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CONSTRUCTION AND PERFORMANCE EVALUATION OF A SCREW PRESS MACHINE TO EXTRACT JATROPHA OIL

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ABSTRACT: Utilization of biofuel produced from Jatropha oil represents one of the most promising options for the use of conventional fossil fuels. Biofuel *via* biodiesel, a promising substitute as an alternative fuel has gained significant attention due to the predicted shortness of conventional fuels and environmental concern. Experiments were carried out through two successful agricultural seasons of 2016 and 2017 at Department of Agricultural Engineering, Faculty of Agriculture Zagazig University to constract and evaluate the performance of a screw press machine suitable for Jatropha seeds. The performance of the screw press was estimated under four different machine capacity and four different seed moisture contents. The performance of the screw press was evaluated taking into consideration oil yield, extraction efficiency, specific energy and operational cost. The experimental results represented that the highest value for each of oil yield and extraction efficiency was 43 kg.hr.$^{-1}$ and 81%, respectively and also the values of specific energy and operational cost were 258 kW.hr.Mg^{-1} and 1229 LE.Mg^{-1}, respectively at moisture contents of 12% and machine capacity of 166 kg.hr.$^{-1}$

Key words: Jatropha seed, screw press, extraction, biofuel, jatropha oil, seed moisture content.

INTRODUCTION

Jatropha curcas L., a perennial plant grown in tropics and subtropics is popularly known for its potential as biofuel. The plant is reported to survive under varying environmental conditions having tolerance to stress and an ability to manage pest and diseases. Jatropha is a drought-resistant shrub or tree, which is widely distributed in wild or semi-cultivated areas in Central and South America, Africa, India, China and South East Asia. In the forthcoming years, 1-2 million hectares of *Jatropha curcas* L. are expected to be annually planted, reaching 12.8 million hectares worldwide (**Contran *et al.*, 2012**).

Jatropha can be used as cooking/lighting fuel, bio-pesticide, organic fertilizer, combustible fuel, and for soap making **(Karaj and Müller, 2009)**. The capability to grow on poor quality soils not suitable for food crop makes jatropha oil a possible solution of all the controversies related to biodiesel production. The energy crisis born from the oil problem determined a renewal of attention on the possible possibilities of production of substitute fuels for the operation of the machines and the thermal engines. The fuel's production based on vegetable oils requires a renewal attention about the research of replacement fuel for the operating of machines and thermal engines. So, for helping to solve the fuel problem by construction of a screw press machine for jatropha oil extraction.

Singh *et al.* (2008) reported that jatropha seeds have oil percentage 29% with oil recovery 85% by using mechanical expeller. Moreover, it has been found that all components of the Jatropha fruits can be utilized efficiently for energy purposes.

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Haque *et al.* (2009) studied the physical and mechanical properties of jatropha and castor seeds. Physical properties such as length, width, thickness, weight and bulk density were measured to find out the size, shape and space required by the seeds. Mechanical properties like hardness and crushing strength of the seeds were determined as well. Hardness and crushing strength of the seeds were measured by a Manual Hardness Tester. A length was 17.1 mm for jatropha and castor. Hardness were found 2.7 and 1.9 $kg_f.mm^{-2}$, while crushing strength were 38.1 and 26.6 $kg.cm^{-2}$ for jatropha and castor seeds, respectively.

Antony *et al.* (2011) compared between the physical properties for Jatropha oil and diesel fuel for obtaining the base line data for analysis. The physical properties such as density, flash point, kinematic viscosity, cloud point and pour point. The values obtained from the Jatropha oil is closely matched with the values of conventional diesel and can be used in the existing diesel engine without any modification.

Dhale and Modak (2011) mentioned that his screw press method is less capital intensive, technically less extensive, compared with the solvent extraction method and less labor-intensive than the aqueous method. It is also continuous, unlike the hydraulic and the aqueous methods that are done batch wise. These advantages of the screw press over the other methods make screw pressing popular and inevitable in future oilseed processing. To increase vegetable-oil production therefore, a good understanding of the working principles of the screw press is desirable.

Azmi *et al.* (2013) stated the physical and mechanical properties of jatropha fruits such as dimensions, sphericity, bulk density, solid density, porosity, coefficient of static friction on steel, rupture force, deformation at rupture point, deformation ratio at rupture point, hardness. The solid density value of 970 $kg.m^{-3}$ was obtained which implies that the fruit could float in water for easy cleaning and separation from foreign materials. The coefficient of static friction was 0.44 on stainless steel. The average values obtained for the detachment force and rupture force at vertical orientation were 16.62 N and 57.17 N, respectively. They also indicated that physical and mechanical properties are essential for design and development of processing machines.

