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Effect of Hammer Shape and Impact Area on Hammer Mill Performance under Different Feed Rates

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Abstract: The research aims to compare the performance (PC) and specific energy consumption (Spc.) of the hammer mill when using the T-hammer against the (traditional) rectangular hammer. A homemade mill with four hammers was used in experiment. 36 treatments: 2 hammer shape x 3 impact area (840, 720 and 960 mm^2) x 2 feeding rates (1500 and 3000 g min^{-1}) x 3 replicates, with completely random design. The results showed that there was no significant effect of hammer shape on PC at the feed rate of 3000 g min^{-1}, while there was an effect at the rate of 1500 g min^{-1}. An effect was also found for the impact area on the PC at both feeding rates and on Spc., as an inverse relationship appeared between the impact area and mill productivity at the feed rate 1500 g min^{-1}. The area of 720 mm^2 surpassed the area 480 and 960 mm^2 at the rate of feeding 3000 g min^{-1}, as it recorded 1215.65 g min^{-1} compared to 950.65 and 882.65 g min^{-1}, respectively. There is effect of feeding rate on PC and Spc. The traditional hammer is recommended for simplicity of design, manufacture and performance at high feed rates compared to the T-shaped hammer.

Keywords: Grinding, Impact energy, mill capacity, Specific energy consumption, mill blade, flow rate.

Introduction

Hammer milling machines are widely used in agrarian fields and animal feed plants because of their ability to pound materials in different degrees (coarse, medium and fine). The machine's basic operation was based on the collision force (mechanical impact force) decreasing the size of the materials (Djuro *et al.*, 2016). Grinding is important processes and energy-intensive processes in the feed industry, accounting for 71% of total power consumption during feed processing (Shirshaab & Jassim, 2021). Grinding energy requirements are determined by the kinematical and geometrical parameters of the grinding machine, as well as the physical properties of the ground material (Dabbour *et al.*, 2015). The hammer is the most important component of the crusher. The type, shape, and characteristics of the hammer have a significant impact on the grinder's output. The rectangular mallet is the most well-known hammer shape used in the hammer unit (traditional). Ali *et al*. (2019) conducted research in which he replaced rectangular mallets with steel rings (new hammer) and discovered a reduction in energy consumption due to the new hammer's lighter weight as compared to the rectangular hammer. When a new hammer form (a triangle with an inclination of 45 degrees from the horizontal plane perpendicular to the mill's rotation axis) was used instead of inclined hammers at angles of 0, 35, and 55 degrees, Mircea-Valentin *et al*. (2013) observed an increase in mill productivity and a decrease in real energy consumption. Satoshi *et al*. (2004) investigated the effect of hammer styles by cutting the edge of the hammer at different angles ranging from 15 to 30 degrees and discovered that milling efficiency improved. The highest efficiency was achieved with the lowest level of energy requirements by using the highest feed rate of 120 kg.hr^{-1} with various velocities and diameter of sieve holes, according to a study conducted using three levels of feed rate 60, 90, and 120 kg. hr^{-1} with various velocities and diameter of sieve holes (Ibrahim *et al*., 2019). The effective work surface area may not be utilized due to insufficient power transfer to the hammer and consequently, the performance of the mill will be reduced (Heimann, 2019).

Due to the variety of hammer shapes used in hammer mills. It makes the concerned people have difficulty choosing a particular shape in the mills. Therefore, the present study was conducted to compare the performance of hammer shape (T- shape versus rectangle shape) and the effective surface area under two mill feeding rates.

Materials & Methods

A small local mill was built with the specifications mentioned in table (1). To guide an investigation and crush yellow corn kernels. A strainer was used to clean the grains of contaminants, and the moisture content was calculated using the wet weight of 10.4 percent (Oluwole *et al*., 2019). The effect of hammer shape, impact area and interference was studied using a feed rate of 1500 and 3000 g min^{-1}. The experiment was carried out according to a fully randomized design with three replications for each treatment. Analyze the results using the $spss_{23}$ program.

Table (1) : Specifications of the locally grain mill.

