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DEVELOPMENT OF A SMALL SCREW EXPELLER FOR EXTRACTING OIL FROM LINSEED

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ABSTRACT

The main objective of the present study was to develop a small and simple expression machine for oil extraction from most common oilseeds by cold pressing. The machine was designed and constructed at the machine shop of Agricultural engineering research institute, (A En R I).

The effect of major parameters were investigated such as: screw type, screw revolving speeds, outlet clearances and moisture content of oilseeds and their effects on machine feeding rate, expression efficiency and energy requirements. Two versions of the screw expeller were tested: the standard and the tapered screws.

The oil expression efficiency decreased as both the screw speed and outlet clearance increased. The expression efficiency increased with the increase of the oilseed moisture content from 6.3 to 9 %. But increasing of oilseed moisture content from 9.0 to 12.0 % tended to decrease the expression efficiency. However, the tapered screw recorded the highest values for the maximum and minimum efficiencies than the standard screw.

Increasing the screw speed and oilseed moisture content, with the decrease of outlet clearance tended to increase the energy requirement. The tapered screw needed more energy than the standard screw.

Generally, the optimum operating conditions of the tapered screw gave reasonable expression efficiencies 84.26% and 63.44% at of the tapered screw that screw speed ranging from 30 to 50 rpm, 0.4 mm outlet clearance and 9.0 % oilseed moisture content.

The total costs of the machine were estimated at 3.73 and 3.79 L.E/h for standard and tapered screw respectively at the optimum conditions.

Introduction

Oil extraction is one of the main feed industries in the Arab Republic of Egypt. The removal of oil from plant materials can be achieved by extraction, expression and or combination of extraction and expression. The mechanical expression of oil from oilseeds is the most widely used method for oil extraction for small units and at small rates.

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Linseed was used in the present investigation, which was selected based on its prevalence in Egypt. Linseed oil has been used for several centuries for food, feed and in the manufacture of paints and varnishes.

Thieme (1968) and Mahatta (1977) mentioned that the simplest method was extracting oil from the pretreated row materials by pressure. The solvent extraction is not suitable for small and medium-sized oil mills.

Tindale and Hill-Haas (1976) stated that the screw presses would be used for many years to come. Sivakumaran et al., (1985) determined the operating conditions of a small expeller. They found that the minimum oil content was 7.17 %, which corresponded to on oil expression efficiency of 91.4 %. Sivakumaran and Goodrum (1987) using peanut as the material found that a reduction in internal pressure led to increase peanut feed rate and lowered the extraction efficiency.

Pathak et al., (1988) evaluated energy economics of different oilseed processing technologies. They reported that the energy requirement of the solvent extraction method was greater than the mechanical extraction one.

Khan and Hanna (1983) stated that the mechanical expression of oil seed offers the possibility of using the cake residue has relatively low initial and operational costs and produces uncontaminated oil. The oil yield using this process is dependent on particle size, moisture content, heating temperature, heating time, applied pressure and pressing time.

Sivala et al. (1991) studied the effect of moisture content on oil expression from rice bran. They indicated that the oil yield is dependent not only on moisture content but on applied pressure as well.

Abd EL-Rahim et al, (1981) and Nasen (1987) stated that the specific energy of compression was essentially independent of crop moisture content.

Theoretical consideration

The principle of the expression operation is that the material is continuously moved under increasing pressure by a screw in a horizontal cage or barrel. In the expeller operation, the seeds enter to the front part of the pressure screw and move with the helical thread of the screw, which propels the seeds through a specially shaped cage. During this forward movement, the clearance between screw and cage is gradually reduced. The screw propelled the volumetric displacements of the seeds, and as they moved, they were subjected to increasingly higher pressure, which squeezed the oil from them.

The major part of the expression machine is the screw. The important factors in the selection are length, diameter and revolving speed. The approach given by Zhijun and O'callachan (1992) to analyze the performance of the expeller may be summarized as follows:

Figure (1) shows the geometry of a tapered screw and a simple model with the following expressions:-

$$Tan\ \phi = \frac{(R_0 - R_d)}{L} \quad \ldots\ldots\ldots\ldots(1)$$

$$Tan\ \psi = \frac{(R_0 - R_d)}{L_z} \quad \ldots\ldots\ldots\ldots(2)$$

$$L_z = \frac{L}{\sin\theta} \quad \ldots\ldots\ldots\ldots(3)$$

Where:

Φ = Screw taper angle (rad.).
Ψ = Channel taper angle (rad.).
R_0, R_d = Radii at inlet and discharge ends of the screw (m).
L = Axial length of the screw(m).
L_z = Length of helical channel (m).
R,θ, Z = Polar coordinates.
θ = helix angle at mean radius with direction normal to the screw axis (rad).

