Performance evaluation of screw-press oil expeller using a continuous spiral and decreasing length of pitch of screw

Dilip Jain[1*] and Siddhant Jain[2]

(1. *Central Institute of Post-Harvest Engineering and Technology, PAU Campus, Ludhiana, 141004, INDIA;*
2. *Departments of Chemical Engineering, Indian Institute of Technology, HausKhas, New Delhi, INDIA*)

Abstract: Mechanical designing of screw-press for obtaining optimum flow and pressure will be very costly affair. The flow velocity and pressure was predicted using an analytical solution of an isothermal Newtonian flow in finite screw channel. An innovative design of continuous spiral screw was developed for screw-press oil expeller. The flow velocities in the down channel range from 125 to 175 mm/s through the length of screw from 150 to 500 mm for the screw drive of 48 rpm. The maximum pressure was built at the end of screw in the range of 9 - 10.57 x 105 Pa. The theoretical pressure was close to the pressure measured during experiments for mustard and sunflower oilseed expelling. The lower screw speed resulted low heat generation and higher oil recovery.

Keywords: Oil expeller, screw design; flow profile; pressure profile.

Citation: Jain, D., and S. Jain. 2015. Performance evaluation of screw-press oil expeller using a continuous spiral and decreasing length of pitch of screw. AgricEngInt: CIGR Journal, 17(1): 213-222.

1 Introduction

Oil expression from oilseed is primarily expelled in mechanical press. The conventional theory of mechanical oil expression incorporate the rupturing of oilseed cells through thermal pre-treatment, crushing and pressing (Mrema and McNulty, 1985; Harmanto et al., 2009). Screw presses have effectively used in past many decades as mechanical press to expelled oil from oilseeds. These were developed by approximation approach. Virtually, many previous studies at simulation of press operation (Vadke et al.,1988; Shirato et al.,1978; Shirato et al., 1971) required prior knowledge of press characteristics such as the operating pressure, and since such parameters are usually unknown at the design stage, such works were of limited use to engineers working on screw press designs (Oyinlola, et al., 2004). Mechanical behaviour of oilseed was studied with uniaxial loading under hydraulic press for determination of oil expression (Herak et al., 2013; Owolarafe et al., 2008; Bargale, et al., 2000; Mrema and McNulty, 1985). Wang *et al.*, (2004) had developed the model to describe the fluid flow, heat transfer and melting of biomaterial in a single-screw extruder. The model was used to analyse the profile of pressure and production bulk temperature along the down channel of screw and die during extrusion.

Omobuwajo*et al.*, (1998) had developed a mathematical model to study the theory of screw press mechanism for oil expression for prediction of extrusion pressure and oil flow. These investigations suggested that theory has to be further explored for better understanding the screw press mechanism.A theoretical analysis is further required for prediction of expelling pressure and oil flow rate in a screw press of known specifications in order to facilitate a fully theoretical analysis and simulation of screw press operation. The aim of this

Received date: 2014-8-8; **Accepted date:**2014-11-28.
***Corresponding author:Dilip Jain,** Central Arid Zone Research Institute, Shastri Nagar, Jodhpur-321003, India. Tel.: +919468853615. E-mail: jaindilip25@rediffmail.com, jaindilip25@gmail.com (Dilip Jain)

presentation is to study theoretically and experimentally the oil extraction parameters such as velocity of flow, pressure in screw channel and oil flow during oil expelling with a given screw configuration. This type of information will be useful in optimization and control of expeller operation.