Parameters	Value, unit	Parameters	Value, unit
4 Blades (Iron)	Total length 100 mm Effective length 80 mm	Ground grain exit height off the floor	70 cm
Blade weight	*98 ±2 g	Power engine (Electrical Motor- single phase)	2HP(1.5 KW), 220 V, 9.3 A
Screen Opening	6 mm	Engine pulley- diameter	10 cm
Total screen area	12800 mm^2 (16cm × 8cm)	Engine velocity	2830 RPM
Grinder - case diameter	30 cm	Grinder pulley- diameter	8 cm
Grinder - effective diameter	27 cm	Grinder velocity	2264 RPM
Hammer disk- diameter	10 cm	----	---

Fig. (1): Hammer mill.

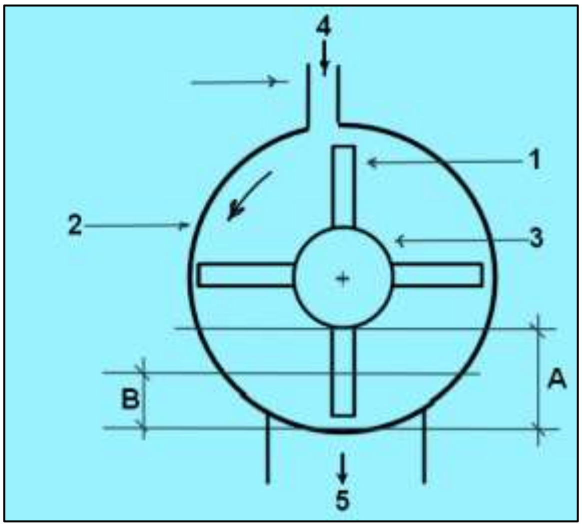

Fig. (2): Description of mill parts and feed. (rate A: 3000 g min $^{-1}$; B: 1500 g.min^{-1}). A, full explotion of impact area B, incomplete explotion 1- blade 2- room of milling 3- hammer dick 4- gate, 5- exit hole.

A feeding rate: A gate in the passage connecting the tank and the top of the mill was used to monitor grain descent into the grinding chamber. During the specified operating time, the gate opening was changed to drop the grains according to the feeding rate 1500 and 3000 g.min^{-1} (Dabbour *et al*., 2015). The below fig. (2) clarify that.

Studied factors

1- **Hammer's shape** is two levels, a- The Traditional hammer (Fig. 3a) and b- the T-shape hammer (Fig. 3b).

2- An area of impact is three levels, a- 480 mm^2 , b- 720 mm^2 and c- 960 mm^2

$A_t = b \times L$ …(1)

Where,

A_t , An area of impact face of the traditional hammer

b , hammer's thickness ; L, hammer's length fig (4)

$A_{T\text{-shape}} = (I_1 \times b) + (I_2 \times B)$ …(2)

Where,

$A_{T\text{-shape}}$, An area of impact face of the T-shape hammer

I_1 , I_2 , B , b , it shows in fig. (5)

3- Feeding rate is two levels , a- 1500 g min^{-1} b- 3000 g min^{-1}

Indicators and metrics of success were studied.

Mill production capacity

After running the mill for one minute and stopping it with an electronic timing regulator linked to the mill motor, the crushed grains were collected and weighed with an electronic scale. The following equation was utilized to quantify the mill production capacity (g min^{-1}) (Basiouny & El-Yamani, 2016).

$$MPC = \frac{WG}{T} \qquad \ldots(3)$$

Where,

MPC, Mill Production Capacity (g. min^{-1})

WG, weight of grains after the grinding (gram)

T, the time of grinding(minute)

Specific energy consumption

The specific energy consumption requirement was calculated by using the equation 4 (Ibrahim *et al*., 2019).

$$Spec. = \frac{CP}{MPC} \qquad \ldots(4)$$

Where,

Spec., Specific energy consumption (kw h kg^{-1})

Cp, Consumed power (kw), it Calculated from equation 3

$$Cp = \frac{I.V\ \eta \cos\theta}{1000} \qquad \ldots(5)$$

Where,

I= line current strength (Amperes).

a b

Fig. (3): a and b: Hammer's shape.

V = Potential strength (voltage) being equal to 220V.

Cos θ = power factor (being equal to 0.84).