It is assumed that, the oilseed flowing within the screw channel could be treated as a solid plug, the volumetric flow rate of the solid plug can be obtained by the following equation: -

$$Q_v = V_{pl} \int_{R_d}^{R_o} \left(2\pi R - \frac{e}{\sin\theta} \right) dR \quad \ldots\ldots\ldots(4)$$

Where:

Q_v = Volumetric flow rate, m^3 /s
V_{pl} = Axial velocity, m /s
e = Land width of screw (m)
$(\frac{e}{\sin\theta})$ = The part of the cross-sectional area occupied by the flights (m^2).

By taking an average angle (Θ), the integration of the above equation gives:

$$Q_v = V_{pl} \left[\pi \left(R_o^2 - R_d^2 \right) - \frac{H\rho}{\sin\theta} \right] \quad \ldots\ldots\ldots(5)$$

Where:

H = mean height of the plug, m

By using the relation:

$$Q_m = Q_v \cdot \rho$$

Where:

Q_m = Mass flow rate, kg/s

ρ = Density of materials, kg/m^3

We obtain

$$Q_m \doteq V_{pl}\,\rho \left[\pi \left(R_o^2 - R_d^2 \right) - \frac{H \rho}{\sin \theta} \right] \quad \text{..........(6)}$$

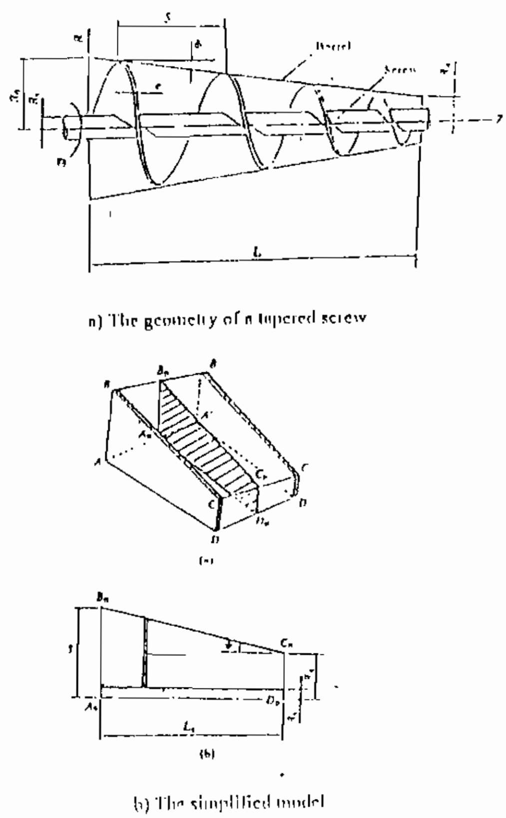


Fig., (1): The geometry of a tapered screw and the simplified model (Figure courtesy of Zhigun and O'Callaghan, 1992).

This theoretical equation shows that the maximum mass flow rate depends upon the screw size and shape. The taper of the screw has the effect of reducing the maximum flow rate.

The actual mass flow rate is dependent upon the frictional properties of the material on the barrel and on the screw, and upon the final pressure build-up.

The following empirical equation Srivastava et al., (1993) has been used for designing the screw. The choosed parameters (screw specifications and revolving speeds) gave acceptable feeding rates. Theoretical feeding rate using this equation with the maximum and minimum revolving speeds (90 and 30 rpm) were 231.71 and 77.24 kg/h respectively.

$$Q = 60 \frac{\pi}{4}\left(D^2 - d^2\right) \left(S - S_1\right) N \gamma \phi$$

Where:

D = Outlet diameter of the screw (0.1 m),
d = diameter of the shaft at the feed end (0.085 m),
S = Pitch of the screw (0.05 m),
S_1 = Thickness of the wing of the screw (0.015 m),
N = Screw rotating speed (30, 50, 70 and 90 rpm),
γ = Specific weight of the mass (625 kg/m^3),
Φ = Coefficient depending on uneven load of material or under loading taken as (0.9).

Materials and methods

- The manufactured expression machine:

The small expression machine used in this study was modified and fabricated at the workshop of Agricultural engineering research institute, (A En R I), Dokki, Giza (El-Ashry, 1999).Two different designs of screws were used in the designed expeller machine. The first one was standard screw and the second one was tapered screw with trough depth 1.5 and 1.5-1.0 cm respectively. The most important technical Specifications of the modified expression machine are shown in table (1) and figure (2).