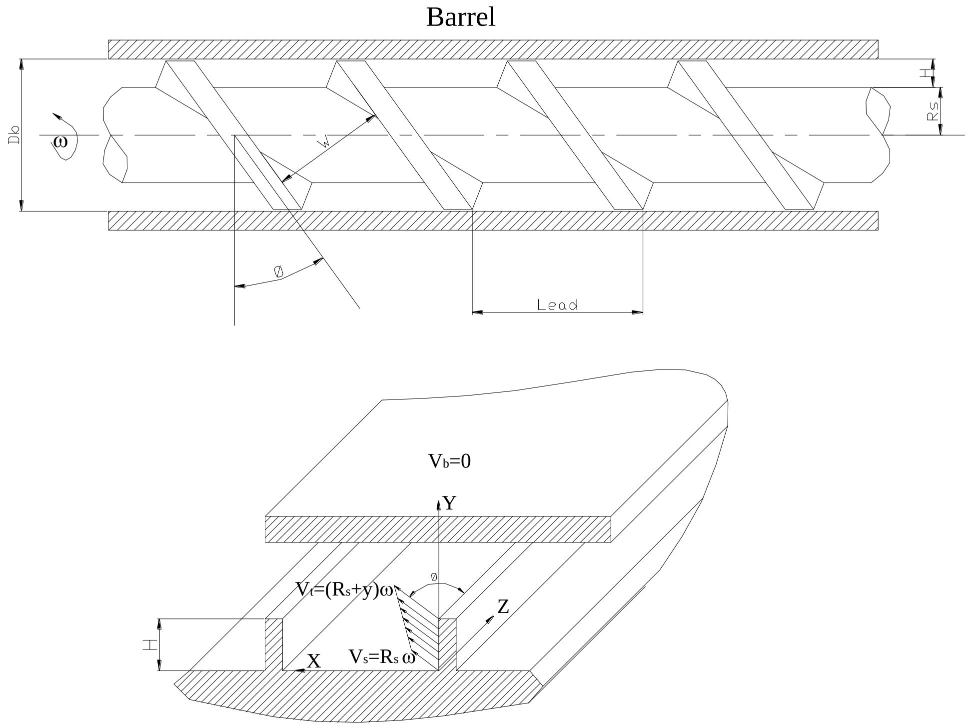
2 Materials and methods

2.1 Theoretical consideration of screw press mechanism

2.1.1 Down channel velocity

Development of the mathematical model based on the transport phenomena is much relevant and concern for precision design and efficient oil extraction. The flow theory of a screw press is fundamental to understand the screw press technology.

It is the pertinent to understand the screw press mechanism to express the mathematics of the flow theory. Therefore, the formulation mathematical form of screw-press flow theory, analytical solution and three dimensional down channel velocity distributions for the screw press oil expeller based on the theory given by Li and Hsieh (1996) is much of relevance. Considering the screw curvature is assumed to be small so that the barrel surface and screw channels can be unwrapped and become flat plates (Figure 1).



Real and unwrapped geometry of screw and barrel system

Figure 1 Schematic of screw mechanism and channel with unwrapped screw and barrel system

The final solution for down channel velocity $v_z(x,y)$ was given in following Equation1.

Where; $v_z(x,y)$ is the down channel velocity, m/s; R_s is screw root radius, m; ω is rotational speed of screw, s^{-1}; ϕ_b is helix angle of screwR_b, rad; R_b is internal barrel radius, m; H is Maximum channel depth, m; μ is viscosity of the Newtonian fluid, Pa.s; P is pressure, Pa; x is channel width coordinate, m; y is channel depth coordinate, m; z is down channel coordinate, m; a&b are factors defined; W is width of the channel at the internal radius of barrel, m; H is maximum channel depth, m.

$$v_z(x,y) = R_s\omega\cos\phi_b f_{v1} + (2R_b - H)\omega\cos\phi_b f_{v2} + \frac{1}{\mu}\frac{\partial P}{\partial z}.(aW^2 f_{V3} + bH^2 f_{V4}) \quad (1)$$

and

$$f_{v1} = \frac{4}{\pi}\sum_{i=1,3,5..}^{\infty} \frac{\sin\frac{i\pi x}{W}}{i} \frac{\sinh\frac{i\pi(H-y)}{W}}{\sinh\frac{i\pi H}{W}}$$

$$f_{v2} = \frac{2}{\pi}\sum_{i=1,3,5..}^{\infty} \frac{\sin\frac{i\pi y}{H}}{i} \frac{\sinh\frac{i\pi(W\text{-}x)}{H}+\sinh\frac{i\pi x}{W}}{\sinh\frac{i\pi W}{H}}$$

$$f_{v3} = \frac{4}{\pi^3}\sum_{i=1,3,5..}^{\infty} \frac{\sin\frac{i\pi x}{H}}{i^3}\left[\frac{\sinh\frac{i\pi(H\text{-}y)}{W}+\sinh\frac{i\pi y}{W}}{\sinh\frac{i\pi H}{W}}\text{-}1\right]$$

$$f_{v4} = \frac{4}{\pi^3}\sum_{i=1,3,5..}^{\infty} \frac{\sin\frac{i\pi y}{H}}{i^3}\left[\frac{\sinh\frac{i\pi(W\text{-}x)}{H}+\sinh\frac{i\pi x}{H}}{\sinh\frac{i\pi W}{H}}\text{-}1\right]$$

There constants a and$b$ in Equation 1 are dependent on the H/W ratio. When the H/W ratio is small, a=0 and b=1; when the H/W ratio is large, a=1 and b=0.

2.1.2 Pressure characteristics

Considering the flow between two planes (screw channel) the velocity is simplified to (Chorlton, 2004) as given in Equation 2.

$$v_z(x,y) = \frac{P}{2\mu} z(Z-z) - V_{\max}\left(1-\frac{z}{Z}\right) \quad (2)$$

Where; Z is down channel length, m; $V_{\max}$ is maximum velocity, m/s.

