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Influence of Knives Wear Phenomena on Hammer Mill Productivity and Product Quality

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ABSTRACT

This research aimed to determine the change of cutting knives decision depending on knife wear phenomena, and its effect on hammer mill productivity and product quality. It can be done by tracing the knives wear stages and determine its safe time range to replace the knives. The experiments were done in El-Serw village Damietta Governorate from 2014 to 2016, by grinding both of corn ear and dough as popular agricultural productive using the traditional hammer mill. The studied variables also are four concaves hole diameters (2.5, 4.0, 8.0 and 12.0 mm), five operating hours of new knife, 150, 200, 250 and 300 h for corn ear. While, for dough, are used two concaves hole diameters (2.5 and 4.0 mm) and operating hours of new knife, 200, 400, 600 and 800 h. The measurement includes specifications of knives, product quality and hammer mill performance. The research recommended that the hammer mill knives must replacement after 220 operating hours to grind corn ear and 600 operating hours to grind dough which represents the safe limit time to keep product quantity and quality in accepted state.

Keywords: hammer mill, knives wearing, productivity, dough, corn ear, element of knife, quality, energy, MWD, PSD.

INTRODUCTION

The easy and popular direction at crushing any agricultural production is usage the hammer mill. The hammer mill knives are the effect part to reduce the sizes of agricultural materials. However, the knives material make a principle factor to quality, quantity and economic at using the hammer mill especially at agricultural products. To facing the variation in ability to withstand crunches knives differences in the types of agricultural products which invited many research to study the properties of agricultural products and experience some of the raw materials in the manufacture of knives (Abd El-Ghany, 2003). Abd-Elrahman (2013) and Ahmed (2013) studied the grinding specifications of some agricultural products as rice straw, corn stover, cotton stalks, soya bean straw, corn grains and mango kernels. But the studies can't determine the time of knives replacement to keep the high performance of hammer mill. Amer (2007) reported that the adding some of elements to the steel go to provide resistance of wear and hardness such element as carbon, chromium and nickel. Thus to increase steel resistance corrosion, oxidation and improve the hardening such element adding as vanadium. While to removal steel oxidation such element adding as manganese and aluminum. Furthermore Habib (2002) mentioned that devotion ways of some steel properties as steel hardness by increasing carbon portion. Steel toughness can raise by increasing silicon and molybdenum. The strength can increase by increasing chromium. Oxidation resistance can raise by increasing chromium and molybdenum. Impact and wear resistance can increase by increasing vanadium.

Neale (1995) indicated that, the metal wear caused by hard particles like that occurs during grinding process and can be likened to a cutting or machining operation. Moreover, there is a relatively simple link between metal wear resistance and hardness. The wear phenomenon may cause severe surface damage, and this damage would be led to significant deterioration. Maleque and Salit (2013) signed that the types of metal could be classified into the abrasive wear, erosive wear, surface fatigue, corrosive wear and fretting. Lindström (2006) clear that at using hammer mill, each of the knives four corners are used before being replaced. High wear resistance and toughness can be done by many ways as case hardening, cladding, or use of steel with high hardness. The hardness of the surface layer may around 900 Vickers, which regularly decreases down to 300 Vickers, at about 1.0 mm depth into the material. Khurmi and Gupta (2005) reported that treating metals with heat is an operation involving the heating and cooling of a metal or its alloys in the solid state for the purpose of enhancing. Its mechanical and physical properties without any change in chemical constitutes. There are several methods of heat treatments like hardening, tempering, annealing, normalizing, and spheriodising. Topbas (1998), Ismail, *et al*. (2008) and in reported of Standard of Heat Treaters Guide (1995) explained that, it must keep Si between 0.55 to 0.7% and Cr between 0.9 to 1.2%. They conducted that lower Si element mean oxidation, while lower Cr element decreases the both of transformation temperature and hardness also significant amount of wear resistance at using circular saw which used to cut bars, pipes and particular in metal industry. Wessling *et al*. (1996) conducted that the new anti- corrosive technique of polyaniline, which is an organic metal (conductive polymer) can used. Heimann (2000) reported that hammers should be replaced whenever the wear extends about 25% along the width of the hammer. In addition to loss in capacity and efficiency, excessive wear can lead to severe unbalance in a set of hammers causing extreme hammer mill vibrations. Excessive wear of the hammer holes or grooving of the pins generally indicated an inconsistent feed (surges that cause the hammers to rock on the pins) or the need for a heavier hammer pattern.

Mani *et al.* (2004) stated that hammer mill energy required depends on its initial particle size, material properties, moisture content, mass feed rate, and machine variables. They clear that a grinding machine is predominating measured mean diameter, particle size distribution and total specific energy.