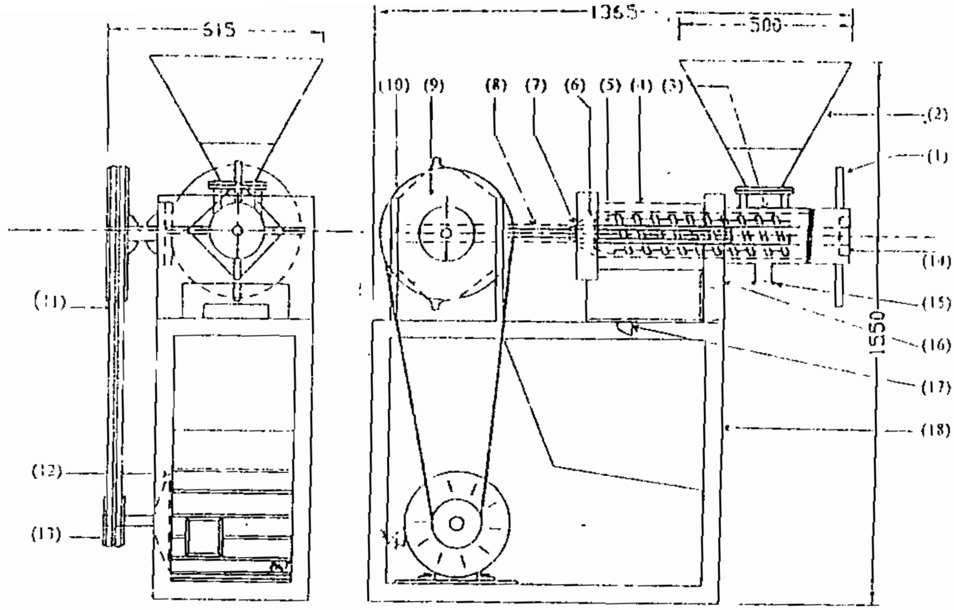
Table (1): Specifications of the modified machine.

Feature	Measurements	
Screw (worm):	**Standard**	**Tapered**
Length, cm	56	56
Diameter, cm	10	10
Pitch, cm	5	5
Trough depth, cm	1.5	1.5 - 1.0
Number of flights	10	10
Speed, r.p.m	30, 50, 70 and 90	
Electrical motor:		
Power, kW	7.5	
Volt, V	380	
Ampere, A	17.0	
Speed, rpm	970	
Reduction speed unit and power train:		
Number of teeth for pinion gear	5	
Number of teeth for spur gear	38	
Number of pulleys	4	
Diameter of pulleys, cm	8.4, 14.0, 20.0 and 38.0	

Experimental oilseeds:

Linseed (variety Giza 8) was used in this study. The flax seed is flat and oval with a pointed end the average value of its three principal dimensions and hardness are as follows: 4.91 mm Length, 2.45 mm Width, 0.98 mm Thickness and 49.6 % Porosity. This variety was obtained from Gemmaza Agricultural Research station during 1996-1997 harvesting season.

Hardness of oilseeds measured using hardness tester 174866 Kiya Seisakusho and it was 14.0 kg. Volume and seeds density were determined by the water displacement methods as described by Dutta et al., (1988) and Oje and Ugbor (1991). The desired moisture level of seed samples was adjusted by adding a certain amount of distilled water and sealing in polythene bags and stored in the refrigerator for at least 2 days to get uniform moisture in the samples. The moisture content was determined according to ASAE standard, 1994.



Dim. in mm.

Elevation **Side View**

1. Handle lever
2. Feed hopper
3. Feed end.
4. Cage
5. Press screw
6. Chuck
7. Meal discharge
8. Horizontal shaft
9. Speed reduction unit (gear box)
10. Driving pulley
11. V-Belt
12. Motor
13. Motor pulley
14. Bearing
15. Sliding plate
16. Cage breacket
17. Oil outlet
18. Frame (main frame).

Fig., (2): Elevation and side view of the modified expression machine.

Procedures and measurements:

Twenty kilograms of seeds were pressed at outlet clearance 0.8 mm to heat the press machine to its working temperature range above 80 ^{0}C. The experimental sample, three kg of seeds, were then poured into the hopper.

The effect of the following variables on the performance and efficiency of the modified machine were studied: -

1- Four levels of screw speed (30, 50, 70 and 90 rpm).
2- Three levels of outlet clearance (0.4, 0.8 and 1.2 mm).
3- Three levels of moisture content of oilseeds (6.3, 9.0, and 12.0 %).

An average of three replicates of this procedure was taken. Then the machine-feeding rate (kg/h) and energy requirements (kW.h/ton) were estimated for each test. Also the expression efficiency and cost estimated.