η = Mechanical efficiency assumed (85%).

Results & Discussion

The effect of hammer's shape , impact area and interference on mill Production Capacity g min^{-1} (1500 g min^{-1} of feed rate).

Table (2) that shows the results of the experiment related to the data of the hammer shape and the area of influence when using a feed rate of 1500 g min^{-1} (incomplete loading of the mill capacity) there is a significant effect ($p \leq 0.05$) of the hammer shape on the production capacity of the mill, as the T-shape's hammer recorded 735. 78 g min^{-1} compared to the Rectangular Hammer, which recorded 613.05 g min^{-1}. The reason may be due to the better distribution of the dimensions of the t-shaped hammer compared to the rectangular shape one and possibly the lower impact area under the conditions of incomplete loading of the mill chamber (feed rate 1500 g min^{-1}). Moreover the results showed a significant effect in the opposite direction of the impact area on the mill's production capacity (Fig. 6)..

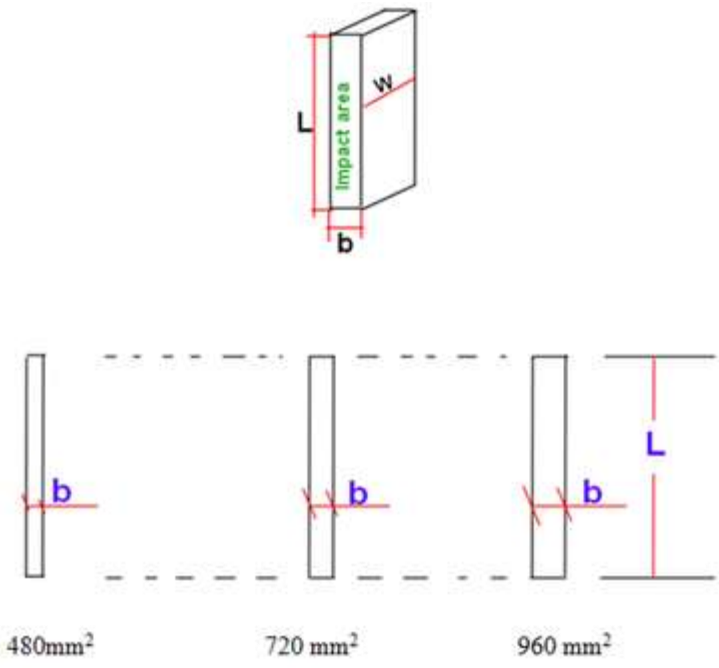

Fig. (4): Levels of impact area of traditional hammer

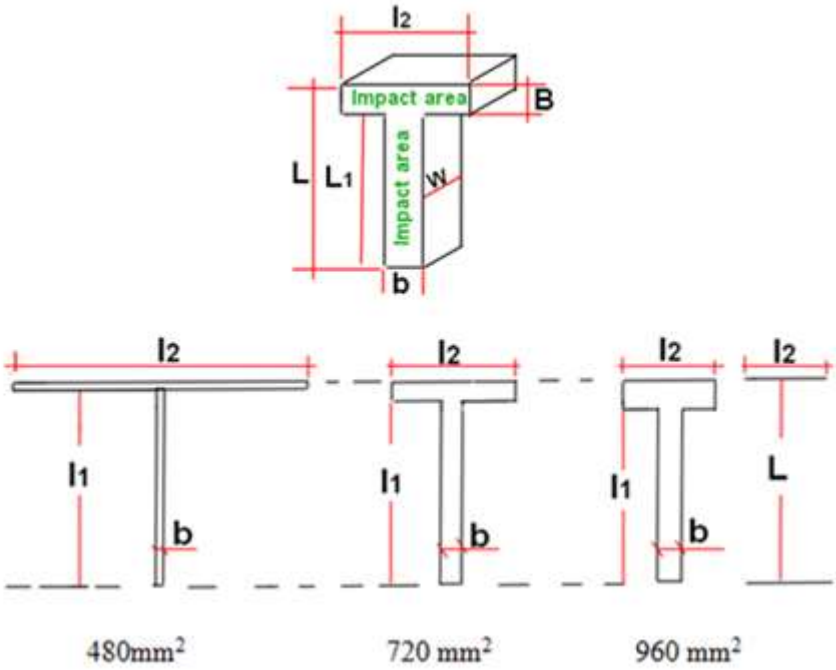

Fig. (5): Levels of impacts area of the T-shape hammer.