Chavan *et al.* (2013) indicated that some plants can used to produced biodiesel like *jatropha curcus* and *Pongamia pinnata etc*. and more. There is a best source as a raw material oil for biodiesel production as per ASTM 6751.

Evon *et al.* (2013) evaluated the feasibility of mechanical pressing to extract oil from jatropha seeds using a twin-screw extruder. Also they found oil extraction yield increased with decreasing temperature and screw rotation speed. Highest oil extraction yield of 70.6% with lowest residual oil content was obtained under operating conditions of 153 rpm screw rotation speed and 5.16 kg/hr., inlet flow rate of jatropha seeds. The corresponding expressed oil was inexpensive to produce 71 W $hr.kg^{-1}$ seed processed or 314 W hr./kg expressed oil for specific mechanical energy compared with another continuous technique commonly used for mechanical extraction of jatropha oil. Its quality was also satisfactory for biodiesel production. The density and the kinematic viscosity of oil were 915 $kg.m^{-3}$ and 36.7 St.

El-Nono and Abdel-Gawad (2015) tested and evaluated the expelling machine at five screw speeds 25, 35, 45, 55, and 65 rpm and four levels of press head clearance 0.5, 1, 1.5, and 2 mm to determine the best machine capacity, percentage of oil recovery, percentage of residual oil and specific energy consumption. The results showed that the maximum machine capacity was 39 $kg.h^{-1}$ of raw material at 2 mm outlet clearances and 65 rpm of screw speed. The best operating pressing conditions for the wheat germ oil recovery was 45.7% at the 25 rpm of screw speed and 0.5 mm press head clearance, when the required specific energy was 0.0232 $kW.hr.Mg^{-1}$.

The present study aims to investigate the effect of feeding rate and moisture content on jatropha oil extraction using local screw press machine.

MATERIALS AND METHODS

Field experiments were carried out through two successful agricultural seasons of 2016 and 2017 at Department of Agricultural Engineering, Faculty of Agriculture Zagazig University to construct and evaluate the performance of a screw press machine suitable for jatropha oil extraction.

Manufactured Screw Press Machine

A screw press machine was designed and manufactured from low cost, local material to overcome the problems of high power and high cost requirements under the use of the imported machines. The screw press machine was manufactured specially for this work and constructed at a private workshop in Sharkia Governorate. The manufactured machine consists mainly of screw shaft, press vessel, choke plate, oil outlet and cake outlet, seed hopper, power source and transmission system is shown in Fig. 1.

Screw shaft

A screw with tapered root type was designed to provide rate of pressure increase depending on the taper angle of the shaft compared to straight screw shaft. The length of the screw was 650 mm with outside diameter of 70 mm to give clearance between screw and barrel.

The root diameter was inclined through the screw with thread depth decreases continuously along the screw shaft as shown in Fig. 2. There is a small clearance between the vessel and the screw shaft by 4mm. In such a case, friction force between the screw shaft and vessel increases, and required torque becomes higher.

Press vessel

Vessel is the cage of the screw shaft. Vessel is supposed to canalize the compressed cake, allow oil to flow back and flow out of the vessel in order to prevent any choking. So, important points while designing the vessel mainly depend on two zones which are the oil drainage holes and the grooves inside surface of the vessel.

The vessel material is selected as mild steel piping ANSI/ASME B31.3 for the ease of manufacturing. The maximum tensile stress of this material is 450 MPa. With a factor of safety of 1.5, the maximum available stress inside the vessel can be 300 MPa by thickness of 25 mm. The length, internal diameter and thickness were 480, 90 and 10 mm, respectively. Also 60×60 mm opening for mounting of hopper was machined from 60 mm distance at the beginning of the vessel. Oil drain openings of 150 mm length were drilled at the bottom mid zone of the vessel with breadth of 40 mm. A flange was welded to the end of the barrel to support the die plate.

Seed hopper

A square frustum-shaped hopper was constructed and mounted at the intake of the press vessel. It was constructed from 2 mm thick MS sheet. The height, top (inlet) opening and bottom (exit) opening to press barrel. The height of the frustum is 250 mm and it has a square top of length 200 mm. Provision for feed-rate control device and two slide rails (on which the feed rate control device moves) are provided. By this means, the quantity of seeds entering into the vessel per unit time can be regulated.