Egela *et al.* (2003) studied the effect of some operational parameters on the fineness of the ground corn and also on the energy consumption. The concave opening size of 14mm, number of hammers of 45 and the speed of 28.6 $m.s^{-1}$ resulted in medium ground corn fineness. The concave opening size of 6mm, 60 hammers and 36.7 m.s^{-1} were used; the hammer mill feed opening and rotor shaft speed were the most significant factors affecting energy requirements. Also, Ghorbani *et al*. (2010) found that the highest and lowest specific energy of alfalfa chops with sizes of 18, 15 and 12mm were 30.96 and 5.06 kJ kg^{-1}, respectively.

Therefore, the objective of this work is to determine the change cutting knives decision depending on knife wear, hammer mill productivity and product quality.

MATERIALS AND METHODS

The experiments were carried out at El-Serw village, Damietta Governorate from 2014 to 2016 for grinding both of corn ear and dough as popular agricultural products used to animal fodder. The used hammer mill (Fig. 1) mainly consists of trapezoid hopper with upper square opening of 500 × 500 mm and lower rectangle opening of 200 × 300 mm and 440 mm height. The cutting unit has 650 mm diameter and 325 mm width. It includes six secondary bars, each one carried six knives and with output opening of 250 × 150 mm.

1- Hopper 2- Rotating shaft 3- Motor 4- Knife
5- Secondary bar 6- Concave

Fig. 1. The investigated hammer mill

Besides, the frame made of U shape steel of 90 × 45 mm width and height. The frame has out dimensions of 1700 × 610 × 450 mm length, width and height respectively. The power source is three phase motor with 29kW and 1200 rpm. The shaft revolution of hammer mill is 3000 rpm.

A common new knife used has dimensions of 150 × 50 × 4 mm for length, width and thickness respectively. The knife material tests in CMRDI (2013) and LEC (2016). The tests report is the knife made from heating treatment steel (DIN CK75) with 180 g mass, microstructure of tempered marten site, 48 HRc hardness, 97.89% Fe, 0.753% C, 0.28% Si, 0.737% Mn, 0.0065% V, 0.0146% P, 0.00029% S, 0.0177% Al, 0.245% Cr, 0.0252% Ni and 0.0213% Cu. This knife component is good to be used in hammer mill for agricultural products.

The agricultural products used are corn ear triple hybrid TC310 species, of 13 % moisture content. Also for grain and ear hardness is 231.2 and 368.8 N respectively and grain and ear shear is 167.5 and 255.4 N respectively. The dough (residues) has 17 % moisture content, hardness of 92.6 N and shear of 69.4 N.

The experiments individual included two groups of original knives "36 knife for each group". Each one used for grinding the agricultural products under study. All the in-door experiments study the knife wear phenomenal for hammer mill during conducted the mill with original knives. Each experimental sample is about 10 kg for each treatment. The strip plot design with three replicates was done as experimental design. Experimental on corn ear are four concaves (2.5, 4.0, 8.0 and 12.0 mm hole diameter), five operating hours of beginning set the new knife "it mean that 0.0 operating time", 150, 200, 250 and 300 h. While, for dough, are used two concaves (2.5 and 4.0 mm) and operating hours of new knife, 200, 400, 600 and 800 h. To achieve the objective of study the measurements were divided into three divisions:

1- Knives wear evaluation

The knives wear was determined by measuring knives dimensions and pending hole area (using the Auto cade image program) and it's mass during different operating hours (Fig. 2). The knife mass, wear percentages obtained from:

$$Wear\ percentage = \frac{M - Mu}{M} \times 100 \quad ....\% \qquad (1)$$

Where: M = Mass of original knife, kg
Mu = Mass of used knife, kg

The reduction ratio of centrifugal force calculated from:

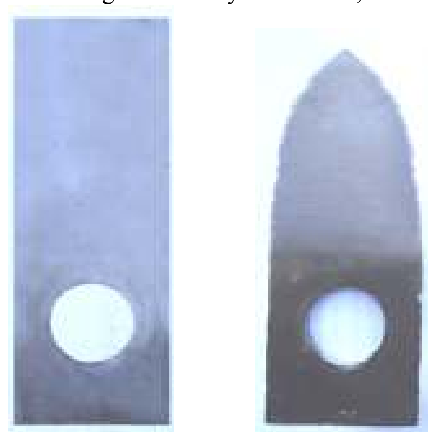
$$Centrifugal\ force = 100 - (\frac{Fu}{Fn} \times 100) \quad ....\% \qquad (2)$$

Where: Fn = centrifugal force of original knife, kN
Fu = centrifugal force of used knife, kN

The centrifugal force "F" identified as the following:

$$F = N\, m\, r\, \omega^2 \quad ....kN \qquad (3)$$ [Hannah and Stephens, 2004]

