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MATHEMATICAL MODEL TO PREDICT OF THE SINGLE SCREW EXTRUDER DESIGN SPECIFICATIONS FOR FISH OIL EXTRACTION

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Abstract

Mathematical and prediction models provide solutions for designing machines and help determine the design factors for many models of different capacities and sizes. Fish oil extrusion machines play a crucial role in the production of fish oil, a valuable commodity widely used in various industries, including pharmaceuticals, food, and cosmetics. The design and performance of these machines significantly impact the efficiency and quality of fish oil extraction processes. In this study, we explore the predictive outcomes of scaling up design of a fish oil extrusion machine by different capacities and sizes. This scaling-up process aims to assess the feasibility and potential benefits of increasing the size and capacity of the extrusion machine. The results obtained from the program provided a lot of data on the geometric design of different sizes and capacities of the cold-press fish oil extraction machine. the mathematical model was predicted with design specifications as the hopper volume, discharge rate, capacity of screw conveyor, in the barrel, diameter of shaft, and power required by screw conveyor of the extruder based on the main dimensions, inlet diameter, hopper outlet size, and hopper height values, 0.06m^3*, 0.3kg/s, 91.68kg/h, 0.13m ,18.4kw, 0.7m, 0.55m, 0.75m.*

Key words*: *mathematical models*, *oil extracting, extruder machine, design specifications

INTRODUCTION

Engineering design and performance evaluation are important, especially for the cold-press fish oil extraction machine. Fish oil is primarily sourced from whole fish or their livers. However, certain fish by-products, particularly from processing fatty fish, can provide excellent-quality fish oil for human consumption. These by-products, such as trimmings, heads, tails, and skins, are often discarded in traditional processing methods.

Utilizing these by-products maximizes the output of vital nutrients such as omega-3 fatty acids while reducing waste. These by-products can be transformed into high-quality fish oil fit for human consumption with the right processing methods. This strategy provides an environmentally responsible and sustainable way to get this advantageous dietary supplement [7].

Often known as ω−3 or n−3 fatty acids, omega-3 fatty acids are a well-known type of polyunsaturated fatty acids that are known to have possible health advantages. The three main omega-3 fatty acids are docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), and alpha-linolenic acid (ALA). Both linoleic acid and ALA are classified as essential fatty acids, meaning they are necessary for human health but cannot be produced by the body [1].

In order to efficiently extract and process valuable omega-3 fatty acids and other vital nutrients from fish and fish by-products, fish oil extruder machines are a crucial part of the fish oil production process.These machines play a critical role in the aquaculture and seafood industries, providing a means to convert raw fish materials into high-quality oils used in various applications, including dietary supplements, pharmaceuticals, and food additives [14].

Usually installed on splined shafts, extruders have one or two intermeshing screws that can rotate either counter-rota tingly or co-rota tingly. All of these parts are included in a modular barrel. The extruder can operate as a positive displacement pump due to its special intermeshing, co-rotating twin screw design. Regardless of screw speed and pressure, this feature guarantees a steady throughput.Additionally, this design promotes efficient mixing of materials within the extruder. This module enables the collection of a liquid filtrate expelled from the material during compression [9].

Various extraction methods are employed to obtain fish oil, each yielding different productivities depending on the waste sources utilized. For instance, oil productivity from head, skin, off cuts, trimmings, viscera, and backbone frames ranges from 86 to 210 g oil per 1,000 g of waste. In the case of salmon by-products, oil productivity varies between 8.60% and 21.00% under constant pressure conditions. Furthermore, fish oil extracted from these sources is rich in functional EPA (eicosapentaenoic acid, 20:5 ω-3) and DHA (docosahexaenoic acid, 22:6 ω-3), making it highly beneficial for human consumption [4].

Cold pressing is widely preferred due to its versatility, simplicity, minimal manpower requirement, cost-effectiveness, environmental friendliness, and the absence of harmful organic solvents. This method offers high-quality oil production without subjecting the raw material to heat treatment, preserving its natural properties and Flavors. In cold-pressed extraction, pressure alone is used to extract oil, with little to no heat applied to the paste. Typically, cold presses are mechanized, often employing a screw device tightened against the paste to extract oils efficiently. While cold pressing may result in a lower yield compared to other methods, it ensures a superior quality of oil, making it a preferred choice for various applications [14].

Cold press extraction is not only energy-efficient but also environmentally friendly, making it a preferred method for obtaining fish oils. This process minimizes energy consumption compared to conventional extraction methods, contributing to sustainability efforts. Additionally, cold press extraction ensures the production of high-quality oils with enhanced purity. By avoiding high temperatures, which can degrade the oil's nutritional content and introduce unwanted compounds, cold press methods preserve the natural integrity and freshness of the extracted oil. As a result, fish oils obtained through cold press extraction are renowned for their exceptional purity and nutritional value, making them highly desirable for various applications [5].

During the cold pressing process, the weight of oil extracted from salmon by-products increased with longer pressing times, leading to higher oil productivity. Optimal conditions were achieved with a pressing time of 180 minutes, resulting in an oil weight of 93 g per 500 g of salmon by-products, an oil productivity of 18.00%, and an extraction efficiency of 98.46% at constant pressure [3].

The performance test conducted on the extruder demonstrated its effectiveness in extracting oil from Catfish (*Clarias gariepinus*) with high efficiency.The extruder's straightforward design made it easier to fabricate, operate, repair, and maintain locally. The extruder, which was driven by a 5 hp single-phase electric motor, demonstrated an outstanding average extraction efficiency of 90.40 percent.It was observed that the machine's performance parameters generally improved with an increase in machine speed, indicating its adaptability and responsiveness to varying operating conditions. Overall, the extruder's performance highlights its suitability for small-scale oil extraction operations, offering a reliable and efficient solution for local processing [2].

It is possible to divide the available configurations of the conveyor into four basic categories: Low-work screws (These screws are characterized by their gentle handling of materials, making them suitable for delicate or fragile products), Standard screws (versatile and cost-effective, making them a popular choice for general-purpose conveying tasks), High-shear screws (designed to exert greater force on the material being conveyed, resulting in more intense mixing or shearing action). and Vented screws (feature special configurations that allow for the release of trapped air or gases during conveying) [13].

Screw extruders are essential for processing highly viscous and multiphase systems, like fish oil extraction. Mixing is crucial in fish oil extrusion to ensure consistent quality. The extruder's screw configuration and parameters are carefully designed for efficient mixing, ensuring uniformity. Additionally, the modular barrel design allows precise control overtemperature, pressure, and residence time, enhancing mixing efficiency and optimizing oil extraction conditions. Operators can adjust these parameters to achieve the desired oil yield and quality [10].

utilizing Solidworks software to design and analyze extruder elements using the Finite Element Method (FEM) and fatigue evaluation of a press's single screw for obtaining fish oil. A feeder, nozzle (barrel), filter mesh, pressure chambers, screw axis, and waste output are among the machine's operational components [6].