The capacity decreased by increasing the area of impact. The 480 mm^2 area recorded the highest production capacity of 787.23 $g.min^{-1}$ compared to the 720 mm^2 and 960 mm^2 area which recorded 684.075 and 551.95 $g.min^{-1}$, respectively. While it showed no significant effect of interference shape and area of impact of the hammerThis result may be due to a decrease in the amount of surface area of the grains due to a decrease in the effective hammer surface area, and consequently the pressure on the grains becomes greater, which leads to an increase in grinding (Budacan & Deac, 2013).

The effect of hammer's shape, impact area and interference on Specific energy consumption kw h kg^{-1} (1500 g.min^{-1} of feed rate).

The results of the experiment with the shape of the hammer and the area of impact shown in table (3). There is no significant effect ($p \leq 0.05$) for the shape of the hammer and the interference on the specific energy consumption, while there is a significant effect of the affected area on the specific energy consumption of the mill operating. Area 480 mm^2 recorded the lowest specific energy consumption of 0.03 kwh kg^{-1}compared with 0.04 kwh. kg^{-1} and 0.05 kwh. kg^{-1} for the area 720 mm^2 and 960 mm^2, respectively. This result represents a relative increase (per one kg of production capacity) and therefore the reason for its appearance is due to the relative increase in the production capacity of the mill resulting from the use of the 480 mm^2 area as it show from the results of table (2).

Table (2): Effect of hammer's shape, impact area and interference on mill Production Capacity g min^{-1} (1500 g min^{-1} of feed rate).

Impact area(B) / Hammer shape (A)	480 mm^2	720 mm^2	960 mm^2	Mean of hammer shape
Traditional hammer	672.500^{ns}	664.750^{ns}	501.900^{ns}	613.050^{b}
T- Shape hammer	901.950^{ns}	703.400^{ns}	602.000^{ns}	735.783^{a}
Mean of impact area	787.225^{a}	686.075^{b}	551.95^{c}	
L.S.D, B =103.116, Different letters indicate a significant differences between the averages of the treatments on a level of (p<0.05). NS. It is not significant differences between the averages of the treatments by ANOVA table on a level of (p<0.05).				

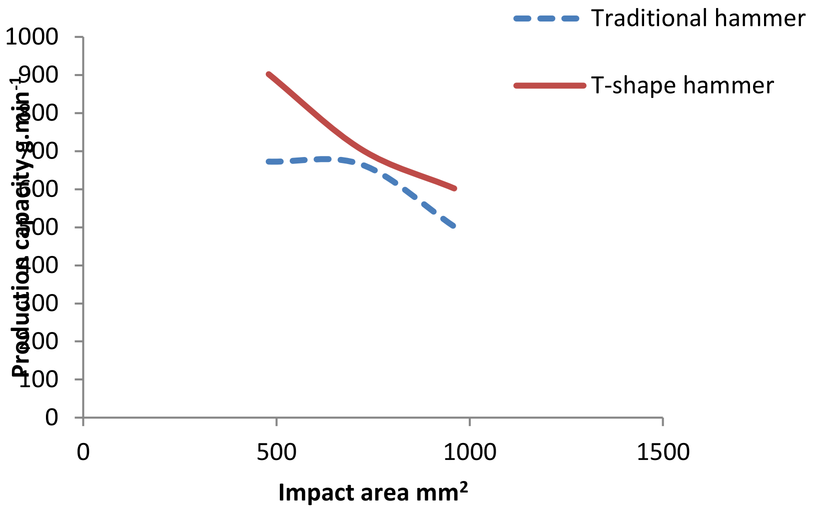

Fig. (6): Relationship between the impact area and production capacity.

Table (3): Effect of hammer's shape , impact area and interference on specific energy consumption kw.h.kg^{-1} (1500 g min^{-1} of feed rate).