Oil drainage zone

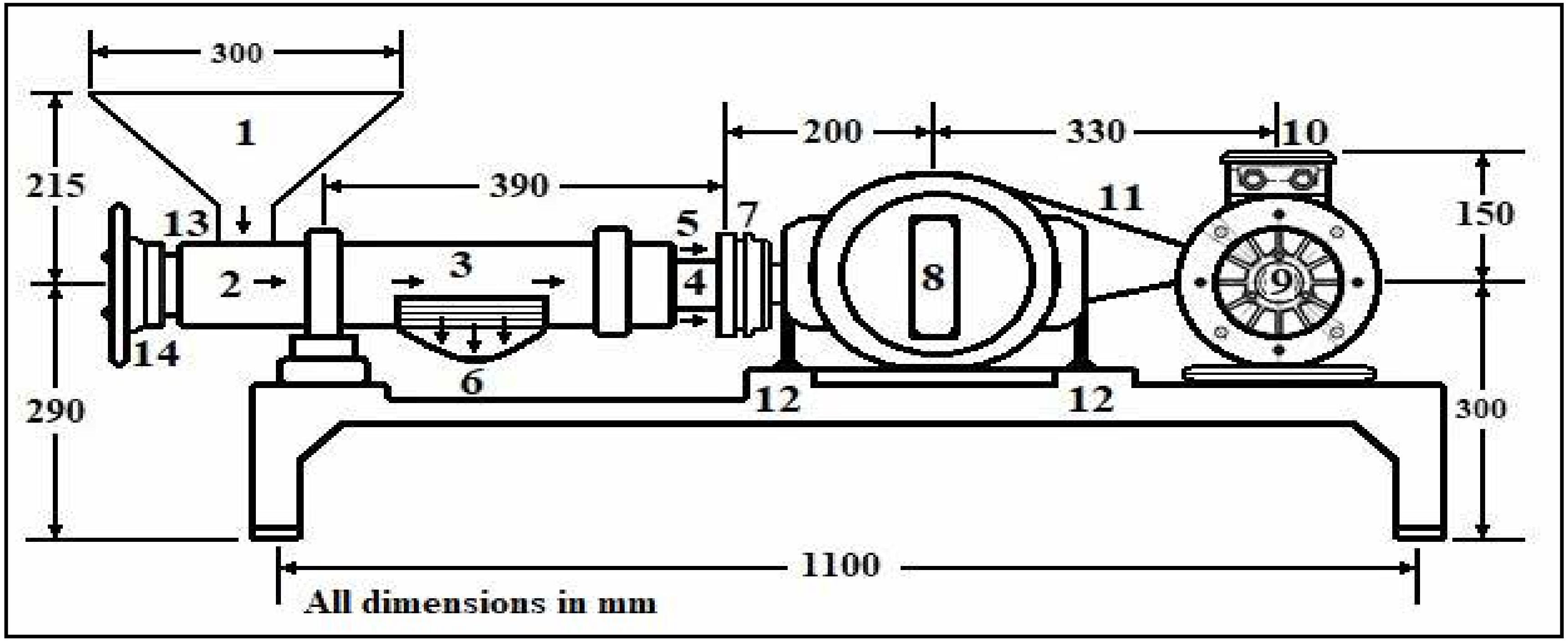
The oil channel was U-shaped, inclined at angle of 15^o to the horizontal. Oil flows from the high-pressure zone to the low-pressure zone until it finds an opening to rush out. For oil drainage, holes are machined onto the vessel. Oil drain openings had an extent of 2.5 mm with a length of 150 mm. These openings should be far enough from the cake drainage zone at where the pressure is maximum, otherwise the holes can be choked with high pressurized cake. Therefore, oil drainage holes should be placed where the seeds are not compressed yet.

Cake outlet

The cake outlet was located at the end of the press vessel. A circular channel with open ends was used for cake outlet and it was made from mild steel of 25 mm thickness and length of 50 mm. The cake outlet channel extended from the choke plate.

