, 2020).According to a study conducted in Kenya by Ngugi, the presence of contaminants in sand weakens the binding between reinforcement bars and concrete, hence reducing the structural integrity of structures(Ngugi et al., 2014). The study also demonstrated the significance of particle sizes, shapes, textures, and workability in determining the compressive strength of concrete. This findings supports the research by Aïssoun et al(Aïssoun, Hwang, Khayat, & Structures, 2016).

According to research by Fall et al., adding just enough water to sand significantly reduces the amount of friction that results from sliding(Fall et al., 2014). The development of capillary water bridges raises the sand's shear modulus, which makes sliding easier. When there is too much water present, the capillary bridges coalesce and shrink, which lowers the modulus; in this instance, however, the friction coefficient rises once more. The findings demonstrated a direct correlation between the friction coefficient and the shear modulus, which has significant implications for the transport of granular materials(Cheung & Dawson, 2002). It is believed that sands that are moist show an increase in volume when compared to dry sands. Sand can expand by up to 35% of its dry volume if it contains 5-7% moisture.

Sand sieve is designed to separate solid particles(Gee & Or, 2002). The sieving apparatus works by enabling solid particles of varying sizes to pass through pores that have been orderly organized in a way appropriate for the particle sizes and shapes(Poullet et al., 2019; S.-W. Zhao, Dou, Guo, & Cai, 2005). For this study, an experimental investigation has been made to study the effects of moisture content and sieve sizes on the results of sieving time of sands using a simple designed semi-automatic sand sieving machine. The sand sieving was done on sand of different moisture content (1442 kg/m$^3$- 2082kg/m$^3$) and two sieves' sizes 7 mm x 7 mm and 3mm x 3mm. Time taken to sieve (in seconds) to the achieve fine sand (kg) were measured to analyse the effects of moisture content and sieve size on the sieving time of sand.

## II. Working principle

The motor-driven rotational motion is utilized by the proposed semi-automatic sand sifting machine (Figure 1). The two sprocket and chain pulley system aids in boosting the speed transmitted to the shaft. The vibrating table's operation is mostly dependent on the conversion of rotational motion given by an A-C motor. The eccentric sieves are linked to the shaft by the motor. When the motor is activated, power is conveyed via the shaft to the eccentric sheaves, which transform the rotational motion into up- and down linear motion of the springs. The reciprocating action of the springs causes vibrations in the top table, which allows for sieving. Sand is poured into the sieve's opening.

The shaft will exert a centrifugal force on the machine to assist in sieving the sand as it rotates on pillow block bearings at both ends of the sieve. Because of the forces and motion happening on the machine, the smaller sand particles that are smaller than the sieve mesh are driven out of the sieve. Larger particles that cannot pass through the sieve fall off the sieve by rolling down to the other opening end of the sieve by gravity. Effect of moisture content in the sand and sieve size on the sieving time of sand and quality/quantity of the output was analysed.

Figure 1: Designed Semi-automatic Sand Screening Machine

## III. Design Calculations

**Motor specifications**

Conversion factor from HP to watts

$$1HP = 745.7Watts \qquad (1)$$

To calculate torque of motor before reduction we used

$$Power = T \times 2\pi \frac{rpm}{60} \qquad (2)$$

To acquire the needed shaft speed of rotation, the motor speed must be reduced. The requisite shaft speed will be computed as follows:

$\frac{N_{motor}}{N_{shaft}} = \frac{D_B}{D_A}$ $where\ N_{motor}$ = rpm for the motor

$N_{shaft}$ = rpm for the shaft

$D_B$ = diameter for pulley B

$D_A$ = diameter for pulley A

$$\frac{700}{N_{shaft}} = \frac{30}{10}\ N_{shaft} = 250rpm$$

a) Power transmitted by the solid shaft

Power, $P = T\omega$

Where,$\omega = \frac{2\pi N}{60}$ $P = 4.5441 \times \frac{2\times\pi\times250}{60}$ P = 118.96W

Calculation of stresses on shaft will be calculated using $\tau$.