Impact area(B) / Hammer shape (A)	480 mm^2	720 mm^2	960 mm^2	Mean of hammer shape
Traditional hammer	0.037 ^{NS}	0.039 ^{NS}	0.050 ^{NS}	0.042^{NS}
T- Shape hammer	0.028 ^{NS}	0.036 ^{NS}	0.041 ^{NS}	0.035 ^{NS}
Mean of impact area	0.033^{b}	0.037^{b}	0.046^{a}	

L.S.D, B = 0.006, Different letters indicate a significant differences between the averages of the treatments on a level of ($p<0.05$).). NS. It is not significant differences between the averages of the treatments by ANOVA table on a level of ($p<0.05$).

Effect of hammer's shape , impact area and interference on mill Production Capacity g. min^{-1} (3000 g min^{-1} of feed rate).

Table (4), one note that the hammer shape has no significant effect on the production capacity of the mill at the feed rate of 3000 g. min^{-1}. The reason for this result may be due to the equalization and full utilization of the impact area. On the other hand there is an effect of the influence area on the mill capacity. The impact area exceeds 720 mm^2 over the area 840 mm^2 and 960 mm^2, where it recorded 1215.7 g min^{-1} compared to 750.7 and 882.7 g min^{-1}respectively, therefore we find from Figure 7 an exponential relationship (non-linear) between the impact area and the displacement of the mill. This may be due to the effectiveness of this area (720 mm^2) in the working area inside the 10 cm wide grinding chamber. Heimann (2019) confirmed this relationship as well.

Effect of hammer's shape, impact area and interference on Specific energy consumption kw h kg^{-1} (3000 g min^{-1} of feed rate)

The results in table (5) show no significant effect of hammer shape, as well as the interference between shape and hammer area on the specific energy consumption. While there is a clear impact on the impact area, as the area 720 mm^2 recorded the lowest specific consumption of operational energy, amounting to 0.021 kw h kg^{-1} compared to 0.027 and 0.029 kw h kg^{-1} for area 840 and 960 mm^2, respectively. The reason for this result is that the hammer has an area of 720 mm^2 in the production capacity, so the negative energy consumption appears, this can be explained by the fact that the impact area, when reduced, leads to a decrease in energy requirements.

Table (4): Effect of hammer's shape, impact area and interference on mill production capacity g min^{-1} (3000 g min^{-1} of feed rate).

Impact area (B) / Hammer shape (A)	480 mm^2	720 mm^2	960 mm^2	Mean of hammer shape
Traditional hammer	1046.800^{bc}	1157.450^{ab}	924.500^{cd}	1042.917 ^{NS}
T- Shape hammer	854.500^{df}	1273.850^{a}	840.800^{df}	989.717 ^{NS}
Mean of impact area	950.650^{b}	1215.650^{a}	882.650^{b}	

L.S.D, B = 99.276, AB=140.398, The difference indicate a significant differences between the averages of the treatments on a level of ($p<0.05$). NS. It is not significant differences between the averages of the treatments by ANOVA table on a level of ($p<0.05$).

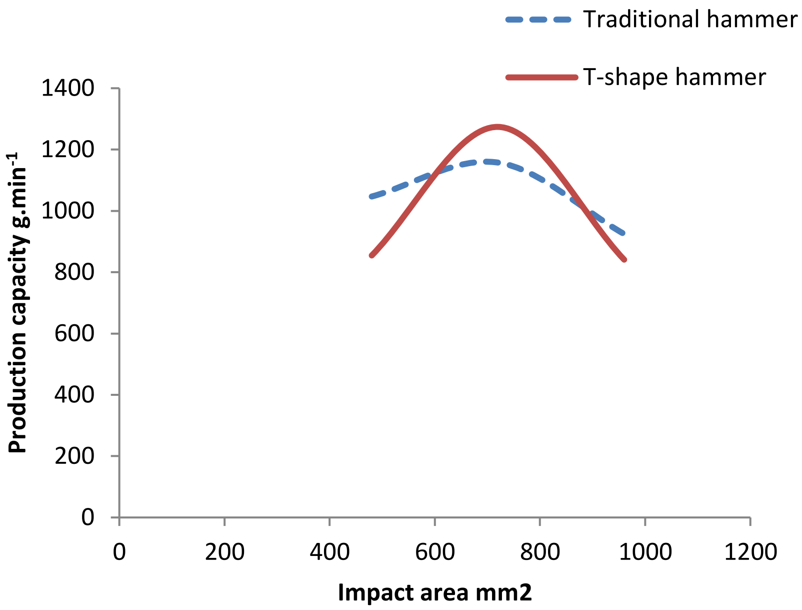

Fig. (7): relationshipe between the impact area and production capacity at 3000 g.min^{-1}.