Where: N = number of hammers
m = mass of each hammer, kg
r = radius of hammer, m
ω^2 = angular velocity of hammer, radian/sec



New knife Final used knife

Fig. 2. Knives shape before and after used

2- The product quality

The product quality can be determined by estimating the:

- **Percentage of grinding size distributions** "PSD" by weighting and sieving each sample using six different sieves with mesh sizes of 1.19, 0.84, 0.59, 0.297, 0.194 and less than 0.105 mm and weighting the samples on each sieve. The percentage of size distributions was calculated by:

$$Percentage\ size\ distribution = \frac{On\ sieve\ mass}{Total\ mass\ of\ sample} \times 100 \ \ldots\ldots\ldots\ \% \quad (4)$$

- Mean weight diameters "MWD" of grinding using RNAM equation (1983), as follows:

$$MWD = \frac{1}{W}(1.015A + 0.713B + 0.443C + 0.245D + 0.149E) \ldots\ldots\ mm \quad (5)$$

Where: A + B +… E = mass of grinding, kg.

W = A + B +... E, kg.

3-The machine performance:

The machine performance can determine and evaluation by machine productivity and energy consumed.

- Machine productivity (Mp):

The machine productivity can estimated by the following:

$$Mp = \frac{1}{T} \ldots\ldots\ \ldots\ldots\ \ldots\ Mg\ /\ h \quad (6)$$

Where: T is required time for grinding one kg.

- Hammer mill specific energy:

It determined using the digital device (LVM 210: Sony LG). It measures the line current and the potential difference volt. The power (P) is measured directly. The useful grinding power (with load – without load) is calculated, and then the hammer mill specific energy "Se" is estimated according to the following equation:

$$Se = \frac{P}{Mp} \ldots\ldots\ \ldots\ldots\ \ldots\ kW.h/Mg \quad (7)$$

Where: P = consumed power, kW.

$$P = \frac{\sqrt{3}\, I . V . \eta . Cos\ \theta}{1000} \ldots\ldots\ \ldots\ldots\ \ldots kW$$

Where:

$\sqrt{3}$ = Coefficient current three phase (being equal 1.73),

I = Line current strength in amperes,

V = Potential difference (Voltage) being equal to 380 V,

Cos θ = Power factor (being equal to 0.84), and

η = Mechanical efficiency assumed (90 %).

The mathematical analysis for the machine productivity and total specific energy were done using the excel program.

RESULTS AND DISCUSSION

Knives wear evaluation

The knives wear as a percentages of wear (%), mass reduction (g), and expanding of pending hole area (cm^2) evaluated during ending set knife of 300 h. The achieved data illustrates in Fig. (3). For corn ear, as shown in Fig. (3) the percentages of knife wear was 41.17 % and the knife mass reduced from 180.0 to 105.9 g. This due to the wear at lips of knives which resulting from the friction and stroke on corn ear (Fig. 2). These results agreement with the results obtained from (Abd-Elrahman, 2013). Also, the pending hole area of knife expanded by 77.03 % (from 3.14 to 5.55 cm^2) per 300 h. However, Fig. (4) illustrates the effect of operating hours on reduction ratio of centrifugal force. The figure clears that the centrifugal force reduction ratio of hammer decreased from 0.00 to 46.66 % by increasing the operating hours from 0.0 to 300 h, respectively.

On the other hand, for grinding the dough, increasing at end set knife to 800 h, the percentages of knife wear was 35.42 %, the knife mass reduced from 180 to 116.24 g and the pending hole area of knife expanded by 0.95 % from 3.14 to 3.17 cm^2. Percentages of knife wear were 10.56, 21.07, 32.05 and 41.16 % at operating hours of 150, 200, 250, and 300 h, respectively for corn-ear. While for dough, the percentages of knife wear were 5.65, 18.61, 27.08 and 35.42 % at operating hours of 200, 400, 600 and 800 h, respectively.