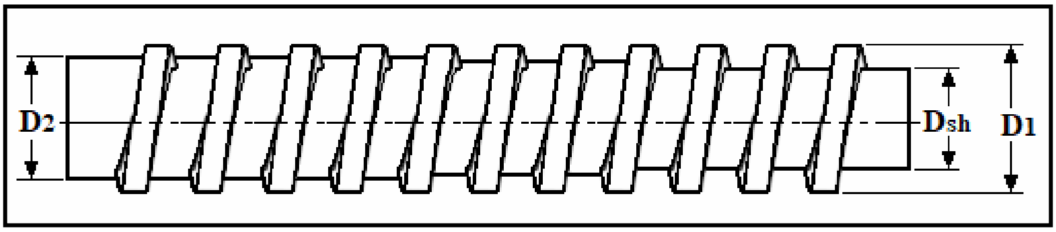
Power Source and Transmission System

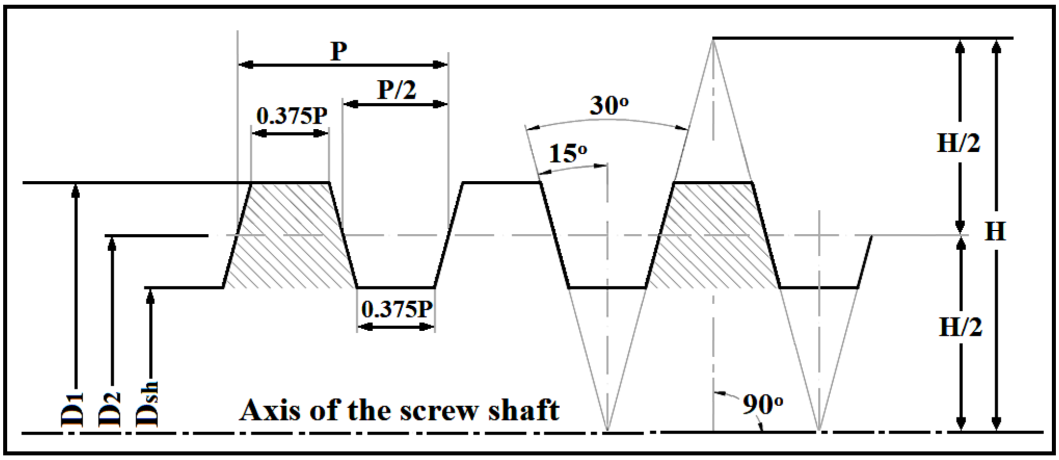
The press screw machine was powered by an electric motor 11.03 kW (15.00 hp) at a rated speed of 90 rpm. Two pulleys diameter 150 mm and 300 mm were fixed on screw shaft and the prime mover and was connected through V-belt. The power is transmitted from the power source to the other moving parts by means of pulleys and V-belt with different speed ratios because it can easily be installed and removed.



No.	Part Name	No.	Part Name
1	Seed hopper	8	Differential system
2	Feeding zone	9	Power source
3	Press vessel	10	Electrical panel
4	Screw shaft	11	Transmission system
5	Choke plate and cake outlet	12	Main frame
6	Oil drain openings	13	Feed rate controller
7	Coupling joint	14	Pressure controller

Fig. 1. Elevation view of the screw press machine





Symbol	Basic dimensions of screw press
D1	Outside diameter of screw shaft = 70 mm
D2	Diameter of screw shaft at exit = 60 mm
Dsh	Diameter of screw shaft at intake = 40 mm
P	Thread Pitch = 20 mm
H	Height of fundamental triangle = 40 mm

Fig. 2. Screw press with trapezoidal thread type and basic dimensions of screw press shaft

Design of Screw Press Machine

The screw threads

The worm shaft is primarily a sharpened screw conveyor with the volumetric displacement being decreased from the feed limit of the press barrel to the discharge limit. The screw treading system was design as a step shaft and decreasing screw depth using the following equation (Khurmi and Gupta, 2005).

$$d_d = d_f - (n - 1) \quad (1)$$

Where:

d_d = screw depth at the discharge end.

d_f = screw depth at the feed side = 15 mm.

n = number of screw turns = 11.

Accordingly, the screw depth would be decreased consistently from 15 to 5 mm of the feed end up to the discharge end of the screw press.

Screw shaft

The screw shaft is the major component of the screw press machine and is acted upon by materials treatment and screw thread. During the extraction process, the shaft squeezes and conveys the seeds for jatropha oil extraction under level of high pressure. Therefore, a mild steel bar grade-A694 F60 was used for designing the screw shaft with yield strength, ultimate tensile strength and elongation percentage as 414 $N.mm^{-2}$, 517 $N.mm^{-2}$ and 20%, respectively. To safeguard against tensional stresses and bending, the diameter of the worm shaft was determined from the following equation **(Khurmi and Gupta, 2005; Ojolo *et al*., 2012)**.

$$D_{sh} = \frac{16\,Ft}{0.27\pi.\delta o} \quad (2)$$

Where:

D_{sh} = diameter of the screw shaft = 37.38 mm.