Table (5): Effect of hammer's shape, impact area and interference on specific energy consumption kw h kg^{-1} (3000 g min^{-1} of feed rate).

Impact area (B) / Hammer shape (A)	480 mm^2	720 mm^2	960 mm^2	Mean of hammer shape
Traditional hammer	0.024 ^{ns}	0.022 ^{ns}	0.027 ^{ns}	0.024^{NS}
T- Shape hammer	0.030 ^{ns}	0.019 ^{ns}	0.030 ^{ns}	0.026 ^{NS}
Mean of impact area	0.027^a	0.021^b	0.029^a	
L.S.D, B = 0.003 The difference in the letters indicate a significant differences between the averages of the treatments on a level of (p<0.05). NS. It is not significant differences between the averages of the treatments by ANOVA table on a level of (p<0.05).				

The effect of feeding rate on the production capacity of the mill

Fig. (8) shows a significant effect of the feeding rate on production capacity. The feed rate 3000 g min^{-1} recorded the highest milling capacity of 1042.9 g.min^{-1} and 991 g.min^{-1} for the T-shape hammer and the rectangular hammer respectively compared with the feed rate 1500 g min^{-1} for the 737.03 g.min^{-1} T-shape hammer and the 316.07 g.min^{-1} rectangular hammer. The reason for this result may be due to the full utilization of the impact area of the hammers when using a high feed rate (3000 g.min^{-1}). The results of several researchers have shown an increase in the capacity of the mill with an increase in the feeding rate, as researcher (Dabbour *et al.*, 2015; Ibrahim *et al.*, 2019).

The effect of feeding rate on the specific energy consumption of the mill

The results of the experiment on the effect of feed rate on specific energy consumption are shown in fig. (9). There is a significant effect ($p \leq 0.05$) of feed rate on specific energy consumption. Feed rate 3000 g.min^{-} . recorded the lowest specific energy consumption of 0.024 and 0.027 kwh. kg^{-1} compared with 0.042 and 0.035 kw h. kg^{-1} for the T-hammer and the rectangular hammer, respectively when using the rate of nutrition 1500 g.min^{-1}. The reason is due to the relative increase in the production capacity of the mill resulting from the use of a feed rate higher than 1500 g.min^{-1}, As well as Ibrahim *et al.* (2019) found the decrease in the consumption power of the mill with an increase in the feeding rate

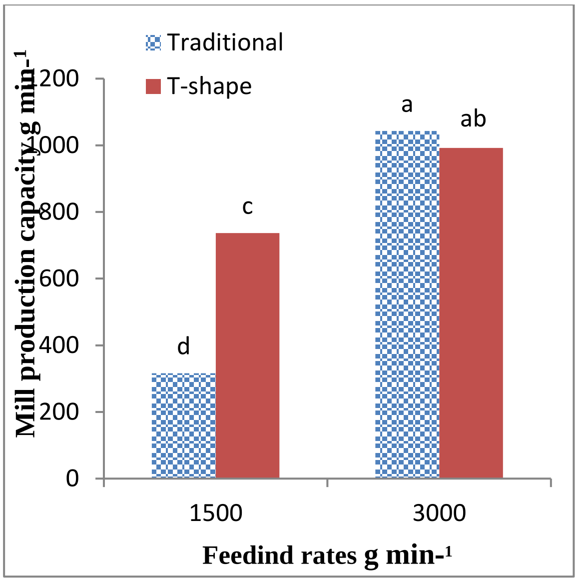

Fig. (8): Comparison of the effect of feed rate rates 1500 and 3000 on mill capacity.