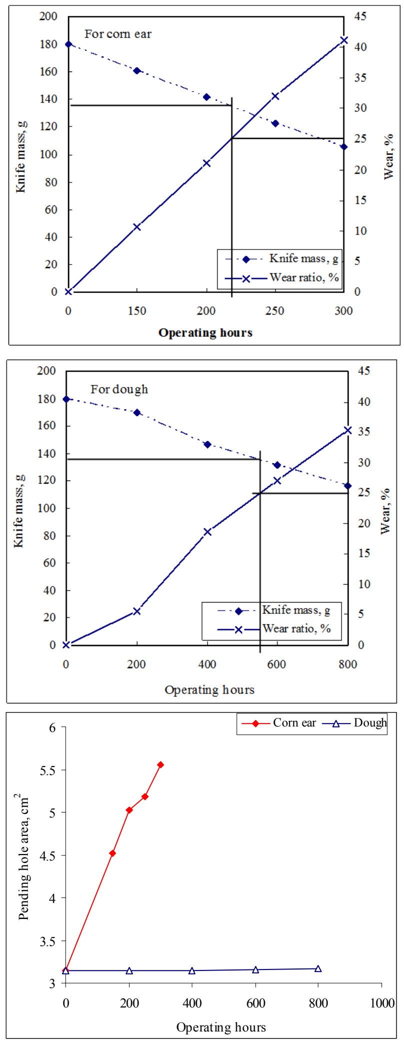


Fig. 3.The effect of operating hours on knife wear

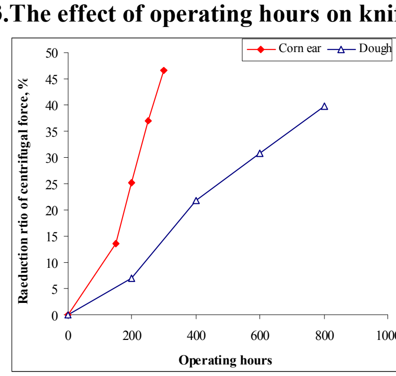


Fig. 4. The effect of operating hours on ratio of centrifugal force

These results were due to wear unevenly on knives which may cause vibration on pin then expanding on hole. These results agreement with Heimann (2000), Ismail, *etal*. (2008) and Abd-Elrahman (2013). Nevertheless, referring to Fig. (4) the centrifugal force reduction ratio of knives reduced from 0.0 to 39.75 % by increasing the operating hours from 0.0 to 800 h, respectively. This is related to the reduction in knives mass and length which diminish the crushing force and increase the clearance between hammer mill knives and concave. The knife mass and percentages of knife wear data clear that according to the recommended from Heimann (2000) the knife can replace at 220 and 590 h for corn ear and dough respectively.

Product quality

Figure (5), clears that the percentages of (PSD) using sieve hole diameter of 1.19, 0.84, 0.59, 0.297 and 0.194 mm were 27.3, 29.6, 32.3, 39.3 and 49.3 %, respectively at beginning set the new knife using concave holes diameters of 2.5 mm for corn ear. However the corresponding data were 49.26, 17.48, 14.52, 18.45 and 0.29 %, respectively at end use knife of 300 h using concave holes diameters of 2.5 mm for corn ear. On the other side, the percentages of (PSD) for dough using sieve holes diameters of 1.19, 0.84, 0.59, 0.297 and 0.194 mm were 19.38, 27.56, 21.81, 28.33 and 2.92 %, respectively at operating hours of 0.0 h using concave holes diameter of 2.5 mm. Also, the corresponding ratios were 32.38, 22.86, 21.81, 21.63 and 1.32 %, respectively at operating hours of 800 h by concave holes diameter of 2.5 mm.

These results affirm that the coarse particles have a 13.87 and 6.64 times fine using the new knife for corn ear and dough, respectively. But the results were 171.5 and 24.55 times using the old knives for the above agricultural production, respectively. These features of the new knives are very important to ensure the obtained of high quality products and preferred specification.