The force transmitted by the shaft per length unit, Ft = 820 $N.mm^{-1}$ and δo = the yield stress for mild steel = 414 $N.mm^{-2}$. The standard of A694 is more rigorous than the more common grades, providing more robust specifications for high-pressure fluid transmission in oil and gas piping systems. The total length of the shaft is 650 mm with a diameter 40 mm based on physical requirement. The screw winding covered a length of 480 mm, leaving a distance of 150 mm and 270 mm for seed intake and pressed cake outlet side, respectively. These dimensions facilitate mounting of bearings and pulleys.

The produced pressure

The pressing area and the pressure produced by the screw thread were determined by the following equations:

$$A_P = \pi D_m nh \text{ and } P_r = \frac{W_e}{A_P} \quad (3)$$

Where:

P_r and A_p = pressure produced and pressing area by the screw thread.

h = screw depth maximum pressure at discharge end.

By compensate for a value, D_m = 40 mm, n = 10, hr. = 5 mm and W_e = 10.482 kN.

Hence, A_p = 6280 mm^2 and P_r = 1.67 MPa. In other words, a pressure of 1.67MPa would be available for squeezing jatropha oil from the cake during operation.

The pressure that can be also withstood by the vessel was determined by the equation presented by **(Khurmi and Gupta, 2005)** as:

$$P_V = \frac{2t\,\delta a}{D_i} \quad (4)$$

Where:

P_V = pressure to be withstood by the vessel.

t and D_i = thickness and the internal diameter of the vessel.

δa = allowed stress (0.**27** δo) and δo = the yield stress of mild steel.

Hence, δa = 111.78 MPa and P_b = 24.84 MPa. Which means that the pressure that the vessel can withstand equal to 24.84 MPa is greater than the pressure produced by the worm screw which reaches 1.67 MPa for jatropha oil extraction. Therefore, the vessel will be withstanding the extraction pressure without an explosion.

The power required of the electric motor

The power required of the electric motor to drive the press screw was determined using the equation below as:

$$P_m = \frac{P_S}{\eta_m \times \eta_t} \quad (5)$$

The power required to drive the press screw was estimated by using the following equation:

Where:

P_m = power of the electric motor.

P_S = power required to drive the screw press.

η_m = mechanical efficiency.

η_t = transmission efficiency.

$$P_S = 4.5\, Q_V . L_S . \rho . g \quad (6)$$

Where:

Q_V = volumetric capacity of the worm shaft and Ls is length of worm shaft. Substituting by Q_V = 0.419 $m^3.hr.^{-1}$ and L_S = 650 mm.

Accordingly, P_S = 5.71 kW, Pm = 9.52 kW (12.94 hp). Therefore, the electric motor for the oil extraction machine selected based on the load specifications of the machine is a three-phase 50Hz motor for industrial purpose. An electric motor with a power rating of (15hp) was selected to drive the press screw. For selecting the motor, it was assumed that the electric motor operates continuously at full load.

Experimental Parameters

The performance of the evaluated machine was experimentally measured under the following parameters:

- Four different seed moisture contents (8, 12, 17, and 22%) of jatropha seeds.
- Four different machine capacities (101, 125, 148, and 166 kg/hr.).

Measurements and Determinations

Evaluation of the performance of extracting machine was based on the following indicators:

Machine capacity

Machine capacity was determined by the following equation:

$$Mc = \frac{Ms}{t} \quad (7)$$

Where:

Mc = machine capacity, kg.hr.$^{-1}$.

Ms = Weight of input sample, kg

t = time required to empty the hopper, hr.

Oil yield

Oil yield of screw shaft can be estimated using the following equation:

$$Oy = \frac{Wo}{tc} \quad (8)$$

Where:

Oy = crude oil yield, kg.hr.$^{-1}$.

Wo = weight of crude oil extracted, kg.

tc = time consumed to extract the seed sample, hr.

Extraction efficiency

Extraction efficiency was determined using the following equation:

$$\eta_e = \frac{Woc}{Oc} \quad (9)$$

Where:

η_e = Extraction efficiency, (%).

W_{oc} = Weight of oil collected, kg.

O_c = Weight of oil content in test sample, kg.

Flow rate of the cake

The mass flow rate of the cake can be determined by using the following equation:

$$Q_c = \frac{Qs}{tc} \quad (10)$$

Where:

Qc = flow rate of the cake, kg.hr.$^{-1}$.

Qs = weight of cake from compressed seed, kg.