$b)\ Shaft\ torsional\ shear\ stress\ = \frac{(T\times R)}{J}$ (3)

Where; J=Polar moment of area= $\pi(\frac{D^4-d^4}{32})$ (Gee & Or)

D=External shaft diameter

d=Internal shaft diameter

R=$\frac{D}{2}$

T=$Torque$

c) Shaftbending stress=$\frac{(M\times R)}{I}$ (5)

Where;$M = Load \times Distance\ of\ load(sieve\ length)$

R=$\frac{D}{2}$, I=$\frac{\pi D^2}{64}$ $,Moment\ of\ Inertia\ of\ solid\ shaft$

$$I = \pi(\frac{D^4-d^4}{64} \qquad (6)$$

$$k = \frac{79 \times 10^9 \times 7.952156 \times 10^{-8}}{1.05}$$

$k$ = 5983.05N/m

d) Torsion angle (θ)=$(\frac{584\times(T-L)}{(G-(D^4-d^4))})$ (7)

$where\ T = Torque$

$D = Exteranal\ shaft\ diameter\ \ G = Modulus\ of\ rigidity$

$$d = Internal\ shaft\ diameter \quad L = Length\ of\ the\ shaft.$$

$$\theta = \frac{4.5441 \times 1.05}{7.952156 \times 10^{-8} \times 79 \times 10^{9}}$$

$$=7.59478733 \times 10^{-4}\ radians$$

e) Sieving Operation Efficiency

$$P = \frac{Wr}{Wt} \times 100\% \qquad (8)$$

Where; P is the percentage of sand retained on a particular sieve, Wr is the weight of sand that did not pass through the sieve, Wt is the total weight on sand taken

## IV. Methodology

To set up the machine, a measured sample of sand was placed on the vibrating table. The motor was switched on to generate the requisite power for vibration after strict monitoring to verify that all of the pieces were properly fastened. The motor stimulated the vibrating tabletop, helping the sieving process.

As a result of the vibration mechanism, the fine sand aggregates fell at the bottom of the sieve and collected at the lower section. The coarsest sand aggregates will not pass through the sieve and hence will be collected at the opposite section of the vibrating table to avoid mixing with the already-sieved fine sand.

Figure 2: Balance Machine

The balance to be used had a sensitive to the extent of 0.1% of total weight of sample taken. The machine was subjected to a series of test in the Mechanical workshop to ascertain its functionality aspect before it was being used to do the test.

## V. Results and Discussion.

### a) Data and data analysis

Table 1 and Table 2 presents the results for sieving 10kg sand with different wetness measured in terms of densities (kg/m$^3$) using two different sieves measuring 3*3mm and 7*7mm. The mass in Kg of sand sieved and unsieved for each density are given in the Table 1and 2. The time taken in seconds sieving the sand of different densities for the two sieves is also presented.

Table 1: Effects of wetness on sieve size 3*3mm

| | DENSITY(Kg/m$^3$) | | | | |
|---|---|---|---|---|---|
| | 1442 | 1602 | 1682 | 1922 | 2082 |
| Mass of sieved sand (Kg) | 8.1 | 6.8 | 6.1 | 4.1 | 2.8 |
| Mass of unsieved sand (Kg) | 1.9 | 3.2 | 3.9 | 5.9 | 7.2 |
| Time taken sieving(S) | 24 | 26 | 27 | 30 | 32 |

Table 2: Effects of wetness on sieve size 7 mm * 7 mm

| | DENSITY(Kg/m$^3$) | | | | |
|---|---|---|---|---|---|
| | 1442 | 1602 | 1682 | 1922 | 2082 |
| Mass of sieved sand (Kg) | 8.8 | 8.525 | 8.3875 | 7.975 | 7.7 |
| Mass of unsieved sand (Kg) | 1.2 | 1.475 | 1.6125 | 2.025 | 2.3 |
| Time taken sieving(S) | 17.2 | 21.15 | 23.125 | 29.05 | 33 |