The study aims to design a simulation to provide complex data to improve manufacturing processes for fish oil extraction extrusion machines.

MATERIALS AND METHODS

Development ofsimulation model to design and fabrication of extruder for fish oil extraction. The simulation model was designed and analyzed using the Solidworks program at the Department of Agricultural Engineering, Faculty of Agriculture, Tanta University, as shown in Fig. 1to extract fish oil by cold pressure to obtain Omega 3.

Fig. 1. Fish oil extruder machine
Source: Authors' designed.

1-Screw axis terminology and design assumptions.

The screw axis has a tapered shape with a pitch length twice the diameter of the screw, which increases in diameter in the initial half of the screw axis. In addition to viscosity and pressure, fish mixtures experience centrifugal forces of gravity and inertia. The screw axis extracts fish oil in three stages: the feed, compression, and metering stages. The feed stage, which has the same channel width along its length, collects the fish mixture in the screw extruder. The compression stage, in which the diameter of the screw gradually increases, further combines the fish mixture. The metering stage, which has a constant channel width, homogenizes or mixes unmixed fish pieces before pressing them into a homogeneous composition. As a result, this knowledge was used to drive the current design to improve both design and performance as shown in Fig. 2.

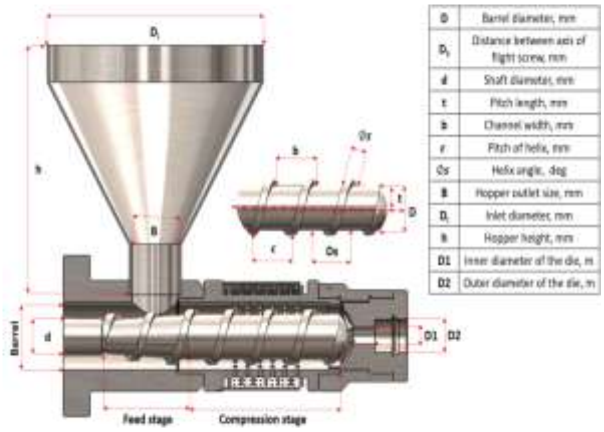

Fig. 2. Principle dimensionsof extruder machine design
Source: Authors' drawing.

1-1-Screw axle with tapered shaft and variable pitch.

Tapered Shaft: The shaft of the screw is tapered, meaning it gradually narrows or widens along its length. The tapering can be in either direction, depending on the specific design requirements. A tapered shaft can help control the compression and flow of the material being processed as it moves through the extraction chamber. It can also contribute to increased pressure and improved extraction efficiency.

Variable Pitch: The pitch of the screw refers to the distance between successive threads. In a screw with variable pitch, this distance changes along the length of the screw. This variation in pitch can serve several purposes:

- It can optimize the material flow and compression within the extraction chamber.

-It can provide varying degrees of pressure and shearing forces on the material, facilitating efficient oil extraction.

-It can help prevent material build up and clogging, ensuring the smooth operation of the extraction machine.

2-The conical type of choke mechanism.

-Conical Shape: The choke mechanism is shaped like a cone, with a gradually decreasing diameter from the wider inlet end to the narrower outlet end. This conical shape creates a narrowing pathway through which the material flows as it exits the extraction chamber.

-Flow Control: The conical choke mechanism serves to regulate the flow of material leaving the extraction chamber. As the material moves towards the discharge end of the chamber, it encounters the conical choke mechanism. The narrowing pathway created by the conical shape causes a constriction in the flow, effectively controlling the rate at which the material exits the machine.

-Pressure Regulation: In addition to controlling the flow rate, the conical choke mechanism also helps regulate the pressure within the extraction chamber. By creating a choke point where the material experiences increased resistance to flow, the mechanism can maintain optimal pressure conditions for the extraction process.

This pressure regulation is important for ensuring the efficient extraction of oil from the material.

-Residual Material Separation: The conical choke mechanism can also aid in separating the extracted oil from the residual material as it exits the extraction chamber.

The narrowing pathway created by the conical shape can cause the heavier residual material to settle and separate from the lighter oil, facilitating easier collection and further processing of the extracted oil.

3-Design of the Fish Oil Extractor

According to Khurmi and Gupta (2011)[8],Ngwu et al (2013) [11], and Olaniyan et al (2007) [12], the extruder parts are designed as follows:

3-1-Hopper

3-1-1Hopper outlet diameter, m

$$B = \frac{\sigma_C\ H_a(\theta)}{\rho g} \qquad (1)$$

$$\sigma_c = \frac{F}{A} = \frac{\pi^2 E}{(\frac{L_u}{r_l})^2} \qquad (2)$$

where:

σ_C= consolidated stress generated in an arch at the outlet, KPa

E=young's modulus, KPa

L_u=unsupported length of column, m

r_l=least radius of column, m

$H_a(\theta)$=Function

ρ=bulk density of material, kg/m^3

g=acceleration due to gravity, m/s^2

3-1-2 Hopper volume, m^3

$$V_h = \pi \frac{(D_i{}^2 - B^2)h}{12} \qquad (3)$$

Weight of hopper, Kg=V_h x ρ ....(4)

where:

D_i= Inlet diameter, m

B= Hopper outlet diameter, m

h= Height of hopper, m

3-1-3 Barrel volume, m^3

$$V_{barrel} = \frac{1}{3}h(A_f + \sqrt{A_f A_c} + A_c \qquad (5)$$

where:

A_f=The area at the feeding section, m^2

A_c =The area at the compression section, m^2

4- Stress in the conical part of the hopper

$$P_v = (\frac{\gamma_p.g.d.\mu_f.K}{4})(1 - \exp\left(-\frac{4.H.\mu_f.K}{D_h}\right) \qquad (6)$$

$$P_W = K\,P_V \qquad (7)$$

$$\tau = \mu\,P_W \qquad (8)$$

where:

P_v=Theoretical vertical pressure, N/m^2

P_w=Jansson pressure equivalent, N/m^2

τ= Shear stress in the conical part of the hopper, N/m^2

γp= bulk density of the powdered solids, Kg/m^3

μ_f=coefficient of friction of the material

H=height of the hopper, m
K=Janssen coefficient
d=shaft diameter, m
g=Earth's acceleration of gravity, m/s^2, and
D_h=diameter of the hopper, m

5- Screw axle and barrel design.