Thus, the pressure in the between planes can be written as Equation3;

$$P_z(x,y) = \frac{2\mu}{z(Z-z)}\left(v_z(x,y)+V_{\max}\left(1-\frac{z}{Z}\right)\right) \quad (3)$$

2.1.3 Theory of oil flow rate

In modeling the oil flow, the oil is assumed to flow through the porous oilseed cake out of the press in the radial direction. Thus Darcy's law for fluid flow through porous media would apply (Bear, 1972). From Darcy's law for fluid through porous media in a rectangular channel may be given as Equation4.

$$q_v = \frac{-k}{\rho g}\frac{\partial P}{\partial \mathrm{y}} \quad (4)$$

Where; q_v is volumetric flow rate of flow in porous media, m^3/s; k is coefficient of permeability, m/s; ρ density, kg/m; g is acceleration due to gravity, m/s^2; $\partial P/\partial y$ is pressure gradient in the channel depth direction, thus mass flux in channel may be given by Equation 5 as

$$q_m = \frac{-k}{g}\frac{\partial P}{\partial \mathrm{y}} \quad (5)$$

Where; q_m is mass flux flow in channel, $(kg/m^2)/s$

Integrating the mass flux, q_m over the channel down flow surface area across which the flow occurs, the mass flow rate of the oil out of the press is given as Equation6.

$$Q_m = \int q_m \partial A_c \quad (6)$$

Where; $A_c = y.x$, is area coordinate, m^2

Since the mass flux is a point property, which varies along z, Equation 6 may be expressed as Equation7.

$$Q_m = y.x.\int_o^z q_m \partial z \quad (7)$$

Where; Q_m is mass flow rate of oil, kg/s

Permeability is a parameter that depends on temperature of the fluid, pressure applied and porosity of the media. Owolarafe et al. (2007) developed a model for permeability which is adopted as follows in Equation8.

$$k = 9.15 \times 10^{-6} T_c + 1.20 \times 10^{-6}\varepsilon + 3.73 \times 10^{-8} P - 3.74 \times 10^{-4} \quad (8)$$

Where; T_c is cake temperature, ^oC; ε is porosity of cake, %;

The porosity and pressure relationship for oilseed are defined in Equation9 as

$P = 8.633 - 0.5703\,\varepsilon$ (or $\varepsilon = 15.1376 - 1.7534\,P$) (9)

2.1.4Heattransfer model of screw press

The experimental and theoretical studies are required on heat transfer between the processing equipment (the pressing chamber) and the oil and oilcake streams during the processing of oilseeds in an expeller. This type of information will contribute to the understanding of the thermal aspects of the operation of the screw press in particular, and presses in general, and this understanding should be useful in the design of better presses. The rate of heat generation at steady state was determined from energy balance by the following Equation10.

$$m_s c_s (T_s - T_r) + q = m_c c_c (T_c - T_r) + m_o c_o (T_o - T_r) \quad (10)$$

where, q is rate of heat generation, kJ/s;m_c, m_o&m_s are mass flow rates of cake, oil and oilcake , kg/s respectively; c_c, c_o&c_s, specific heat capacities of cake, oil and oilseed, (J/kg^1)/K respectively; T_c, T_o, T_s&T_r are temperatures of cake, oil, oilseed and reference, ^{o}K respectively. The reference temperature T_r was taken to be 30^{o}C. The heat loss to the surrounding has been taken to be negligible.

2.2Experimental set-up

2.2.1 Designing the continues spiral screw set

edges are not aligned to keep the continuity of channel. This results in blocking the cake material in channel pathway. To overcome this problem, fibrous material is added with oilseeds to maintain the continuous flow in channel. However, these types of designs of screw configuration are innocently made at the ease of manufacturers and have no base of scientific theory of pressure and oil expression. To validate the theory out line in section 2 for screw extruder for velocity and pressure profile and oil flow rate, a set of continuous screw spiral of variable size of pitch was got fabricated from the manufacturer, (Simplex screw expeller, Ludhiana, India). This screw assembly (Figure 2) was having total length as 500 mm. The flight edges of two pitches of screw sleeves were aligned to keep the continuity of channel. Thus unfolding the screw spiral the screw channel looks like as tapered path as shown in Figure 3. Therefore, the screw channel width was not