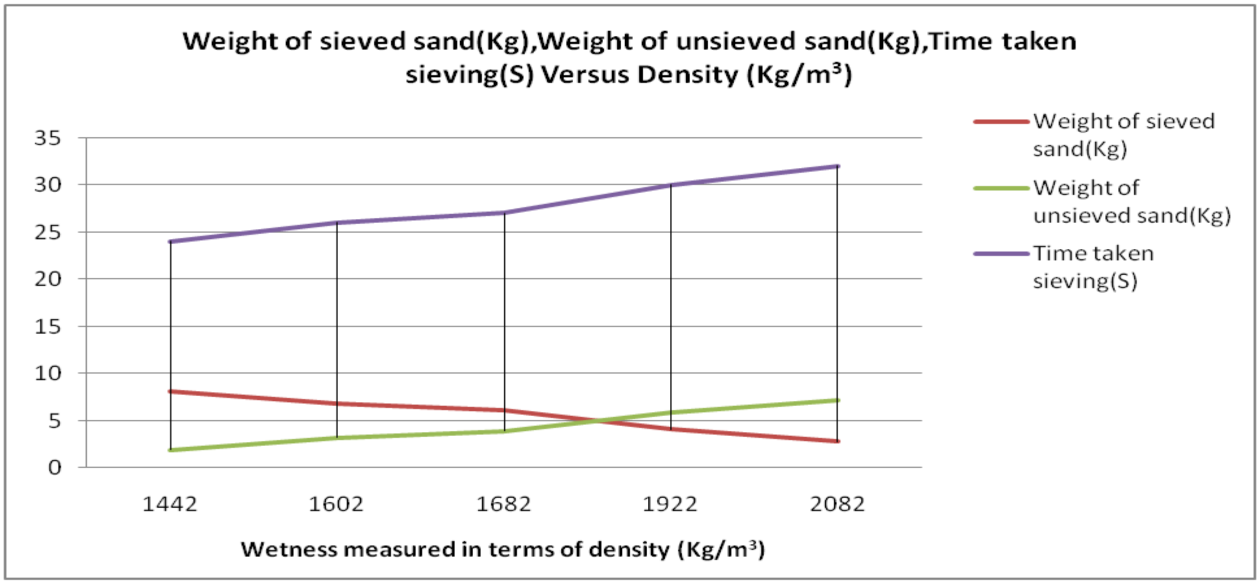

Figure 3: Graph of time and sieved/unsieved sand versus wetness for sieve size 3*3mm