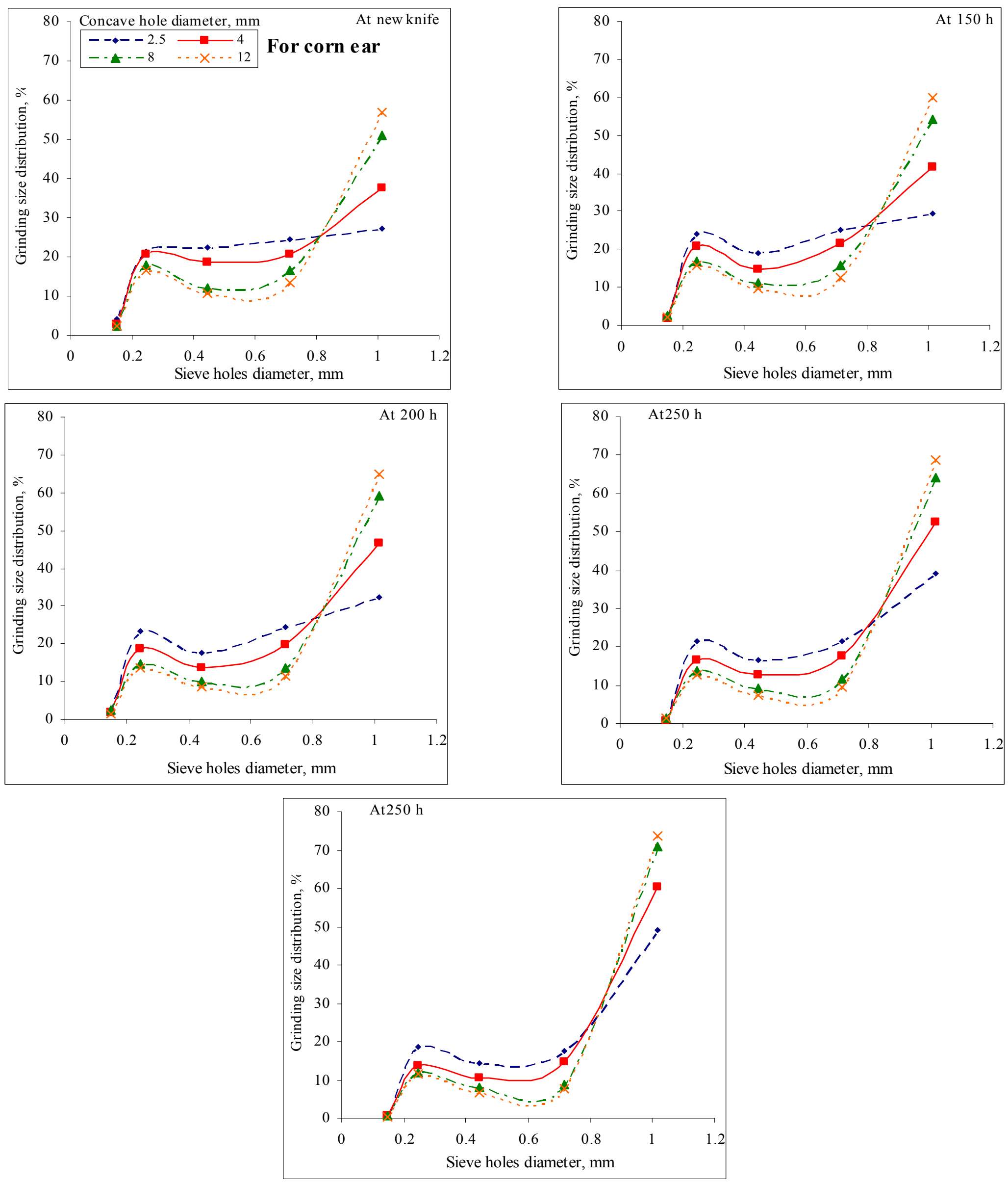


Fig. 5-A. Effect of operating hours and concave hole diameter on particles size distributions% for corn ear.

Fig. (6) illustrates that MWD of corn ear has a direct proportion to both of concave hole diameter and operating hours. From the figure it could be seen that by increasing the operating hours from the new knives to 300 h, the MWD increased at all treatment under study. For corn ear the MWD was 0.33, 0.47, 0.69, 0.77 and 0.90 mm obtained at operating hours of 0.0, 150, 200, 250 and 300 h, respectively and concave hole diameter of 2.5 m. Vice versa, it was 0.66, 0.78, 0.85, 1.00 and 1.60 mm found at operating hours of 0.0, 150, 200, 250 and 300 h, respectively and concave hole diameter of 12 mm. On the other hand, at grinding dough, the MWD was 0.20, 0.30, 0.63, 0.70 and 0.80 mm, at operating hours of 0.0, 150, 200, 250 and 300 h, respectively and concave hole diameter. However, the MWD was 0.27, 0.40, 0.68, 0.76 and 0.90 mm, obtained at operating hours of 0.0, 150, 200, 250 and 300 h, respectively and concave hole diameter of 4 mm. This trend is attributed to decrement effect of reduction knives force by increasing the operating hours on crashing grinding materials by about 2.7 to 2.4 times at concave hole diameters of 2.4 and 4.0 mm, respectively for grinding corn ear but it was 3.97 to 3.37 times at concave hole diameters of 2.4 and 4.0 mm, respectively for grinding dough.

Machine performance

- Machine productivity

Fig. (7) shows the effect of different operating hours and concave hole diameters on machine productivity, for both of corn ear and dough. From the obtained data, it is clear that the machine productivity decreased by increasing the operating hours. However, it increased by increasing the concave hole diameters. By increasing the operating hours from 0.0 to 300 h, the ratios of machine productivity decrease by about 85.30, 85.02, 86.27 and 87.09 %, respectively at concave hole diameters of 2.5, 4.0, 8.0 and 12.0 mm for corn ear.