- Estimation of machine feeding rate:

Machine feeding rate (Mp) was calculated using the following formula:

$$\text{Machine feeding rate (Mp)} = \frac{W}{t} \quad \text{.........................kg/h}$$

Where:

W = expression oilseed weight (kg),

t = time of expression process (h).

Estamation of expression efficiency:

Oil expression efficiency is defined as the ratio of fillitered oil expressed to the total oil content in the oilseeds (Sivakumoran, 1983).

It was calculated as follows:-

$$\textbf{Expression efficiency} = \frac{W_0 - W}{W_0} \times 100 \qquad \%$$

Where:

W_0 = Oil content in the oilseeds (percent).

W = Oil content in the cake (percent).

Estimation of energy requirements:

Both Ammeter and Voltmeter were used for measuring current and potential difference respectively with an accuracy of ±1%. Then, the power was estimated using the knowledge of line current in Amperes and potential difference in Volts. The actual power of the machine (***p***) was estimated according to the following equation (Lock Wood and Dunstan, 1971): -

$$p = \sqrt{3}. \quad I. \quad V. \quad \eta. \quad \cos\theta \ \text{.......... Watt}$$

Where:

I = line current strength in Amperes.

V = Potential difference (voltage), equal to 380 V,

η = Mechanical efficiency, assumed (95 %),

Cos θ = Power factor (was taken as 85 %).

Energy requirements (kW.h/ton), was calculated by dividing the consumed power (kW) by the feeding rate (ton/h).

Total cost:

Total cost was estimated according to the assumption and procedures given by Hunt, 1983 and Bowers, 1987.

Results and Discussion

In order to evaluate the modified machine performance and its expression efficiency during actual expression tests, the factors related to energy requirements and machine-feeding rate have been taken into consideration.

Expression efficiency

The data reported in figure (3) show the effect of screw revolving speeds, outlet clearance of expeller and moisture content of oilseeds on expression efficiency.

The data revealed that at any moisture content of oilseeds, the expression efficiency of expeller decreased as the screw revolving speeds and outlet clearances increased. As an example for tapered screw at 9% moisture content of oilseeds, increasing screw revolving speed from 30 to 90 r.p.m causes a decrease in the expression efficiency from 84.26 to 79.91 % and from82.06 to 75.24 % and from 76.71 to 71.68 % a± outlet clearance of 0.4, 0.8 and 1.2 mm respectively. The average reduction in expression efficiency due to increasing screw speed was 5.7%. High revolving speed leads to small expression efficiency, because it caused a decrease in the feeding load, which led to a decrease in the friction between the expressed material and the cage.

When the outlet clearance increased from 0.4 to 1.2 mm tended to decrease expression efficiency from 84.26 to 76.71 % , from 83.91 to 75.97% from 82.65 to 74.62 % and from 79.91 to 71.68% at screw speed of 30, 50, 70 and 90 r.p.m respectively . The average reduction in expression efficiency due to increasing outlet clearance was 7.5 %. This result can be attributed to the pressed cake passed quickly with lower pressure through expeller due to the increase of outlet clearance.

Also the data indicate that for all outlet clearances and screw speeds the expression efficiency increased with the increase of the oilseed moisture content to certain limit after which it decreases. This comes in agreement with Fasina and Ajibola results (1989). As an example for all screw speeds (30,50,70, and 90 r..p.m) and outlet clearance the average increase in expression efficiency due to increased oilseed moisture content from 6.3 to 9.0 % was 1.5 % . This may be due to the increase in moisture content in the displacement of oil from the surface of oil-bearing materials by the decrease in the oil viscosity, which facilitated its flow. Increasing oilseed moisture content from 9.0 to 12.0 % the average decrease in expression efficiency was 5.3 % which may be due to swelling of the mucilage on oil cells at moisture content above 9 % which produces a cushioning effect on the seed.

The maximum efficiencies (84.26 and 79.26% for tapered and standard screw respectively) were recorded at 9% moisture content 0.4 mm outlet clearance and 30 r.p.m screw speed.