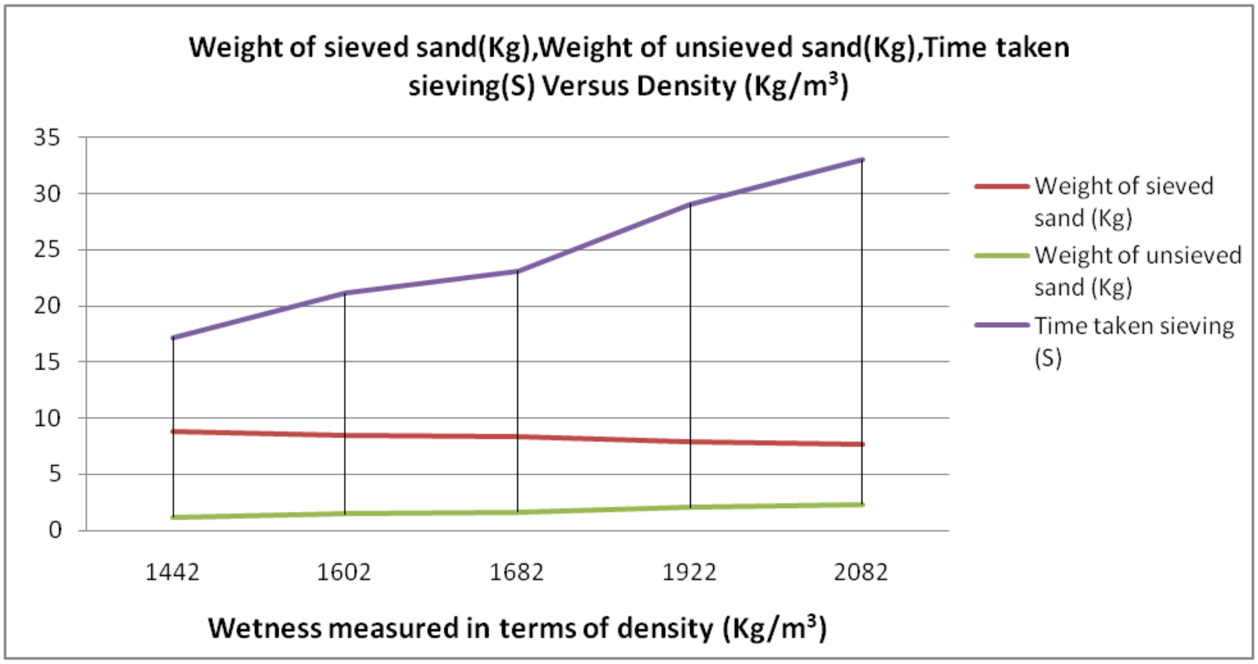

Figure 4: Graph of time and sieved/unsieved sand versus wetness for sieve size 7 * 7mm

### b) Effects of wetness and sieve size on sieving time

The analysis of the results given in Figure 3 and 4, shows that sieving rate decreases with increase in density of raw sand. This implies that wetness of sand impacts negatively on the screening process of sand thus resulting to increase in labour cost. This finding concurs with research done by Braithwaite (1973) and Abu-Hamdeh and Reeder (2000). Also, it was found that the quantity of screened sand increases with increase in sieve size and vice versa. This implies that more time is required to produce finer grains of sand hence higher labour cost(Lasnier, 2017). This explains why the cost of finishing (plaster or flooring) is higher than foundation in construction.

### c) Effects of wetness on mass of sieved sand

The mass of sieved sand decreases with increase in density of raw sand and vice versa (see Figure 3 and Figure 4). This brings convergence point at a density of 1814 kg/m$^3$ where the quantity of sieved and unsieved is equal. This implies that adhesion of sand grains increases with density thus lowering the quantity of sieved sand. This finding supports research done by Chian, Stringer, and Madabhushi (2010) and Y. Zhao et al. (2006). In addition, the results show that the sieving efficiency for dry and wet sand were almost 85% and 15% respectively.

### d) Estimation of Cost Benefit Analysis

**Estimated cost of using sand sieving machine.**

Power of the motor =750 watt =0.75KWA

Power produced in 1hr = 0.75×1=0.75Khr

Working for 8 hours a day = 0.75×8 =6units per day

One month consumption (30 days) = 6×30 =180 units.

Approximate monthly bill = 180 × ksh30 = Ksh. 5,400 + the amount for operator (Ksh. 15,000)

Total cost = Ksh. 5,400 + the amount for operator (Ksh. 15,000) = Ksh. 20,400

**Estimated manual sieving cost**

Daily standard wages = 500Ksh× (4 Labourers) =2000Ksh

Monthly Wages = 2000Ksh×30= KSh.60,000.

When the sand sieving is compared with the manual where casual Labourers are employed for same tasks it gives an estimate cost saving of about **Ksh. 39,600** (60,000-20400) per month with the use of a semi-automatic sand sieving machine which can result to a short payback period.

## VI. Conclusion and Recommendation

The results found that low density sand (dry sand) was able to pass through the sieve due to its less adhesive force and hence took short period of time to be sieved. Screening of dry sand results to less sieving time and significant labour cost savings, while the use of high density sand (wet sand) results to both increased sieving time and labour cost. Sand grains that are moist show an increase in volume when compared to dry sand. It is therefore economical to procure dry sand than wet sand by the contractors as dry sand has more grains per volume and less sieving time in addition to significant labour cost savings thus lowering overall construction costs. There is need for further research on the effects of particle sizes, shapes, textures and even inclusions such as percentage clay.

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