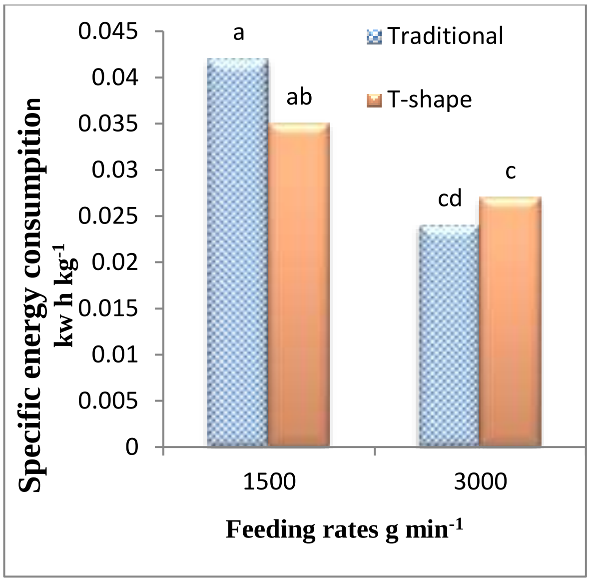

Fig. (9): Comparison of the effect of feed 1500 and 3000 on Spc.

Conclusions & Recommendations

1-There is a significant effect of hammer shape on the production capacity at a feed rate of 1500 g min $^{-1}$. While there is no such effect on the shape of the hammer on the production capacity at a feed rate of 3000 g.min $^{-1}$.

2- There is a significant effect of the influence surface area on the production capacity and specific energy consumption at the feed rate of 1500 and 3000 g min $^{-1}$.

3- There is an inverse relationship between the impact area and the mill production capacity at the feed rate 1500 g.min $^{-1}$, while there is a non-linear relationship between them at the feed rate 3000 g. min $^{-1}$

4- There is a significant effect of feed rate on and the mill production capacity and specific energy consumption.

5- The T-shape hammer can be used at low feed rate (in which the impact area is not fully utilized).

6- It is preferable to use a traditional hammer when the impact area is fully utilized by using a high feed rate of 3000 g.min $^{-1}$ for its high performance compared to the T-shape hammer as well as for simplicity of design and manufacturing.

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تأثير شكل المطرقة ومساحة تأثير سطح الصدم على اداء المجرشة المطرقية تحت معدلات تغذية مختلفة

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المستخلص: يهدف البحث إلى مقارنة السعة الانتاجية (PC) واستهلاك الطاقة النوعي (Spc) للمجرشة المطرقية من خلال استخدام المطرقة شكل حرف T مقابل المطرقة المستطيلة (التقليدية). تم استخدام مجرشة محلية الصنع بأربع مطارق. تضمنت التجربة 36 معاملة : 2 شكل للمطرقة × 3 مساحات صدم (480 و 720 و960 ملم^2) × 2 معدل تغذية (1500 و 3000 جم .دقيقة $^{-1}$) × 3 مكررات ، بتصميم كامل التعشية. أظهرت النتائج عدم وجود تأثير معنوي لشكل المطرقة على PC عند معدل تغذية 3000 جم . دقيقة$^{-1}$ بينما كان هناك تأثير لشكل المطرقة عند معدل 1500 جم . دقيقة$^{-1}$. وجد تأثير لمساحة الصدم على PC في كلا معدلي التغذية . تفوقت المساحة 720 ملم ^{2} على المساحة 480 و 960 ملم ^{2} عند معدل تغذية 3000 جرام .دقيقة $^{-1}$ حيث سجلت 1215.65 جرام. دقيقة $^{-1}$ مقابل 950.65 و 882.65 جرام. دقيقة $^{-1}$ على التوالي. وجد تأثير معنوي لمعدل التغذية على التغذية على PC و SPc . يوصى باستخدام المطرقة التقليدية لبساطة التصميم والتصنيع وافضلية الأداء عند معدلات تغذية عالية مقارنة بالمطرقة شكل حرف T , وتفضل الاخيرة في معدلات التغذية المنخفضة.

الكلمات المفتاحية: الطحن، قوة الصدم، سعة المطحنة، استهلاك الطاقة النوعي، شفرة المطحنة، معدل التدفق.