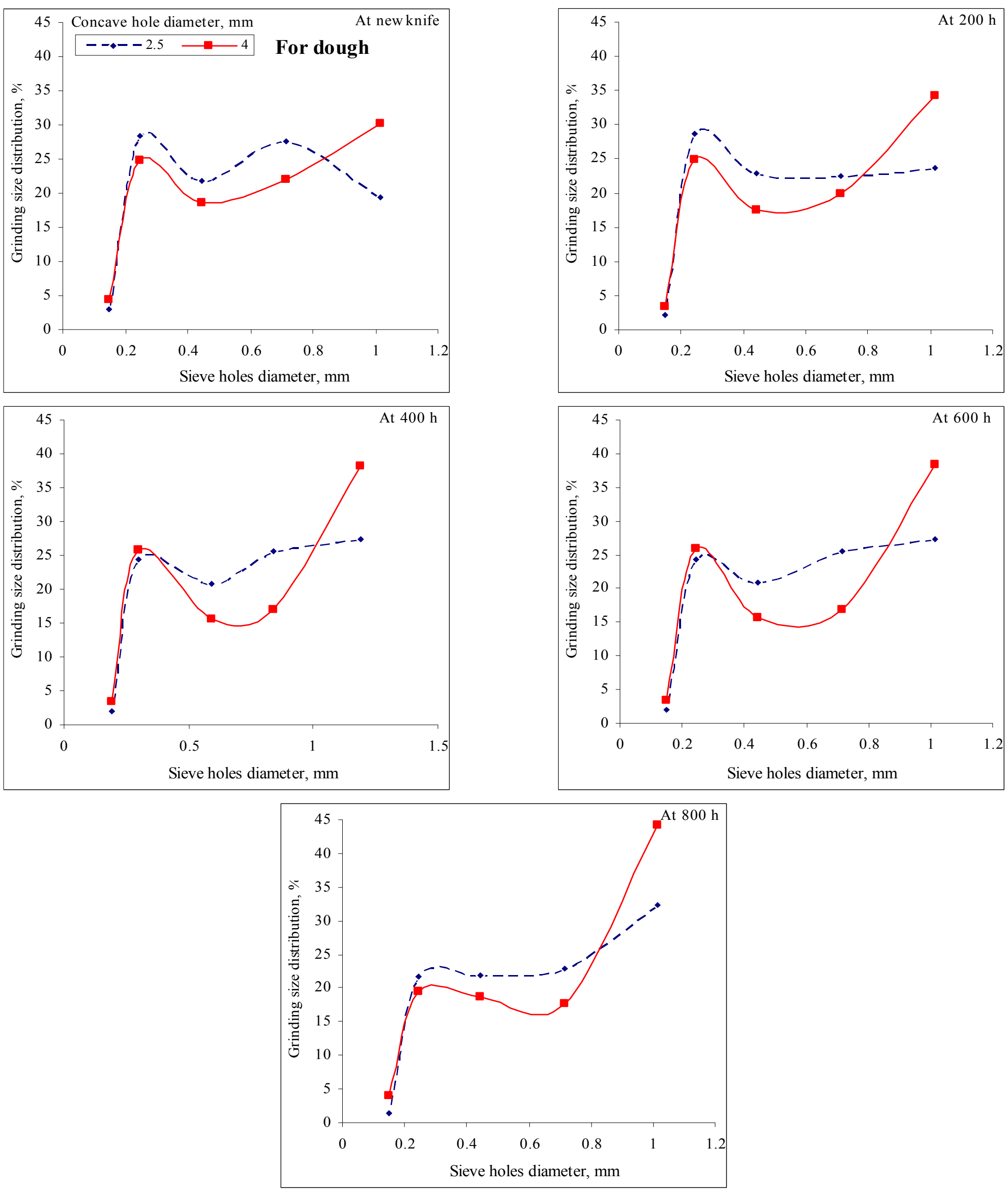


Fig. 5-B. Effect of operating hours and concave hole diameter on particles size distributions% for corn ear.

However, the corresponding ratios were 84.71 and 88.08 %, respectively at concave hole diameters of 2.5 and 4.0 mm for dough. These results may be due to the increase percentage of knives wear by increasing the operating hours, which decreased the knives centrifugal force, thus reducing the efficiency of the knives cut. Also, increasing the concave hole diameter makes materials flow easier.

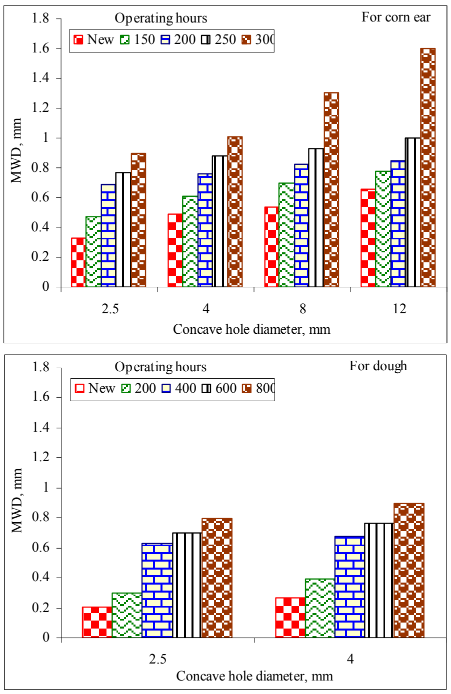


Fig. 6. Effect of concave hole diameter and operating hours on mean weight diameter.