$\frac{a}{D_s} \le \frac{\sqrt{2}}{2}$……………………………………(9)

$\alpha = 2\cos^{-1}(\frac{a}{D_s})$………………………....(10)

$\beta = \frac{\pi}{i} - \alpha$………………………………...(11)

$\emptyset_s = \tan^{-1}(\frac{t}{\pi D_s})$………………………....(12)

$b_{max} = t\cos\emptyset_s - \epsilon_{max}$…………………(13)

$h_{max} = D_s - a$…………………………...(14)

$t = 2\pi L_{Kn}/\delta j_{Kn}$…………………………(15)

$\epsilon_{max} = t\beta\cos\emptyset_s/2\pi$……………………...(16)

a=$\frac{D}{2}$…………………………..………...(17)

i=k×D…………………………………...(18)

H_{feed}= 0.11(D+25)………………….……(19)

$H_{metering}$= 0.04(D+25)……………………(20)

where:
a=Distance between axis of flight screw, m
D_s=Barrel diameter, m
Dr=Root diameter, m
D= diameter of the screw, mm
K=A constant, typically ranging from 0.8 to 1.5 depending on the design and material properties.
H_{feed}=Channel depth in the feed stage, m
$H_{metering}$=Channel depth in the meter stage, m
α=intermeshing angle, degree
t=pitch length, m
L_{kn}=right-handed standard screw
J_{kn}=standard screw element
t=Screw pitch, m
Øs=Pitch angle, deg/ rad
ϵ_{max}=Flight width, m and
b_{max}=Channel width, m

6- Extrusion and die design.

Q= $15n\emptyset p\gamma(D^2 + d^2)\pi$……………….…...(21)

$P_{sc} = 0.7355$ CIQ……………………….…(22)

$P = P_{sc}/Q_f$………………………………(23)

$F_w = PA$……………………………....(24)

$F_\theta = F_w \tan\emptyset_s$…………………………...(25)

$P_{die} = W/A_{die}$………………………......(26)

$A_{die} = n\frac{\pi}{4}(D2^2 - D1^2)$…………………(27)

$\gamma = \frac{3n+1}{4n}(\frac{4Q_m}{\pi R^3})$…………………………...(28)

where:
P=operating pressure in the barrel, KPa
P_{sc}=power required by screw conveyor, kw
Q_f=flow rate of material, kg/s
γ= shear rate of the dough before the die, s^{-1}
n=power index=0.61
R= radius of the die hole, m
F_w=thrust force in the barrel, KN
A= area of extrude, m^2
F_θ=tangential force in the barrel, KN
$\emptyset_s$=pitch angle, Deg/ rad
Q=capacity of screw conveyor in the barrel.t/h
C=constant coefficient for conveyed material
I=length of the screw conveyor, mm
D_1=inner diameter of the die, m
D_2= outer diameter of the die, m
A_{die}=area of annular die, m^2
P_{die}=theoretical pressure on composite through die, KPa and
n=number of the holes of extruder.

7-Shaft design.

$Do^3 = \frac{16}{\pi\tau max}\sqrt{(Km\ x\ M)^2 + (Kt\ x\ T)^2}$...(29)

T=$\frac{P\ X\ 60}{2\pi N}$…………………….....................(30)

M=$\frac{W\ X\ L}{4}$…………………………………..(31)

$Te = \sqrt{(Km\ x\ M)^2 + (Kt\ x\ T)^2}$…………(32)

τ=$\frac{T_{ro}}{j}$……………………………………...(33)

$D_p = \frac{2}{3}D_o$………………………………...(34)

where:
Do^3= diameter of shaft, mm
P=energy, W
T=torque transmitted by the shaft, N.mm
N=rotational speed of electric motor, rpm
K_m=combined shock and fatigue factor for bending
K_t=combined shock and fatigue factor for torsion
T=internal torque of shaft, N.mm
W=central load, N
D_p=pitch diameter, m
L=length between supported bearings, m
M=maximum bending moment, N.mm

τ=torsional loading, Mpa
D_o= external diameter of shaft (worm shaft), m
J=the polar moment of inertia for a solid shaft, m^4, and
T_e=equivalent twisting moment, N.mm

8-Torqueof screw axle.

T=$\frac{P}{\omega}$……………………………………(35)
ω=$\frac{2\pi N}{60}$……………………………………(36)

where:
T=torque of screw axle, W
P=power requirement, W
ω=angular frequency, rad/sec
N=rotational speed of electric motor, rev/min

9-Power requirement.

Pe = 0.7355*Q*C*L…………………….……(37)

where:
Pe=Power required by screw conveyor, Hp
Q=capacity of screw conveyor in the barrel, Kg/h
C=constant coefficient for conveyed material
L=length of the screw conveyor,m

10-Discharge rate, Kg/h.

W=0.58$\rho_b g^{0.5}(B - k\ d_p)^{2.5}$…………...(38)

where:
B=Hopper outlet diameter,m
d_p=Particle diameter,m
K=coefficient of the frictional interaction between the material and the screw or barrel ranges from 0.1 to 0.3.
g=acceleration due to gravity, m/s^2
ρ_b=bulk density of material (kg/m^3)

The C++ programming language was used to build a set of algorithms to determine and predict the design specifications of the fish oil extraction device and predict the specifications of higher productivity with distinction of the design specifications.

The C++ plusProgramming Language is a general-purpose parallel programming language that includes all of C++ plus six new keywords. The processor object is a mechanism for controlling the area. An account may contain one or more processor objects. Inside the Handler object, serialized C++ code can be executed without modification. In particular, it can access local data structures.

Fig. 3. Flowchart of mathematical model for design of extruder machineto estimate the design specifications of fish oil extraction equipment. This program can compute hopper volume, m^3, Discharge rate, Kg/h, Capacity of screw conveyor in the barrel, kg/h and diameter of shaft, m. Also estimate vertical pressure acting downwards, N/m^2, Jansson Pressure Equivalent, N/m^2 , Shear stress in the conical section of hopper, N/m^2 and power required by screw conveyor, Kw.

It calculates the design specifications through known equations, through which the specifications can be given according to the design conditions.

Fig. 4, Flowchart of prediction model for design of extruder machine It predicts specifications at different production levels, distinguishing design specifications through linear equations and others derived from interrelated factors through which specifications can be given according to design conditions.

The hopper outlet diameter and discharge rate, the screw conveyor's power requirements and length, the material flow rate, and the barrel's operating pressure.

Additionally, the barrel's capacity for a screw conveyor, the number of screws rotating, the material hold-up, the extruder's reaction volume, barrel thrust force and area, barrel tangential force, and barrel thrust force.