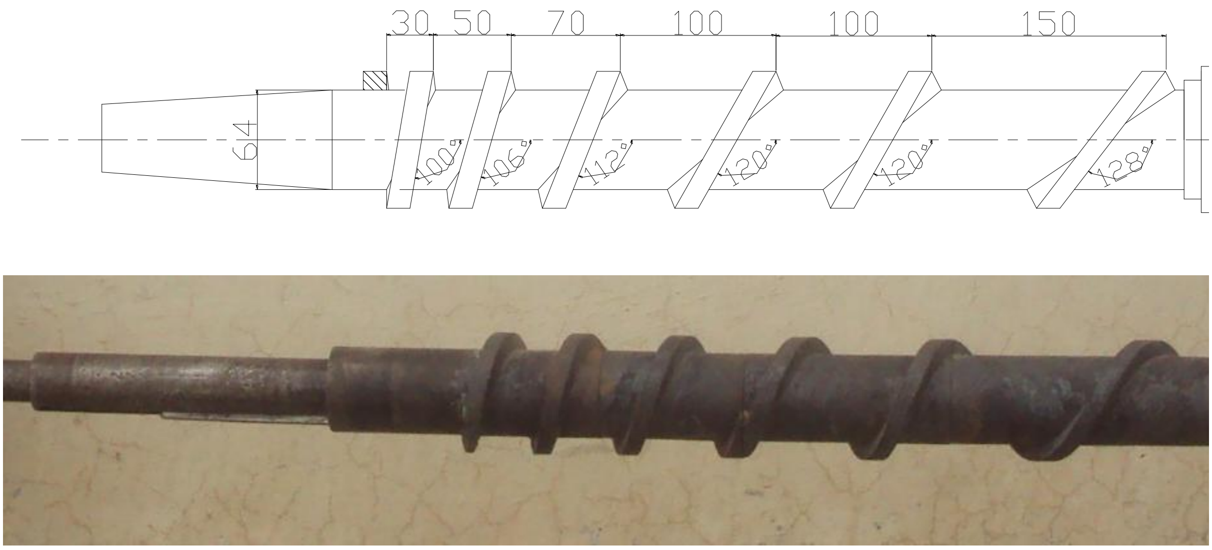


Figure 2 Screw-set with continue spiral setting (all dimension in mm)

The conventional screw press oil expellers are made of 4-8 set of screw sleeves with different pitch in reducing order and mounted on shaft. The spacers are provided in between two screw sleeve and the two flight uniform. The screw channel width of each screw pitch end of 150, 350, 420, 470 and 500 mm derived as 120, 80, 60, 40 and 25 mm respectively. The simulated results were thus obtained for each length of screw length.

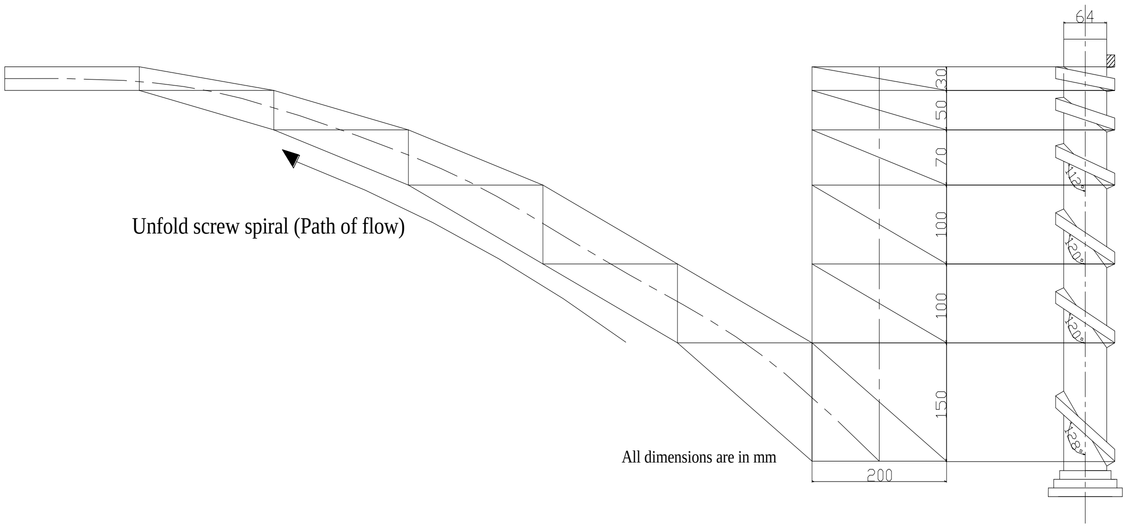


Figure 3 Unfold screw spiral: the path of the flow

2.2.2 Preparation of experimental set-up

The experimental set consisted of a screw-press oil expeller (Make: Simplex Expeller Company, Ludhiana, India) with the screw set of above configuration and a data logger (Century Instruments Pvt Ltd, Chandigarh, India). The temperature indicators and pressure transducers were mounted on barrel of the screw-press at five different length of screw barrel for recording the temperature and pressure respectively (Figure 4).

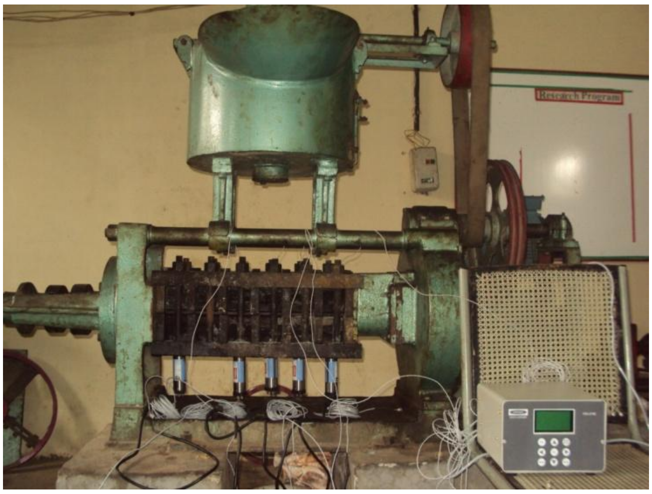


Figure 4 The experimental set: Oil expeller fitted with temperature and pressure transducer

The data logger was having the facilities to record the pressure in kg/cm^2 and temperature in ^{o}C.The batches of 15 kg of oilseeds of mustard (brown Indian mustard, *Brassica juncea*) and sunflower (Punjab sunflower hybrid – 67, *Helianthus annuus*) were used for oil extraction for experimental validation. Experiments were conducted in triplicate. The temperature and pressure were recorded in the data-logger, where the extracted oil was measured in measuring flask. The designed parameters were used for obtaining the theoretical result of velocity and pressure profile shown in Table 1.