The best fit curve that describes the relationship between the machine productivity (Mp) and operating hours (h) at different concave holes diameter as follows:

For corn ear:

At concave holes diameter

2.5 mm $Mp = -0.0079h^2 - 0.4954h + 965.27$ $R^2 = 0.9821$

4.0 mm $Mp = -0.0090h^2 - 0.5850h + 1106.5$ $R^2 = 0.9810$

8.0 mm $Mp = -0.0123h^2 - 0.6653h + 1449.3$ $R^2 = 0.9839$

12.0 mm $Mp = -0.0164h^2 - 0.7762h + 1879.7$ $R^2 = 0.9853$

For dough:

At concave holes diameter

2.5 mm $Mp = 0.0009h^2 - 2.2034h + 1164.6$ $R^2 = 0.9634$

4.0 mm $Mp = 0.0012h^2 - 4.1426h + 2287.2$ $R^2 = 0.9702$

- Hammer mill specific energy

From Fig (8) it may be concluded that increasing operating hours resulted in increasing the hammer mill specific energy (kW.h/Mg), for both corn and dough. Using the concave hole diameter of 12 mm conformed the lowest value of total specific energy of 3.1 kW.h/Mg, at beginning use of knives for corn. On the other hand, the highest value of total specific energy was 40.3 kW.h/Mg at concave holes diameter of 2.5 mm, at end use of knives 300 h. At grinding dough, the highest value of total specific energy was 11.7 kW.h/Mg, by using concave hole diameter of 2.5 mm, at operating hours of 800 h. However, the lowest total specific energy was 1.7 kW.h/Mg, obtained by using concave hole diameter of 4 mm, at the beginning use of knives. This trend is attributed to increasing the clearance between the knives tip and the concave surface by increasing the operating hours to 300 h, because there is more wearing for knives. It leads to more time to grinding materials efficiently and consequently more energy. In addition, it is logical that increasing concave holes diameter makes materials flow easier and little energy needed.

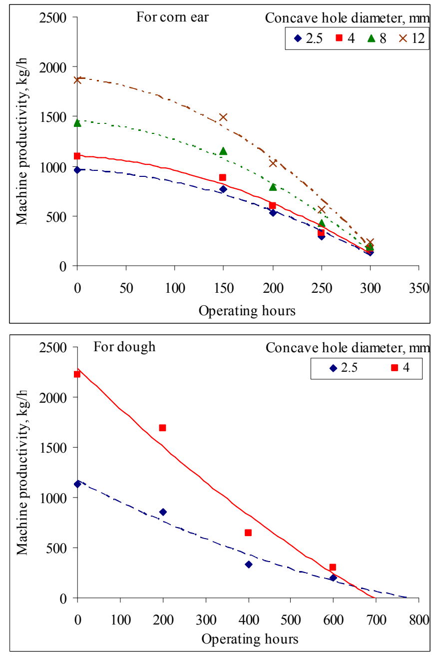


Fig. 7. Effect of operating hours and concave hole diameter on machine productivity.

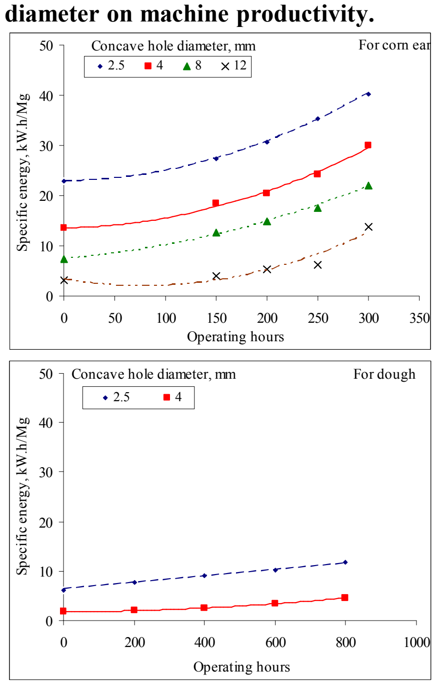


Fig. 8. Effect of operating hours and concave hole diameter on the total specific energy.