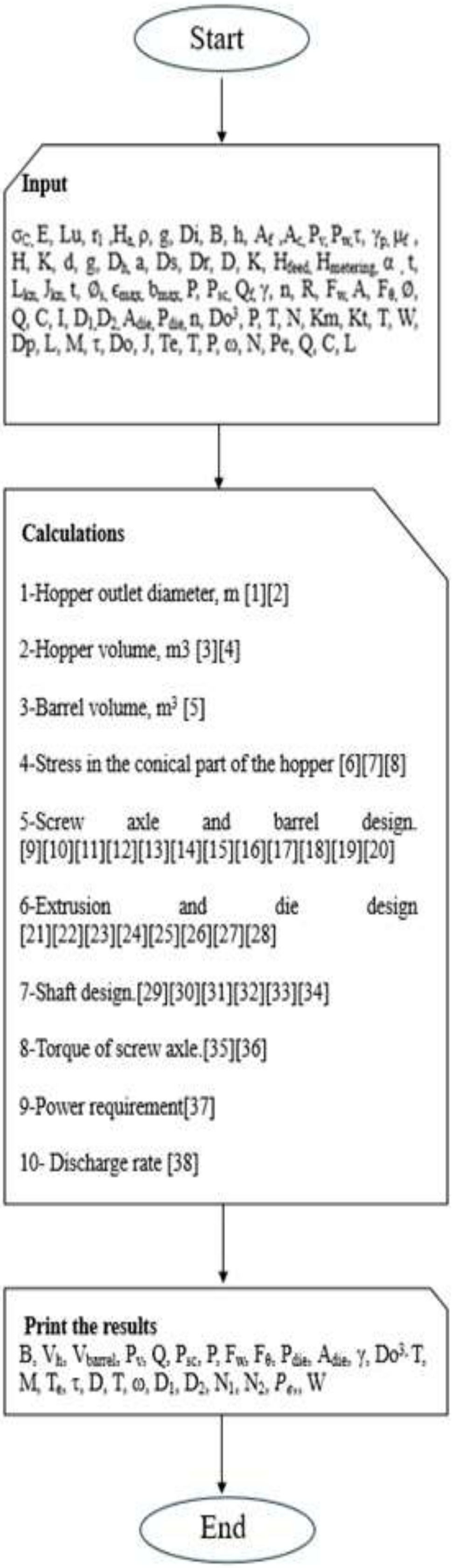

Fig. 3. Flowchart of mathematical model for design of extruder machine
Source: Author's determination.

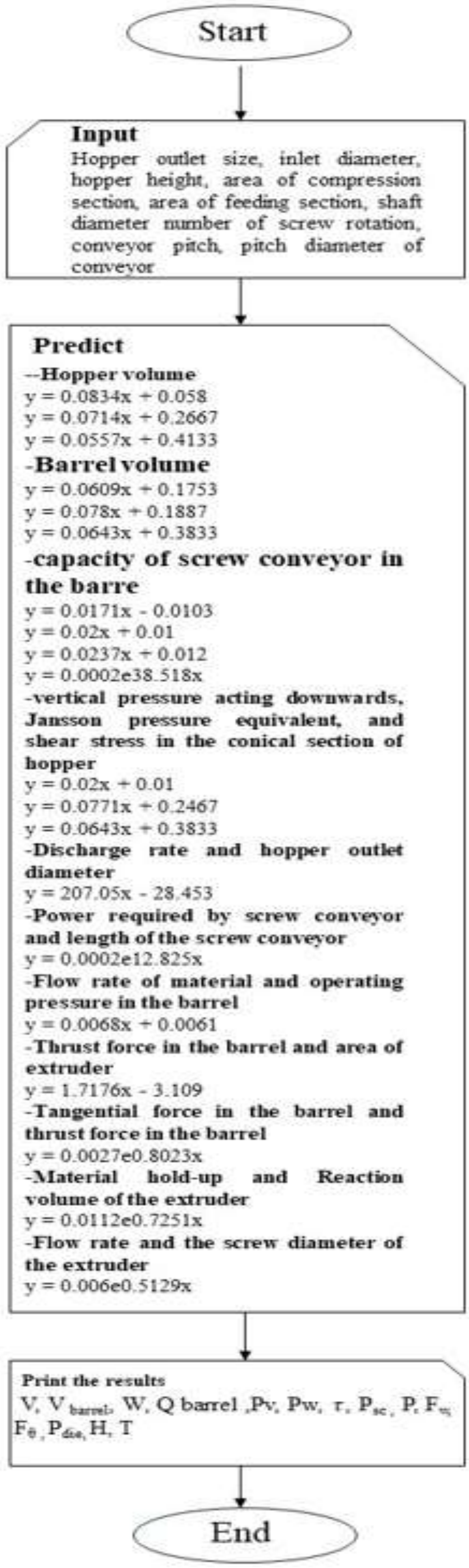

Fig. 4, Flowchart of prediction model for design of extruder machine
Source: Author's determination.

RESULTS AND DISCUSSIONS

It was possible to predict the hopper volume of the extruder based on the main dimensions, inlet diameter, hopper outlet size, and hopper height values, the results were shown in Fig. 5 the maximum value of hopper volume for the extruder machine was 0.068, with inlet diameter, hopper outlet size, and hopper height values were 0.70, 0.55, and 0.75 m, and the minimum value was 0.021 m^3, with the same principal dimensions were 0.30, 0.15, and 0.40 m, respectively.

The simulation model capable to predict with value of barrel volume and compression section in Fig 6.

The results showed a gradation of values between value of barrel volume was 0.08 m^3 with the area of feed, compression section vales were 0.25, and 0.20 m^2 and that with hopper height 0.40 while value of the same indicator was 0.39 m^3 with same previous principal dimensions of design were 0.64, and 0.52 m^2 with a high hopper value 0.75 m respectively.

The model can predict many values in Fig.7showed the values of capacity of screw conveyor in the barrel were 91.68 and 0.48 kg/h with values of conveyor pitch, pitch diameter of conveyor, and shaft diameter were 0.10, 0.16, and 0.13 m for maximum, and for minimum, the values of same indices were 0.015, 0.04 and 0.03m respectively.

As illustrated in Fig. 8, 9, and 10, the hopper height, shaft diameter, and hopper diameter were 0.75, 0.13, and 0.70 m. The vertical pressure acting downward, the Jansson pressure equivalent, and the shear stress in the hopper's conical section were, respectively, 54.79, 26.38, and 15.03 N/m2 at their maximum and 5.21, 2.08, and 1.19 N/m^2 at their minimum.

Fig.11 demonstrated that when the hopper outlet size increased from 0.15 to 0.55 m, the discharge rate results increased from 0.017 to 0.303 kg/h.

Also, Fig. 12 showed an increase in the power required by the screw conveyor from 0.04 to 18.40 kw with an increase from 0.45 to 0.91 mm for the length of the screw conveyor.

As illustrated in Fig 13, the material flow rate increased from 0.012 to 0.043 m3/h while the barrel's operating pressure increased from 0.003 to 0.089 Kpa.

Fig. 14showed an increase inarea of extruder values, the maximum value was 119.39 cm^2 with previous heights value of thrust force in the barrel 9.021 kN, and the minimum value for the same indicator was 0.014 m^2 with lowest values of second indicator 0.014 kN.

Fig. 15 demonstrated an increase in the intangential force in the barrel values. The lowest value for the same indicator was 0.004 kN, while the lowest values of the second indicator were 0.014 kN. The greatest value was 0.254 kN, with the prior height of thrust force in the barrel being 9.021 kN.