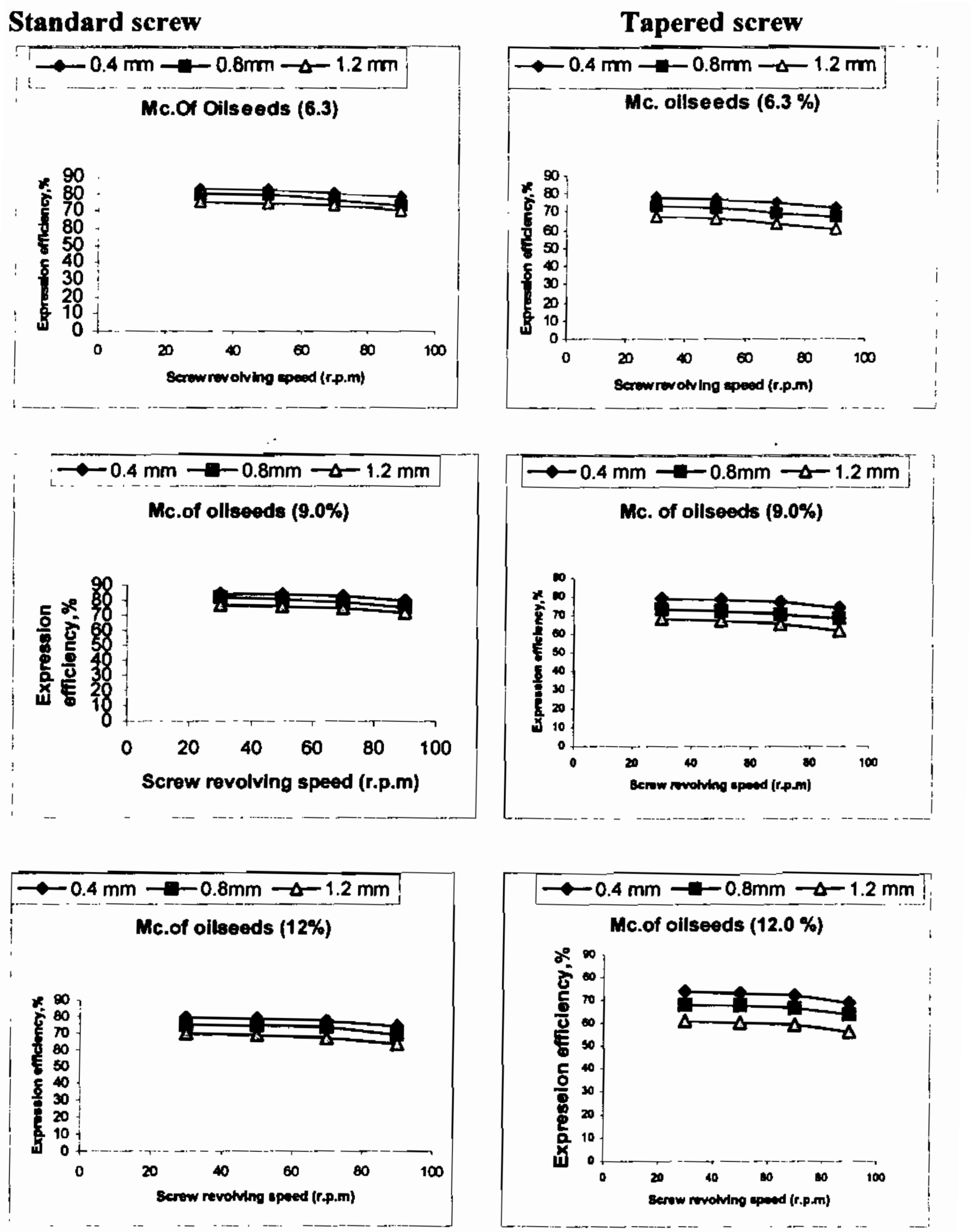


Fig., (3): Expression efficiency as affected by different screw revolving speeds and outlet clearance at different moisture contents (Mc) of oilseeds.

Expeller feeding rate

Data in figure (4) show the effect screw speeds, outlet clearance of expeller and moisture content of oilseeds on the machine-feeding rate.

The data revealed that at any moisture content of oilseed the feeding rate of expeller increased as the screw revolving speed and outlet clearance increased as an example for tapered screw at 6.3 % oilseed moisture content, increasing screw speed from 30 to 90 r.p.m caused an increase in the feeding rate from 57.57 to 72.53 kg/h , from 68.18 to 87.12 kg/h and from 73.45 to 101.47 kg/h at outlet clearance of 0.4 , 0.8 and 1.2 mm respectively

While mean, the data indicated that expeller feeding rate tends to decrease as oilseed moisture content increased from 6.3 to 12 % .

Also it is noticed that, the machine feeding rates at the minimum tested outlet clearance and screw speed (0.4 mm and 30 r.p.m respectively) and the highest oilseed moisture content (12.0 %) were 50.7 and 50.9 kg/h for tapered and standard screw respectively. The feeding rates increased twice (101.47 and 102.57 kg/h for tapered and standard screw respectively) at the maximum tested outlet clearance and screw speed (1.2 mm and 90 r.p.m respectively) and the smallest oilseed moisture content (6.3 %). Also the data indicated that standard screw recorded more feeding rate than the tapered screw in all cases and this is clear due to the high pressure caused by tapered screw.