Energy requirements

The energy requirements for the extraction process can be calculated as follows:

$$E = \frac{Pm}{Oy} \quad (11)$$

Where:

E = specific energy, kW.hr.Mg^{-1}

Operational cost

The operational cost required for the extraction process was estimated using the following equation:

$$Oc = \frac{Mc}{Oy} \quad (12)$$

Where:

Oc = Operational cost, LE.Mg^{-1}.

Mc = Machine cost, LE.hr.$^{-1}$.

Oy = Oil yield, Mg.hr.$^{-1}$.

The machine cost was determined considering conventional method of estimating both fixed and variable costs **(Kepner *et al.*, 1982; Hunt, 1983)** according to price level of 2018.

RESULTS AND DISCUSSION

The obtained results will be discussed under the following items:

Influence of Machine Capacity on the Oil Content and Oil Extraction Efficiency at Different Moisture Contents

The results showed that the oil content and oil extraction efficiency inversely with machine capacity is shown in Fig. 3. It is clear that the oil content and oil extraction efficiency was increased by increasing machine capacity up to 148 kg.hr.$^{-1}$, any further increase in machine capacity up to 166 kg.hr.$^{-1}$ for the same seed decreased oil content and oil extraction efficiency. Obtained results showed that increasing

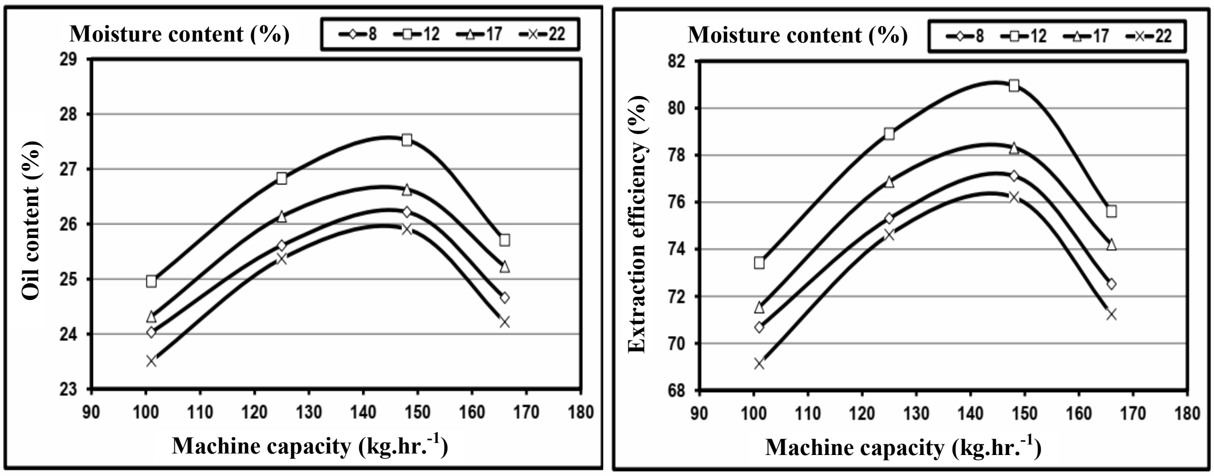


Fig. 3. Effect of machine capacity on oil content and extraction efficiency

machine capacity from 101 to 148 kg.hr.$^{-1}$ measured at different moisture content of about 8, 12, 17 and 22% increased the oil content from 24.03 to 26.22, from 24.96 to 27.53, from 24.32 to 25.23 and from 23.51 to 25.91%, also increased oil extraction efficiency from 70.68 to 77.12, from 73.42 to 80.96, from 71.54 to 78.32 and from 69.14 to 76.21%, respectively. Any further increase in machine capacity more than 148 up to 166 kg.h^{-1} measured at the same previous moisture content decreased the oil content from 26.22 to 24.66, from 27.53 to 25.71, from 26.63 to 25.23 and from 25.91 to 24.22%, also decreased oil extraction efficiency from 77.12 to 72.52, from 80.96 to 75.61, from 78.32 to 74.21, and from 76.21 to 71.24%, respectively.

Influence of Machine Capacity on the Oil Yield and Cake Recovery at Different Moisture Content

The results cleared that oil yield and cake recovery was increased by increasing machine capacity from 101 to166 kg.hr.$^{-1}$ for jatropha seed as shown in Fig. 4. The results showed that increasing machine capacity from 101 to 166 kg.hr.$^{-1}$ measured at different moisture content of about 8, 12, 17 and 22% increased oil yield from 24.27 to 40.93, from 25.21 to 42.68, from 24.57 to 41.88 and from 23.74 to 40.20 kg.hr.$^{-1}$, also increased cake recovery from 76.73to 125.07, from 75.79 to 123.32, from 76.43 to 124.12 and from 77.26 to 125.80 kg.hr.$^{-1}$, respectively.