There is an increase in the results of material hold-up and reaction volume of the extruder and the minimum values were (0.056, and 0.08), and the maximum values of the same indices were (0.72 m^3, and 0.20) as shown in Fig. 16 respectively.

Fig. 1**7** shows an increase from 0.012 to 0.24 m^3/h, and from 0.03 to 0.13 m for flow rate and the screw diameter of the extruder respective.

Fig. 18 shows an increase from 0.2 (model 1 with 9kg/h) to 0.34 m/s (model 6 with90 kg/h as a production) for the number of screw rotations with the same increase in capacity of the screw conveyor in the barrel.

Mathematical model It calculates the design specifications through known equations, through which the specifications can be given according to the design conditions.

Table 1 shows thetechnical parameters of the single screw extrude, the design specifications of different production models of extruders. This program can compute for model M1(9kg/h)hopper volume, was 0.021m^3,Capacity of screw conveyor in the barrel was 0.480 kg/h and diameter of shaft was 0.030 m.Shear stress in the conical section of hopper was1.190N/m^2 and power required by screw conveyor0.047Kw.

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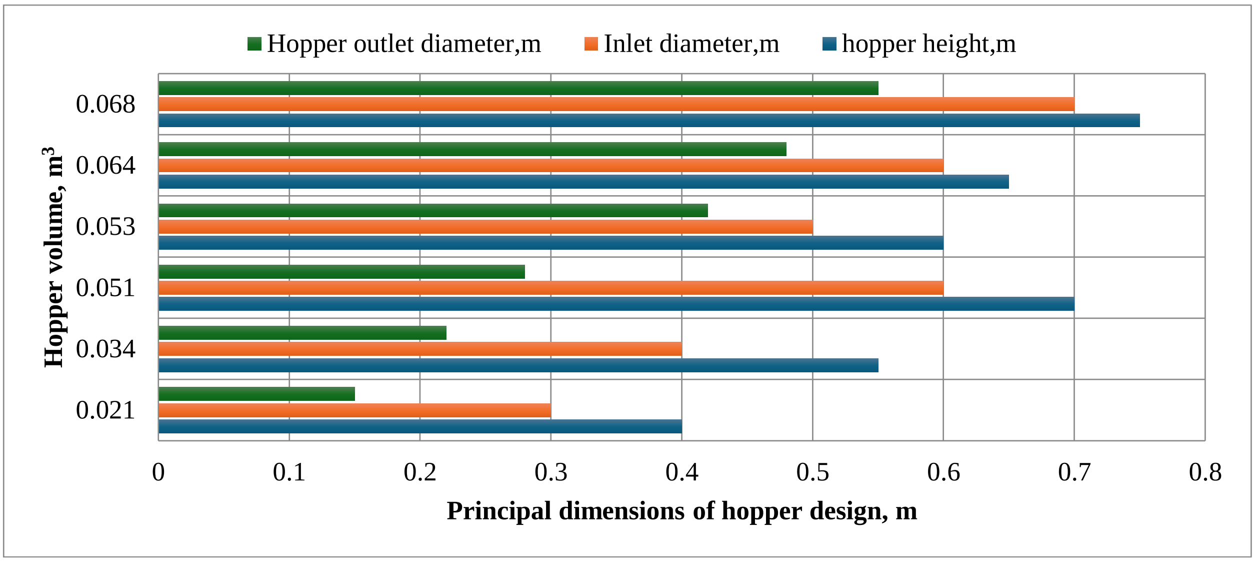

Fig. 5. Relationship between principal dimensions and hopper volume of hopper design
Source: Author's determination.

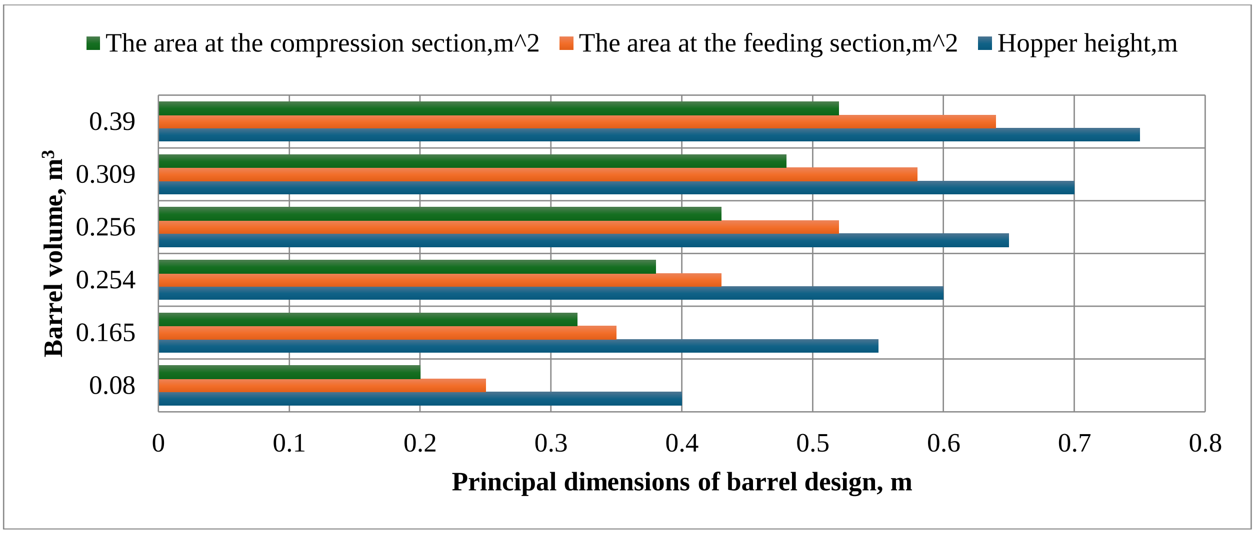

Fig. 6. Relationship between principal dimensions and barrel volume of barrel design
Source: Author's determination.