Table 1 Input parameters and initial values for simulation of modifiedscrew design

Parameter	Value
Internal barrel radius, *Rb*	60 mm
Channel depth, *H*	12 mm
Flight width, *e*	15mm
Width of channel, *W*	120, 80, 60, 40, 25 mm
Viscosity, μ	1000 cp
Pressure gradient, ∂P/ ∂z	5000 Pa
Rotating speed, ω	48 rpm (2л/60) L/s

3 Results and discussion

3.1 Theoretical results of modified screw design

3.1.1 Velocity distribution

The velocity profile (v_z) in down channel is explained with the help of Equation 1 by Li and Hsieh (1996) as the velocity in the screw press is the results of drag and pressure. The velocity profile (v_z) in down channel were obtained with the help of computer programing in Matlabsoftware (Matlab 2006) by putting the parameters of modifies screw configuration. The combination of drag and pressure velocity profile of developed screw is shown in Figure 5a, Figure 5b, Figure 5c, Figure 5d and Figure 5e for the length of screw of 150 to 500 mm. The drag flow is induced by the movement of screw root surface and flight. The pressure flow is built-up by restriction at the end opening (outlet) of screw press and adjustable during operation. The channel height was 12 mm throughout the length of screw channel. Whereas channel width varied as 120, 80, 60, 40 and 25 mm at screw length of 150, 350, 420, 470 and 500 mm, respectively. Therefore, computation of down channel velocity was done at end of each screw pitch. The velocity distribution in channel width showed the concave trend between two flights and similar as reported by Li and Hsieh (1996). The velocity of flow increases with the height of channel and maximum at edge of flight and barrel surface. The velocity of flows also increases as material proceeds in the pathway of channel. The flow velocities in the down channel range from 125 to 175 mm/s through the length of screw from 150 to 500 mm for the screw drive of 48 r/min. These results are in harmony with the down channel velocity estimated by Ferretti and Montanari (2007) by solving the above model equation with a finite deferent method with the help of MS excel application.

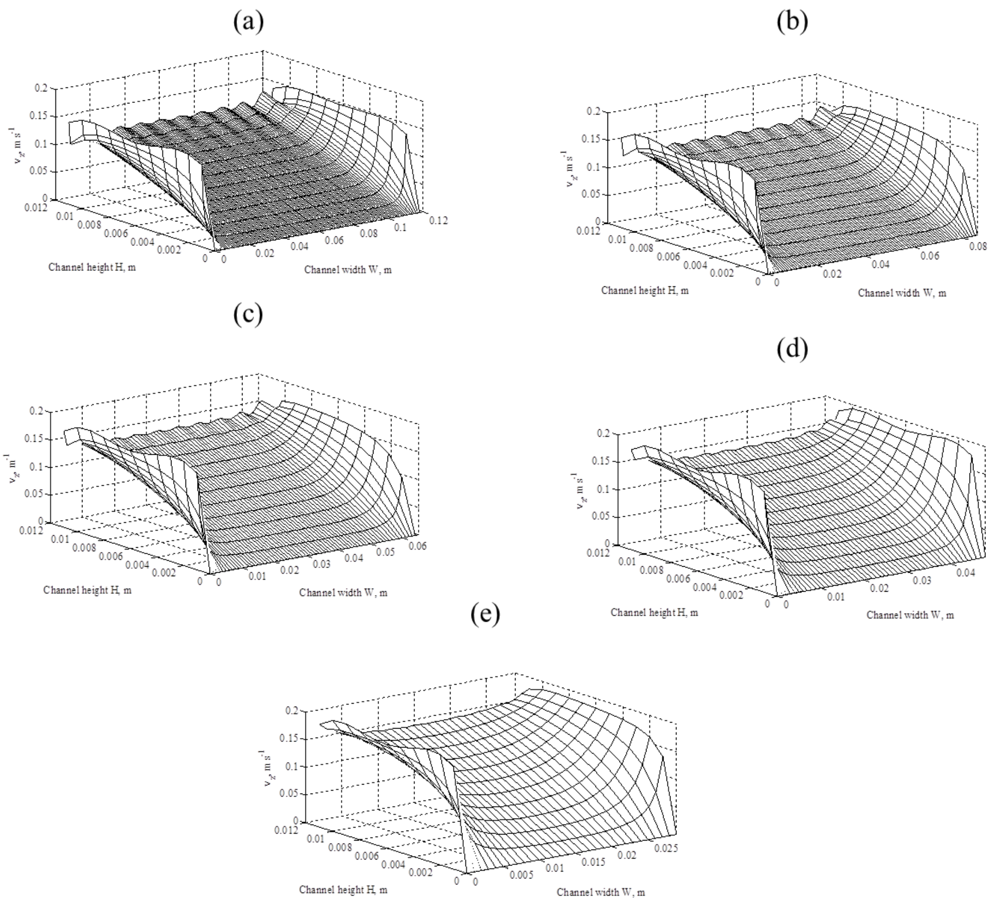


Figure 5 Velocity profile in screw channel due to a combined drag and pressure flow at 150, 350, 420, 470 and 500 mm of screw length as (a), (b), (c), (d), & (e) respectively