Energy requirements

Figure (5) shows that the energy requirements as affected by different screw speeds, outlet clearances of expeller and moisture contents of oilseeds.

It is clear that energy requirements for expression operation increased as the screw speeds and oilseed moisture content increased, while it decreased greatly with increasing outlet clearances. As an example for tapered screw at 6.3% moisture content of oilseeds increasing screw speeds from 30 to 90 r.p.m cause increase in the expeller energy requirement from 67.47 to 77.22 , from 49.14 to 59.88 and from 39.57 tom 48.95 kW.h/t at outlet clearance of 0.4, 0.8 and 1.2 mm respectively.

For tapered screw at 6.3 % moisture content of oilseed increasing outlet clearance from 0.4 to 1.2 mm cause a great reduction in energy requirements as to 43.99 and from 77.22 to 48.95 kW.h/t for 30,50,70 and 90 r.p.m screw speed respectively.

The case of greatest energy requirements for all screw speeds recorded for tapered and standard screws at the large oilseed moisture content (12%) and the small outlet clearance (0.4 mm). While the case of smallest energy requirements for all screw speeds recorded for both screws at the small oilseed moisture content (6.3 %) and the large outlet clearance (1.2 mm). The average reduction in energy requirements for all screw speeds between these two cases were 55.8 and 51.6 % for standard and tapered screws respectively.