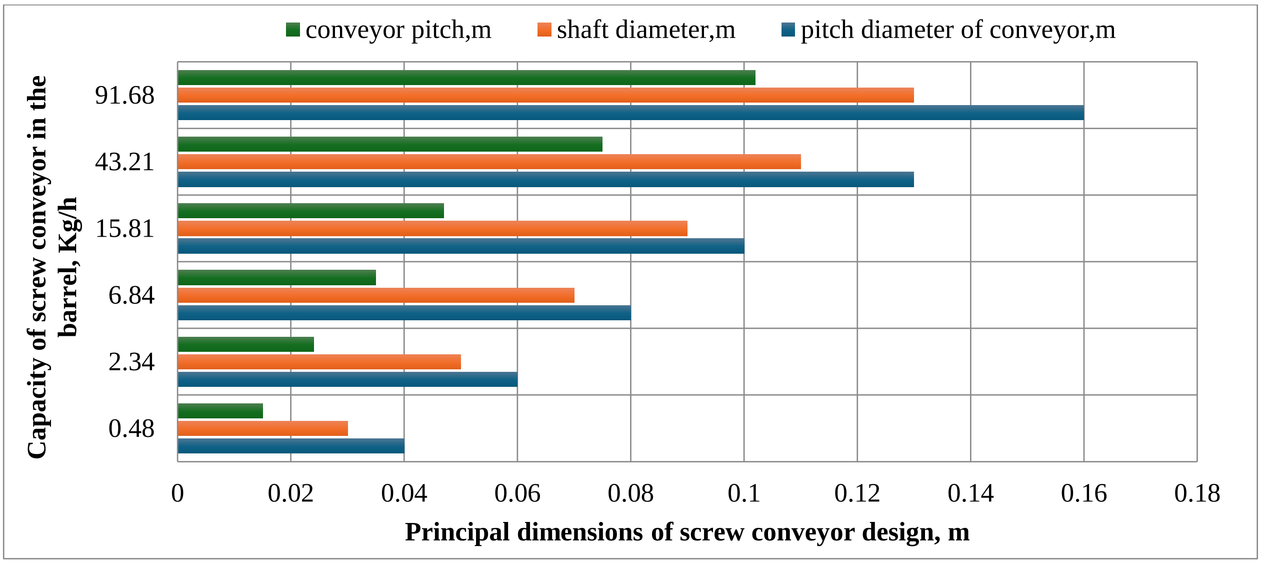

Fig. 7. Relationship between screw conveyor capacity and key screw design dimensions
Source: Author's determination.

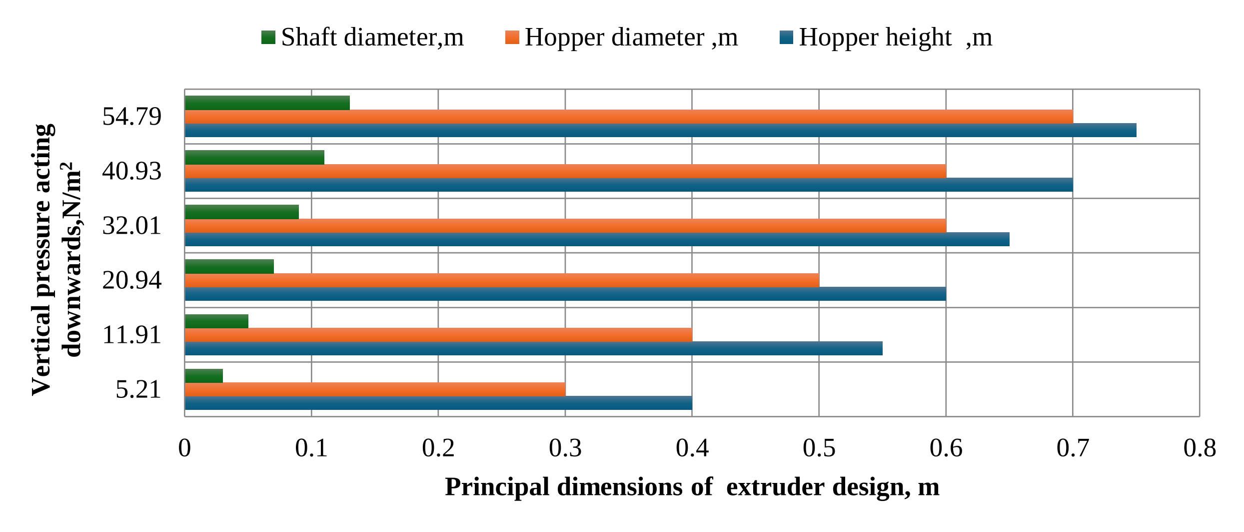

Fig. 8. Relationship between the main extruder design dimensions and vertical pressure acting downward
Source: Author's determination.

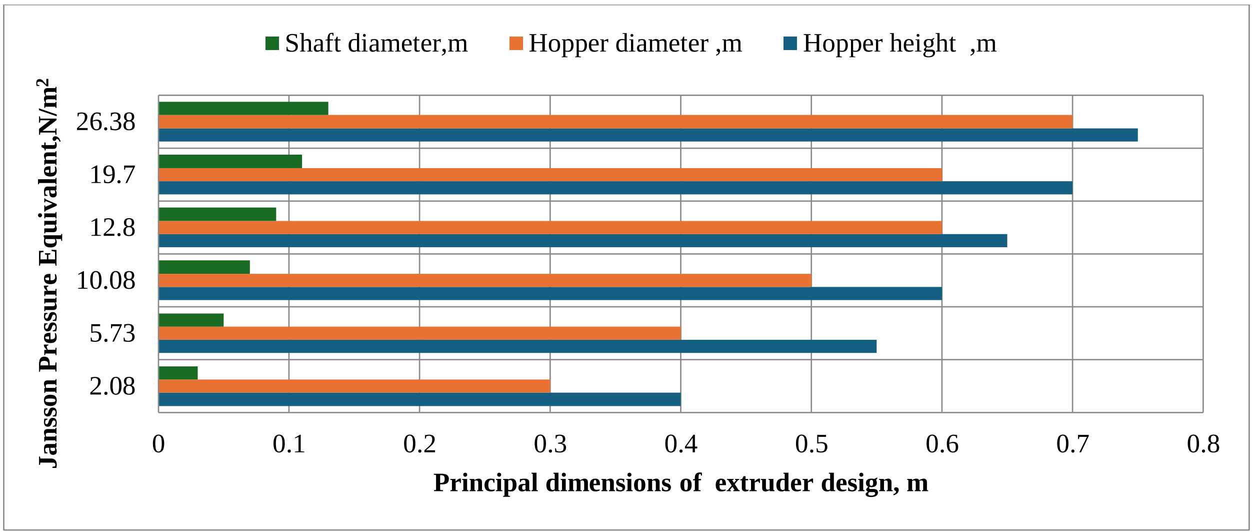

Fig. 9. Relationship between Jansson pressure equivalent and the main extruder design dimensions
Source: Author's determination.