3.1.2 Pressure profiles

The pressure profile at the different length of the barrel was computed with the help of Equation 3. The pressure build up in the down channel at various length of screw is presented in Figure 6a, Figure 6b, Figure 6c, Figure 6d and Figure 6e. The maximum pressure is built at the end of screw in the range of 9 - 10.57 x 10^5 Pa, which is sufficient to express oil from most of the oil seeds (Omobuwajo*et al.*, 1999). The surface response of pressure in screw channel is similar of the velocity profile as concave shape. The pressure also increased toward the end of screw length.

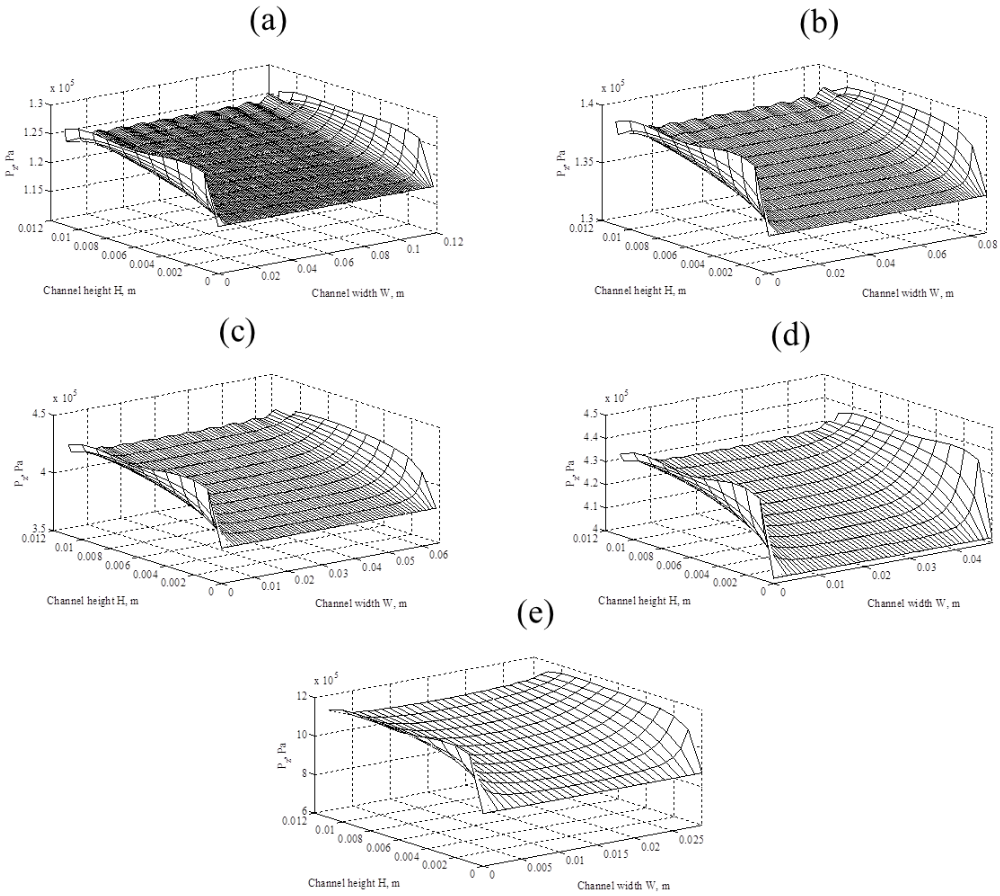


Figure 6 Pressure distribution in screw channel at 150, 350, 420, 470 and 500 mm of screw length as (a), (b), (c), (d), & (e) respectively

3.2 Experimental results and validation

3.2.1 Pressure in screw barrel

The theoretical pressure at the end of screw channel was computation of mean value from the pressure profile. Experimental pressures were observed with the help of pressure transducer mounted on the barrel of the screw-press. The predicted and experimental pressure with screw speed of 30 and 48 r/min and for operating the expeller with mustard and sunflower are presented in the Table 2.

Table 2 Experimental pressure at the end of screw

Experimental and Predicted Pressure				
Oilseeds	Screw Speed,	Pressure 10^5 Pa		
		Experiment	Predicted	% age error
Mustard	30	6.51± 0.05	6.40	1.56
	48	10.57± 0.07	10.27	2.92
Sunflower	30	6.25± 0.04	6.40	2.34
	48	9.47± 0.05	10.27	7.78

The theoretical results of pressure were near to the experimental observations of pressure built up with the per cent error ranged from 1.56 to 7.78. The pressure built up at the end of down channel was higher for mustard expelling as 10.57 x 10^5 Pa at screw speed of 48 r/min. These observations also revealed that higher pressure was built up at the higher speed of screw revolution. The pressure obtained in the designed screw of oil expeller was within the range of pressure reported by Owolarafe*et al.* (2008) under hydraulic expression of oil from oil palm fruits.