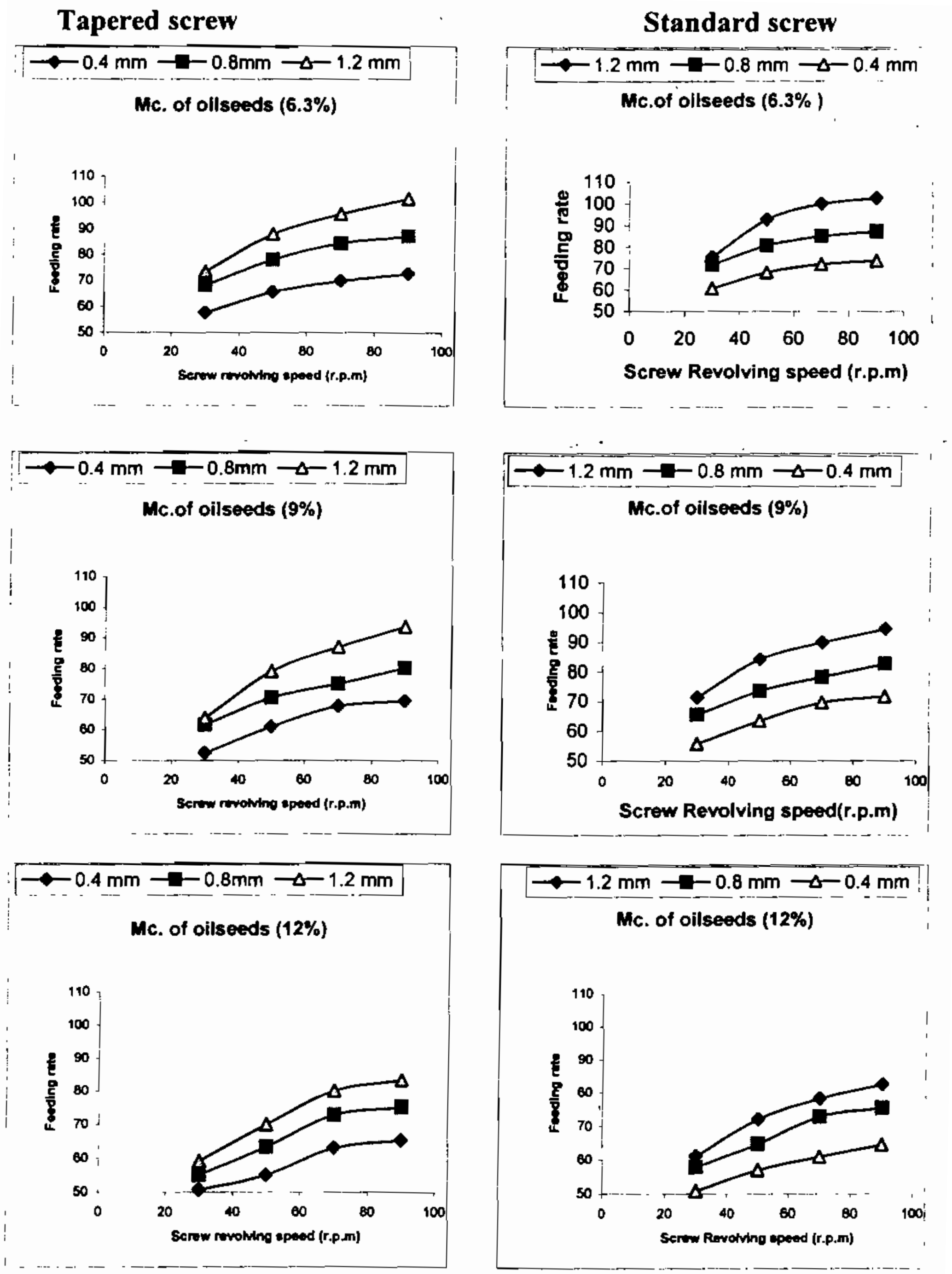


Fig. (4): Expeller feeding rate as affected by different screw revolving speeds and different outlet clearance at different moisture contents (Mc) of oilseeds.

A comparison between the case of minimum energy requirements and the case of best expression efficiency (for both of tapered and standard screws) which need about twice the energy requirement of the minimum case show that , the case of best expression efficiency has about 10% of expression efficiency more than the case of minimum energy . Results are in the favour of the case of the best expression efficiency. Science the cost of the increment of energy per ton of feeding rates not comparable at all with an increase of 10 % in expression efficiency.

The total cost estimation of the expression

The results indicated that the total operational cost per hour increased by increasing the revolving speed, increasing oilseed moisture content and by decreasing the outlet clearance. The clear result for that in the previous behaviors is the increase in energy requirement.

The operational costs for standard and tapered screw were nearly the same. The lowest costs obtained at 30 r.p.m screw speed, 1.2 mm outlet clearance and 6.3 % oilseed moisture content. They were 3.33 and 3.4 L.E/h for standard and tapered screw respectively. The highest costs obtained at 90 r.p.m screw speed, 0.4 mm outlet clearance and 12% oilseed moisture content. They were 4.03 and 4.13 L.E/h for standard and tapered screw respectively.

Comparison between tapered and standard screws

The tapered screw gave better expression efficiency than standard screw. As an example for all screw speeds average increments in expression efficiencies using tapered screw compared with standard screw were 6.89 , 11.45 and 13.81 % at o.4 , 0.8 and 1.2 mm outlet clearance respectively and 9 % oilseed moisture content . These increments in expression efficiencies are accompanied with a small reduction in expeller feeding rate as 3.75, 4.19 and 5.3 % and increases in energy requirement with 10.2, 9.6 and 19.63 % at the same previous conditions. These results can be attributed to capable it of the tapered screw generating a much higher pressure than the standard screw. This high pressure increased the expression efficiency and obviously reduces the feeding rate and increases the energy requirement.

Conclusion

The optimum operation conditions for the expeller machine using tapered or standard screw were found to be at 9 % oilseed moisture content, 0.4 mm outlet clearance and 30 r.p.m screw speed. The tapered screw was better than the standard screw. as it recorded expression efficiency 84.26% , while the standard screw recorded 79.26 expression efficiency at the optimum conditions.