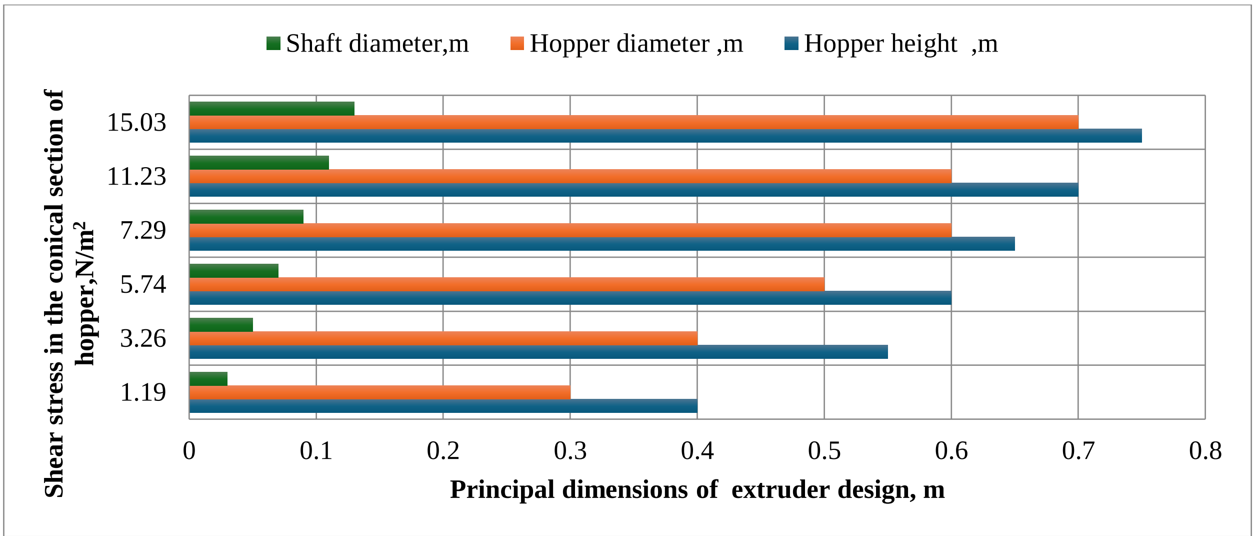

Fig. 10. Relationship between shear stress in the conical section of hopper and principal dimensions of extruder design
Source: Author's determination.

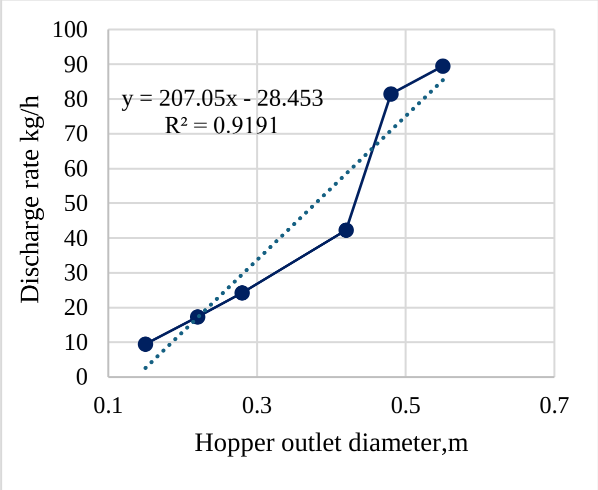

Fig. 11. Relationship between hopper outlet and diameter discharge rate
Source: Author's determination.

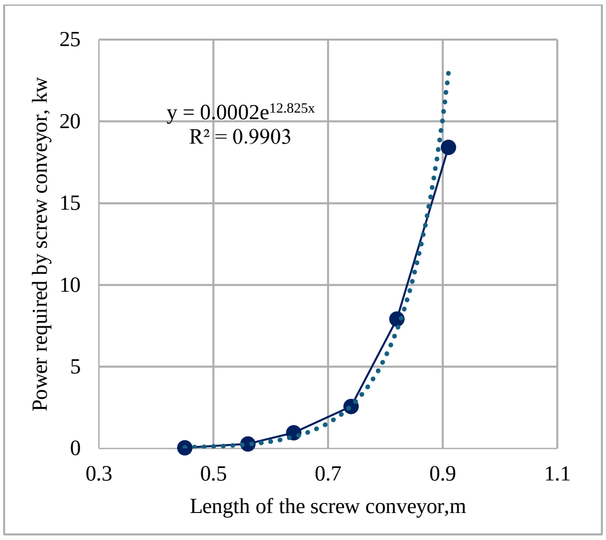

Fig. 12. Relationship between length of the screw conveyor andPower required by screw conveyor
Source: Author's determination.

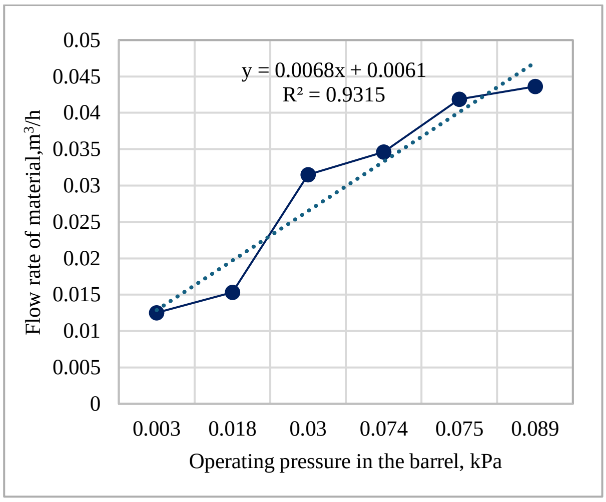

Fig. 13. Relationship between flow rate of material and operating pressure in the barrel
Source: Author's determination.

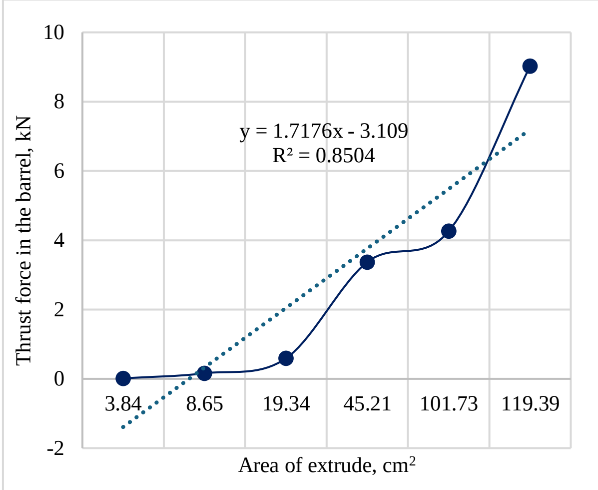

Fig. 14, Relationship between area of extruder and thrust force in the barrel
Source: Author's determination.

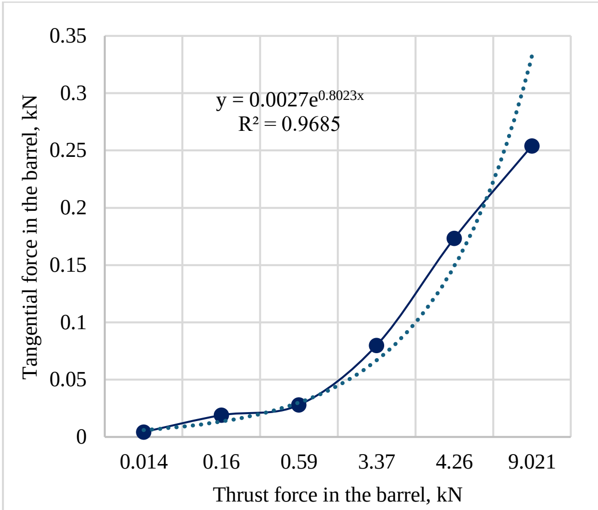

Fig. 15. Relationship between tangential force in the barrel and thrust force in the barrel
Source: Author's determination.