3.2.2Oil flow rate

The prediction of oil flow rate was computed with the help of pressure built in screw channel and the theory outlined in section 2.1.The predicted and experimental oil flow rates are presented in the Table 3. The predicted flow rate of oil is in good agreement with experimental values. The oil flow rate was higher as 0.0052 kg/s^2 at screw speed of 48 r/min for the mustard oilseed expelling. The observed oil flow rates were close to the predicted values in case of expelling of mustard seeds.The variation of experimental oil flow rates for sunflower seeds are due to the husk of the seeds. The husk of sunflower inhibits the flow of oil from the cells also compaction of oilseeds, which may be observed in the lower compact density of oil cake of sunflower seeds as 809 kg/m^3 compared to 1148 kg/m^3 of mustard oil cake at 48 r/min of screw speed.The predicted results of the oil flow rate of mustard and sunflower were same.

Table 3 Experimental and predicted data for oil flow rates oil recovery

Oilseeds	Screw Speed	Oil flow rates kg/s			Oil cake properties	
		Experiment	Predicted	% age error	Cake density kg/m^3	Oil in cake %
Mustard	30	0.0040 $\pm$ 0.0002	0.0048	16.6	1284$\pm$ 80	11.89$\pm$0.59
(41.2%)	48	0.0052 $\pm$ 0.0001	0.0060	13.3	1148$\pm$60	12.75$\pm$0.63
Sunflower	30	0.0026 $\pm$ 0.0002	0.0048	45.8	916$\pm$40	12.64$\pm$0.62
(48.3%)	48	0.0030 $\pm$ 0.0002	0.0060	50.0	809$\pm$ 30	14.45$\pm$0.72

higher mass of oilseed were pressed. On the other hand these results revealed that the higher oilcake density was observed as 1248 kg/m^3 at the lower speed of screw of 30 r/min. The oil extraction could be perceived with the help of percentage oil remained in the oilcake. These results showed that more oil could be extracted from oilseed at the lower speed of screw due to more retention of pressure applied. These results are agreeable with the Vadke*et al.* (1988) on the oil retention in oilcake at different speed of screw.

3.2.3 Rate of heat generated

The heat generation was computed based on the study state condition with help of Equation 10. Table 4 presents the heat generated during expelling of mustard and sunflower oil seeds at both the experimental speed of screw as 30 and 48 r/min. These results show that temperature increased from raw seed (32^{o}C) ranged between 11^{o}C to 17^{o}C of oil and 15to 18^{o}C of oil cake. The more heat was generated at higher speed of screw. The rate of heat generation in developed screw press was comparable to the results of Omobuwajo*et al.* (1998) at the same screw revolution. The high rate of heat generation in operation of sunflower oilseeds was mainly the result of more friction developed by husk while processing of whole oilseeds.

Table 4 Mass flow rates and thermo-physical properties of the mustard and sunflower oilseed, expelled oil and the cake streams

Characteristics	Mustard		Sunflower	
Raw seed	30 r/min	48 r/min	30 r/min	48 r/min
Temperature inlet, °C	32	32	32	32
Specific heat, (kJ/kg)/K	2.56	2.56	3.71	3.71
Mass flow rate, kg/s	0.0160±0.0004	0.0166±0.0004	0.0125±0.0003	0.0138±0.0004
Oil				
Temperature inlet, °C	41±0.5	44±0.5	45±0.5	49±0.5
Specific heat,(kJ/kg)/K	1.833	1.83	1.83	1.98
Mass flow rate, kg/s	0.0040±0.0002	0.0052±0.0001	0.0026±0.0002	0.0030±0.0002
Oil cake				
Temperature inlet, °C	47±0.5	49±0.5	48±0.5	50±0.5
Specific heat, (kJ/kg)/K	2.10	2.10	2.40	2.40
Mass flow rate , kg/s	0.012±0.0002	0.015±0.0003	0.010±0.0002	0.0125±0.0003
Heat generation rate, kJ/s	0.4503±0.0013	0.6161±0.0016	0.5456±0.0015	0.8002±0.0018

4 Conclusion

A new set of continued screw spiral of variable size of pitch was got fabricated for verification of the theoretical model. This screw was having total length as 500 mm. The pressure transducers and temperature probes were mounted on the screw barrel for taking the observation with the help of data logger. The pressure build up was within range of 5 – 10.57 x 10^5 Pa during processing the mustard and sunflower oilseed. The oil flow rate was higher case of mustard oilseed and with higher speed of screw. The oil flow rate was varying between 0.0030 – 0.0052 kg/s for sunflower and mustard. The heat generation was higher while processing the sunflower seed and with the higher speed of screw. The heat generation rate was between 0.4503 – 0.8002 kJ/s.The lower speed of screw revolution resulted in more percentage of oil expelling from oilseeds.