Influence of Machine Capacity on the Specific Energy and Operational Cost at Different Moisture Content

The results showed that specific energy inversely with machine capacity. It is clear that specific energy was decreased by increasing machine capacity. Obtained results showed that increasing machine capacity from 101 to 166 kg.hr.$^{-1}$ measured at different moisture content of about 8, 12, 17 and 22% decreased specific energy from 454.47 to 269.48, from 437.52 to 258.43, from 448.92 to 263.37 and from 464.62 to 274.38 kW.hr.Mg^{-1}, respectively as shown in Fig. 5. The results showed that operational cost inversely affected with machine capacity. Regarding operational cost it was decreased by increasing machine capacity. The results showed that increasing machine capacity from 101 to 166 kg.hr.$^{-1}$ measured at different moisture content of about 8, 12, 17 and 22% decreased operational cost from 2162 to 1282, from 2081 to 1229, from 2135 to1253 and from 2210 to 1305 LE.Mg^{-1}.

Conclusion

The performance of the screw press was evaluated taking into consideration oil yield, extraction efficiency, specific energy and operational cost. The experimental results represented that the highest value for each of oil yield and extraction efficiency was 41 kg.hr.$^{-1}$ and 81%, respectively and also the value of specific energy and operational cost were 258 kW.h.Mg^{-1} and 1229 LE.Mg^{-1}, respectively at moisture contents of 12% and machine capacity of 145 kg.hr.$^{-1}$.