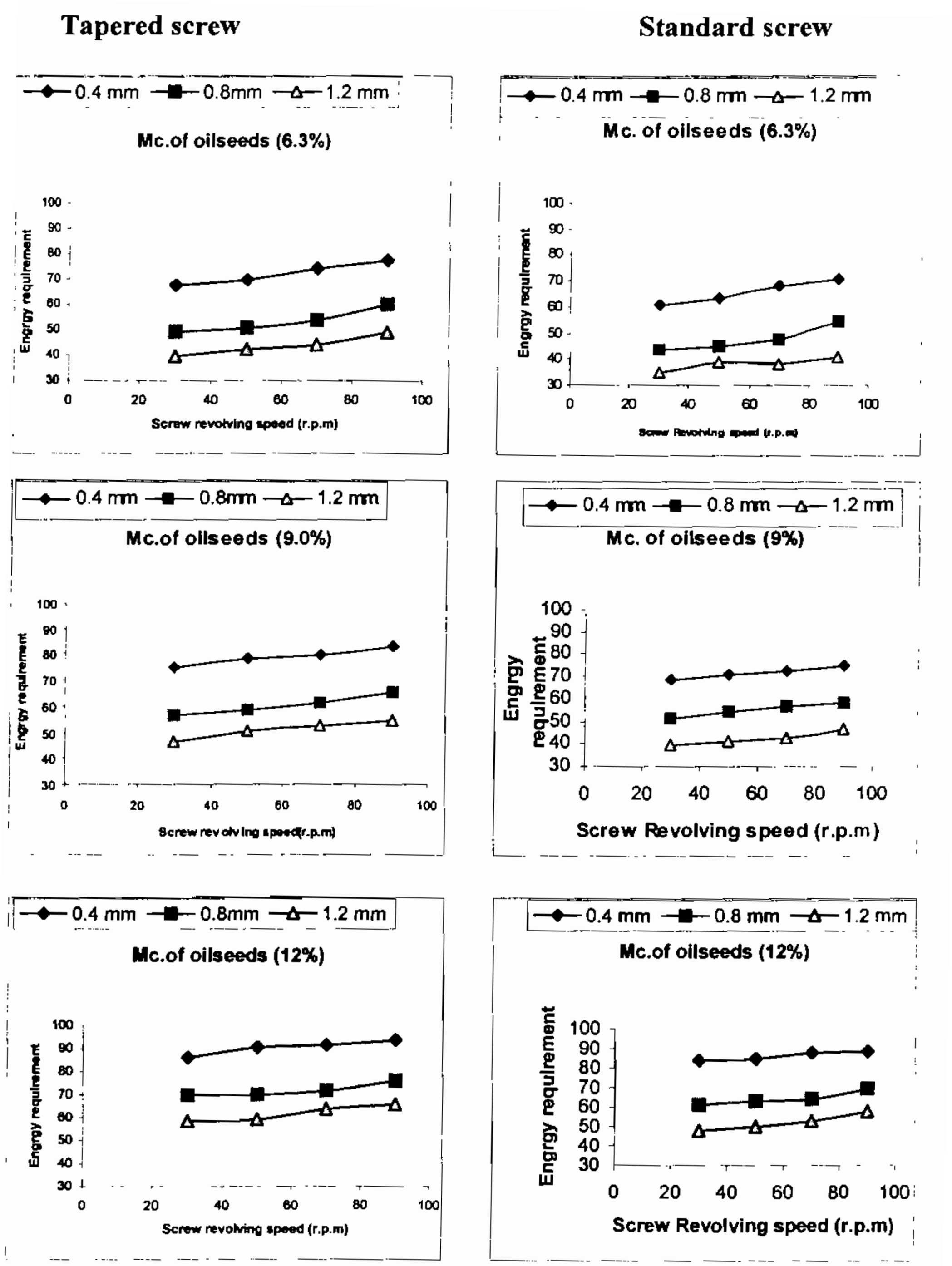


Fig. (5): Energy requirements as affected by different screw revolving speeds and different outlet clearances at different moisture contents (Mc) of oilseeds.

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الملخص العربي

تطوير ماكينة بسيطة لاستخلاص الزيت من بذور الكتان

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استخلاص الزيوت النباتية هي أحد اقدم الصناعات الغذائية في العالم و تحتل صناعة الزيوت في مصر مركزا هاما لأهمية هذه السلع بالنسبة للاحتياجات الغذائية للفرد.

ويهدف هذا البحث ألي تصميم وتنفيذ ماكينة لاستخلاص الزيت من البذور الزيتية تناسب القرية المصرية.

وقد تبين من الدراسات السابقة أن الاستخلاص بالمذيب لا يناسب معاصر الزيت الصغيرة و المتوسطة الحجم لذلك تم تطوير وتصنيع ماكينة بسيطة لاستخلاص الزيت بالضغط الميكانيكي روعي فيها أن تكون صغيرة الحجم منخفضة التكاليف.

كما تم دراسة تأثير بعض العوامل التشغيلية التي تؤثر علي كفاءة الاستخلاص واثر ذلك علي إنتاجية الآلة (طن/س) و استهلاك الطاقة (كيلو وات. س/ طن) أثناء عملية الاستخلاص واشتملت الدراسة علي أربعة مستويات لسرعة بريمة الضغط(30-50-70-90 لفة/ دقيقة) وثلاث مستويات لخلوص راس المعصرة (0.4 - 0.8 -1.2 مم) وثلاث مستويات مختلفة لرطوبة البذور (6.3- 9.0 - 12.0% على أساس جاف) واستخدمت في التجارب بريمتين أحدهما مستدقة و الأخرى قياسية أظهرت نتائج الدراسة المتحصل عليها أن العوامل المثلي لتشغيل الآلة كانت عند سرعة دورانية 30 لفة / دقيقة لبريمة الضغط ومحتوي رطوبي للبذور قدرة(9.0 % أساس جاف وخلوص فتحة الخروج قدرة 0.4مم حيث أعطت الآلة عند تشغيلها تحت هذه الظروف اعلي كفاءة عصر 79.26 % عند استخدام البريمة القياسية و أعلي كفاءه 84.26 % عند استخدام البريمة المستدقة وأظهرت النتائج بصفة عامة أن البريمة المستدقة اكثر كفاءة من البريمة القياسية.