The best fit curve which describes the relationship between the hammer mill specific energy (Se) and operating hours (h) at different concave holes diameter as follows:

For corn ear:

At concave holes diameter

2.5 mm $Se = 0.0002 h^2 + 0.0021 h + 22.889$ $R^2 = 0.9996$
4.0 mm $Se = 0.0002 h^2 + 0.0027 h + 13.601$ $R^2 = 0.9936$
8.0 mm $Se = 0.0001 h^2 + 0.0169 h + 7.3643$ $R^2 = 0.9964$
12.0 mm $Se = 0.0002 h^2 - 0.0342 h + 3.3176$ $R^2 = 0.9022$

For dough:

At concave holes diameter

2.5 mm $Se = 0.0067 h + 6.24$ $R^2 = 0.9936$
4.0 mm $Se = 0.0035 h + 1.42$ $R^2 = 0.9368$

CONCLUSION

The obtained results concluded that the grinding knives under study must replacement after 220 operating hours to grind corn ear and 600 operating hours to grind dough which done at 25% knives wear. At this operating hours the increase percentage from the new knives in MWD, specific energy and percentage of reduction in machine productivity were 54.34, 27.24%; 29.66, 45.22% and 54.90% respectively at concave hole diameters of 2.5 and 12.0 mm for corn ear. Then the corresponding percentages for dough were 71.07, 64.99%; 35.31, 40.85% and 49.94% respectively at concave hole diameters of 2.5 and 4.0 mm.

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تأثير تآكل سكاكين المجرشة على الإنتاجية وجودة المنتج

ناهد خيرى إسماعيل ، أسامه أحمد على فوده ، مختار قطب أحمد و ماجدة محمد أمين موسى

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يهدف هذا البحث إلى تحديد الوقت الأمثل لإتخاذ قرار إستبدال سكاكين المجرشة إعتماداً على تآكل السكاكين والإنتاجية وجودة المنتج. ولإمكانية تحقيق ذلك تم تتبع مراحل التآكل فى سكاكين الجرش لتحديد المدى الزمني الآمن لتشغيل سكاكين المجرشة. حيث أجريت التجارب خلال الفترة من ٢٠١٤ إلى ٢٠١٦ فى قرية السرو – محافظة دمياط باستخدام مجرشة حبوب تقليدية مكونة من ٣٦ سكين حر الحركة. تم تحليل بعض خواص ومكونات خامة السكاكين المستخدمة. ولإجراء التجارب تم استخدام مجموعتين من السكاكين الجديدة لكل نوع من المنتجات الزراعية حيث إشتملت متغيرات الدراسة على: نوعين من المنتجات الزراعية "كيزان الذرة ومخلفات المخابز (عجين)، غرابيل بأقطار "٢,٥ و٤,٠ و٨,٠ و ١٢,٠ مم" لكيزان الذرة و "٢,٥ و٤,٠ مم" لمخلفات المخابز، أزمنة التشغيل "٠,٠، ١٥٠، ٢٠٠، ٢٥٠، ٣٠٠ ساعة" لكيزان الذرة، "٠,٠، ٢٠٠، ٤٠٠، ٦٠٠، ٨٠٠ ساعة" لمخلفات المخابز. وتم قياس وتقدير: - مواصفات السكاكين للدلالة على التآكل الحادث من بدء الاستخدام الأول (بالقياس الوزنى، نسبة التآكل وكذلك القوى الطاردة المركزية للسكاكين) - جودة الجرش (القطر المتوسط لحبيبات الجرش – نسب التوزيع الحجمي لحبيبات الجرش) - أداء المجرشة (الإنتاجية كجم/ساعة - الطاقة النوعية كيلووات.ساعة/ميجاجرام) وأوضحت النتائج أنه يجب إستبدال سكاكين المجرشة عند ٢٢٠، ٥٩٠ ساعة تشغيل لكلٍ من كيزان الذرة والعجين على التوالى والتى عندها وصل معدل التآكل في مادة السكين ٢٥ %. حيث زادت نسب متوسط القطر الموزون بمقدار يتراوح بين ٥٤,٣٤، ٢٧,٢٧% عند قطر غربال ٢,٥، ١٢,٠ مم على الترتيب لكيزان الذرة ، وتراوح بين ٧١,٠٧، ٦٤,٩٩% عند قطر غربال ٢,٥، ٤,٠ مم على الترتيب للعجين (مخلف المخابز)، وزادت الطاقة النوعية المستهلكة بنسبة ٢٩,٦٦، ٤٥,٢٢%، ٣٥,٣١، ٤٠,٨٥%على التوالى للمنتجين الزراعيين وعند نفس الأقطار السابقة للغرابيل. فى حين إنخفضت الإنتاجية بنسب ٥٤,٩٠، ٤٩,٩٤ لكلٍ من كيزان الذرة والعجين على التوالى. لذا توصى الدراسة بأنه يجب الحذر وعدم المغالاة في استخدام سكاكين الجرش حتى لا تصل إلى الحد المفرط من إنخفاض الإنتاجية وزيادة معدلات الطاقة المستهلكة.