Nomenclature

a, b	Factors defined in Equations
A_c	Area coordinate, m^2
c_c, c_o, c_s,	Specific heat capacity of cake, oil and oilseed, (J/kg)/K
D_b	Internal barrel diameter, m
e	The flight width, m
g	Acceleration due to gravity, m/s^2
H	Maximum channel depth, m
k	Coefficient of permeability, m/s
m_c, m_o, m_s	Mass flow rate of cake, oil and oilcake , kg/s
P	Pressure, Pa
$\partial P/\partial x$	Pressure gradient in the cross (width) channel direction
$\partial P/\partial y$	Pressure gradient in the channel depth direction
$\partial P/\partial z$	Pressure gradient in the down channel direction
q_v	Volumetric flow rate of flow in porous media, m^3/s

q_m	Mass flux, kg m^{-2}/s
Q_m	Mass flow rate of oil, kg/s
q	Rate of heat generation, kJ/s
R_b	Internal barrel radius, m
R_s	Screw root radius (=R_b-H), m
T_c, T_o, T_s,T_r	Temperature of cake, oil, oilseed and reference, ^oK
v_x, v_y, v_z	Component of velocity in x, y and z directions, respectively, m/s
v_a	Axial velocity, m/s
W	Width of the channel at the internal radius of barrel (=$2\pi R_b \sin\phi_b$ – e), m
x	Channel width coordinate, m
y	Channel depth coordinate, m
z	Down channel coordinate, m
Z	Down channel length, m
δ	Clearance of screw flight and barrel, m
ε	Porosity, %.
μ	Viscosity of the Newtonian fluid, Pa.s
ρ	Density, kg/m^3
ϕ_b	Helix angle of screw R_b, rad
ω	Rotational speed of screw, s^{-1}

[References]

Bargale, P.C., D. Wulfsohn, J. Irudayaraj, R.J.Ford, and F.W.Sosulski. 2000. Prediction of oil expression by uniaxial compression using time-varying oilseed properties. *Journal of Agricultural Engineering Research*, 77(2):171-181.

Bear, J.1972.*Dynamics of fluids in Porous Media*.Dover Publication Inc. New York, United States.

Charlton, F. 2004.*Textbook of Fluid Drynamics*.CBS Publishers and Distributors, New Delhi.

Ferretti, G., and R. Montanari. 2007. A finite-difference method for the prediction of velocityfield in extrusion process. *Journal of Food Engineering*, 83(1):84-92.

Harmanto, A., E. Hendriadi, Rahmarestia, Mardison, and J. Wiyono. 2009. Performance test of a screw-press machine for extracting Jatropha curcas seed into crude oil as an alternative energy sources. *Indonesian Journal of Agriculture*, 2(1):35-40.

Herak, D., A. Kabutey, M. Monika Divisova, and S. Simanjuntak.2013. Mathematical model of mechanical behaviour of Jatropha curcas L. seeds under compression loading. *Biosystems Engineering*, 114(3):279-288.

Li,Y. and F.Hsieh.1996. Modeling of flow in a single screw extruder. *Journal of Food Engineering*, 27(4):353-375.

MATLAB 6.1 2001.*The language of technical computing*.The Math Works Inc.

Mrema, G.C., and P.B. McNulty. 1985. Mathematical model of mechanical oil expression from oilseeds.*Journal of Agricultural Engineering Research*, 31(4):361 – 370.

Omobuwajo, T.O., Ige, M.T., and A.O. Ajayi.1998. Theoretical Prediction of Extrusion Pressure and Oil Flow Rate During Screw Expeller Processing of Palm Kernel Seeds.*Journal of Food Engineering*,38(4):469-485.

Owolarafe, O. K., G. A.Badmus, and M. O.Faborode.2007. Development of a permeability model for oil palm fruit cake.*International Journal of Food Engineering*, 3(4), DOI:10.2202/1556-3758.1042.

Owolarafe, O.K., A.S.Osunleke, O.A.Odejobi, S.O.Ajadi, and M.O.Faborode. 2008. Mathematical modelling and simulation of the hydraulic expression of oil from oil palm fruits. *Biosystems Engineering*, 101(3):331-340.

Oyinlola, A., A. Ojo, and L.O.Adekoya.2004. Development of laboratory model screw-press for peanut oil expression. *Journal of Food Engineering*, 64(2):221-227.

Shirato, M., T. Murase, N.Hayashi, K. Miki, T. Fukushima, T.Suzuki, N.Sakakibara, and T.Tazima. 1978. Fundamental studies on continuous extrusion using a screw press. *International Chemical Engineering*, 18(4):680-688.

Shirato, M., T. Murase, M. Negawa, and H. Moridera.1971. Analysis of expression operations. *Journal of Chemical Engineering of Japan*, 4(3):59-64.

Vadke, V.S., F.W. Sosulski, and C.A.Shook. 1988. Mathematical simulation of an oilseed press. *Journal of American Oil Chemicals' Society*, 65(10):1610-1616.

Wang, L.J., G.N.Ganjyal, D.D.Jones,C.L.Weller, and M.A.Hanna.2004. Finite element modelling of fluid flow, heat transfer, and modelling of biomaterials in single screw extruder. *Journal of Food Science*, 69(5):212-223.