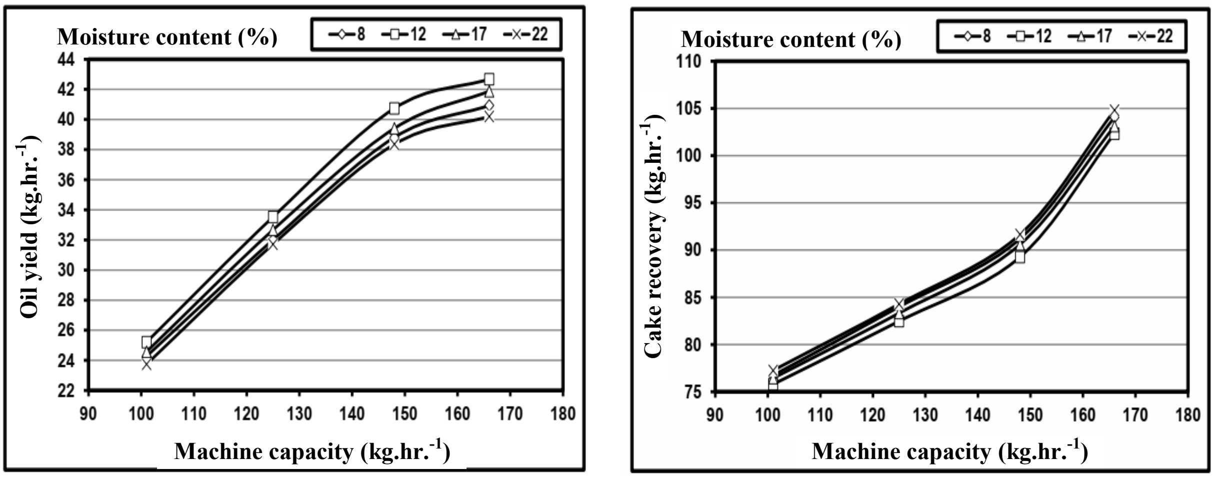


Fig. 4. Effect of machine capacity on the oil yield and cake recovery

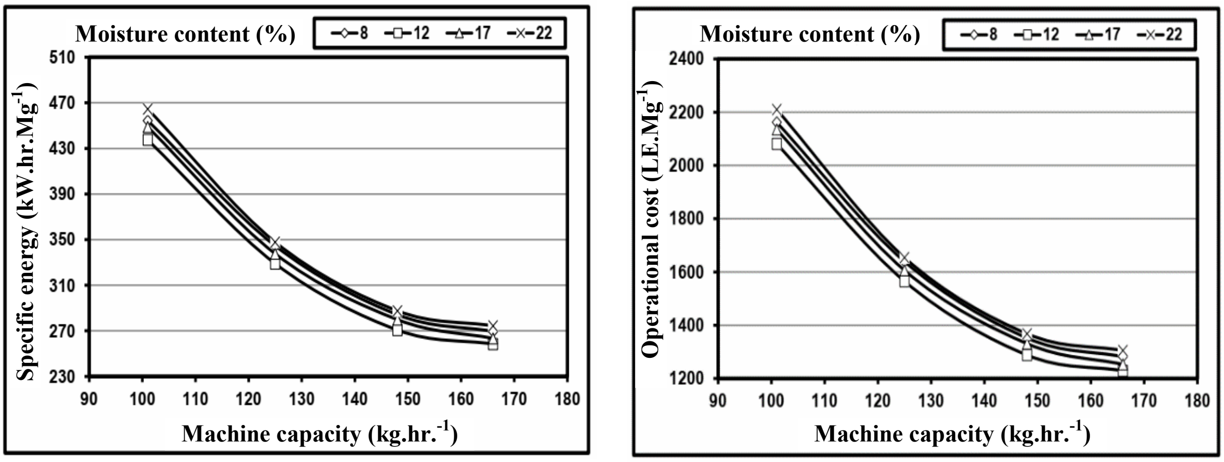


Fig. 5. Effect of machine capacity on specific energy and operational cost

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تصنيع وتقييم أداء آلة الضغط البريمية لاستخراج زيت الجاتروفا

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في إطار أزمة الطاقة المنتشرة عالمياً وتضاؤل احتياطات الوقود الحفرى ومخاوف الانبعاثات الضارة بالبيئة اتجهت الدراسات إلى البحث عن مصادر أكثر استدامة ونظافة وأمناً على البيئة، وكان من أبرز الدراسات هي استخدام الزيوت النباتية كزيت الجاتروفا الذى يمكن إنتاج الزيت الحيوي "البيوديزل" منه واستخدامه كوقود نظراً لفوائده المتعددة كونها محصول غير غذائي وتزرع في الأراضي شبه القاحلة وتروى بمياه الصرف الصحي المعالج، ويتميز بإنتاج جيد للزيت الحيوي، تم إجراء التجارب خلال موسمين زراعيين (٢٠١٦-٢٠١٧) فى قسم الهندسة الزراعية- كلية الزراعة- جامعة الزقازيق حيث تم تصنيع وتقييم أداء وحدة الضغط البريمية لتناسب بذور الجاتروفا وتهدف الدراسة إلى تصميم وتصنيع آلة الضغط البريمية لاستخلاص زيت الجاتروفا والوصول إلى أفضل معاملات تشغيل لكل من سعة الآلة والمحتوى الرطوبى للبذور كما تم تقييم أداء الآلة من الناحية الاقتصادية، وتمت عملية التصنيع بإحدى الورش الخاصة بمدينة الزقازيق- محافظة الشرقية، ولقد تناولت الدراسة وضع المعايير التصميمية لآلة الاستخلاص لتحقيق أعلى معدل أداء بأقل تكاليف وطاقة مستهلكة اثناء عملية الاستخلاص من خلال تصميم بريمة الضغط على هيئة عمود لولبي (حلزونى) ذو مقطع مستطيل الشكل لضمان التأثير الفعال أثناء عملية الاستخلاص، وشملت معايير التصميم كل من: قطر عمود البريمة وعمق التسنين وضغط استخلاص الزيت وتقدير القدرة المستهلكة لاختيار قدرة المحرك الكهربائي المناسبة للآلة موضع التصميم، تم أخذ أربع معدلات من سعة التلقيم هي: ١٠١- ١٢٥- ١٤٨ و ١٦٦ كجم في الساعة عند أربع مستويات للمحتوى الرطوبي لبذور الجاتروفا وهي: ٨ - ١٢ - ١٧ و ٢٢% وذلك بأخذ القياسات التالية: نسبة الاستخلاص، كفاءة الاستخلاص، إنتاج الزيت ونواتج الاستخلاص، الطاقة المستهلكة وتكاليف التشغيل، كما دلت النتائج أن أعلى نسبة استخلاص بقيمة ٢٨% وكفاءة استخلاص بلغت ٨١% مع تحقيق إنتاجية للزيت المستخلص بقيمة ٤٣ كيلوجرام فى الساعة، أدنى طاقة مستهلكة بقيمة ٢٥٨ كيلووات/ساعة لكل ميجاجرام بتكلفة قدرها ١٢٢٩ جنية لكل ميجاجرام عند تشغيل الآلة بسعة ١٦٦ كجم فى الساعة ومحتوى رطوبي ١٢% أثناء عملية استخلاص زيت بذور الجاتروفا.

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