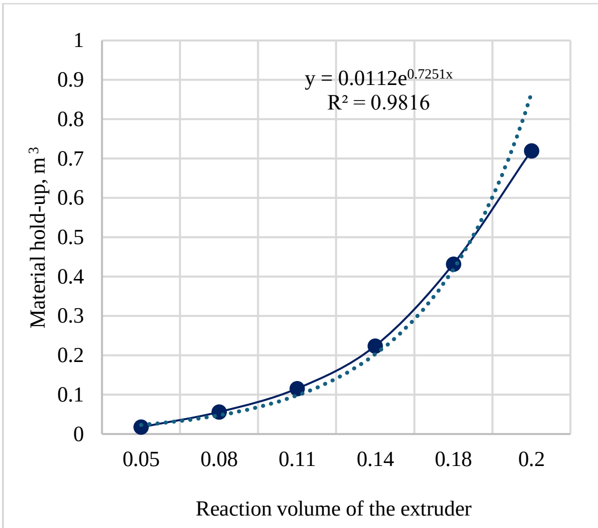

Fig. 16. Relationship between Reaction volume of the extruder and material hold-up
Source: Author's determination.

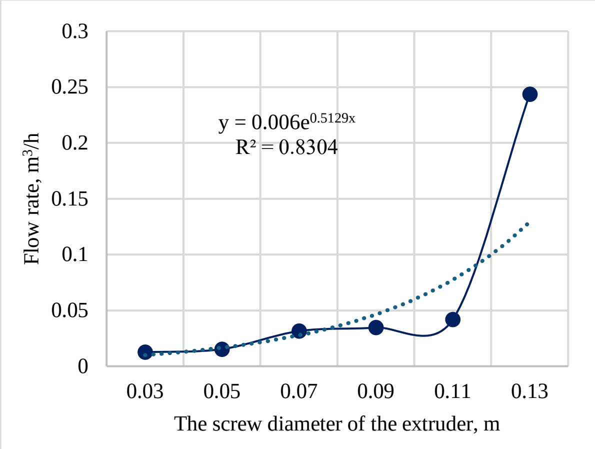

Fig. 17. Relationship between flow rate and the screw diameter of the extruder
Source: Author's determination.

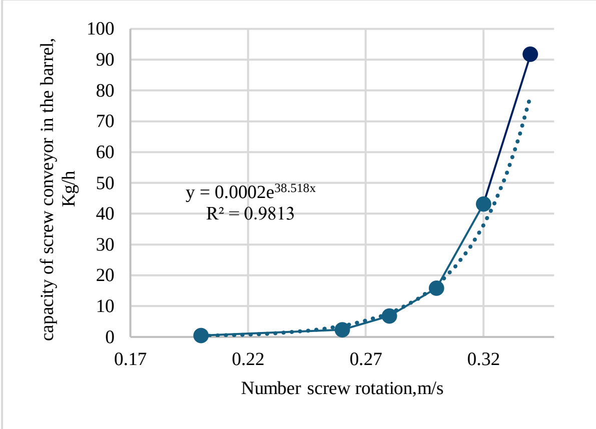

Fig. 18. Relationship between barrel screw conveyor capacity and screw rotation number for six extruder machine models
Source: Author's determination.

Table 1. Technical parameters of the single screw extruder

Indices	Acronym	M1(9)	M2(17)	M3(24)	M4 (42)	M5 (81)	M6(90 kg/h)
Hopper outlet size, m	*B*	0.15	0.22	0.28	0.420	0.480	0.550
Hopper volume, m^3	V	0.021	0.034	0.051	0.053	0.064	0.068
Volume of the barrel, m^3	V_{barrel}	0.080	0.160	0.250	0.250	0.300	0.39
Discharge rate, Kg/h	W	9.477	17.314	24.182	42.245	81.402	90.457
Capacity of screw conveyor in the barrel, kg/h	Q barrel	0.480	2.34	6.84	15.810	43.21	91.68
Diameter of shaft, m	Do^3	0.030	0.050	0.070	0.090	0.110	0. 130
Vertical pressure acting downwards, N/m^2	Pv	5.210	11.910	20.940	32.010	40.930	54.790
Jansson Pressure Equivalent, N/m^2	Pw	2.080	5.730	10.080	12.800	19.700	26.380
Shear stress in the conical section of hopper, N/m^2	τ	1.190	3.260	5.740	7.290	11.230	15.03
Power required by screw conveyor, Kw	P_{sc}	0.047	0.289	0.965	2.581	7.926	18.408
Operating pressure in the barrel, KPa	P	0.003	0.018	0.030	0.074	0.075	0.0890
Thrust force in the barrel, kN	F_w	0.014	0.160	0.590	3.370	4.260	9.021
Tangential force in the barrel, kN	F_θ	0.004	0.019	.0.27	0.080	0.173	0.254
Area of annular die, Cm^2	A_{die}	3.768	8.478	19.004	45.059	97.340	219.015
Theoretical pressure on composite through die, kPa	P_{die}	3.879	19.260	31.280	41.190	74.838	197.917
Material hold-up, m^3	H	0.017	0.056	0.115	0.224	0.432	0.720
Torque, Nm	T	0.047	0.289	0.965	2.581	7.926	18.408
Flight angle, Deg/rad	$\boldsymbol{\beta}$	40.381	42.500	46.390	49.464	54.019	58.288
Screw pitch, m	t	0.007	0.011	0.016	0.036	0.056	0.249
Pitch angle, Deg/ rad	Øs	0.357	0.535	1.239	2.277	6.654	16.554
Flight width, m	ϵ max	0.071	0.122	0.310	0.492	0.500	1.959
Channel width, m	b max	0.028	0.048	0.145	0.255	0.464	1.884
Cost, USD	$	80.42	130.78	209.82	302.57	425.19	628.58

Source: Author's prepared.

Table 2. Regression equations of the single screw extruder design

Indices		**Regression**	**R^2**
Hopper volume	Hopper outlet size	y = 0.0834x + 0.058	$R^2 = 0.9855$
	Inlet diameter	y = 0.0714x + 0.2667	$R^2 = 0.8242$
	Hopper height	y = 0.0557x + 0.4133	$R^2 = 0.7047$
Barrel volume	Area at the compression section	y = 0.0609x + 0.1753	$R^2 = 0.9576$
	Area at the feeding section	y = 0.078x + 0.1887	$R^2 = 0.9906$
	Hopper height	y = 0.0643x + 0.3833	$R^2 = 0.9382$
Capacity of screw conveyor in the barrel	Conveyor pitch	y = 0.0171x - 0.0103	$R^2 = 0.9413$
	Shaft diameter	y = 0.02x + 0.01	$R^2 =0.9578$
	Pitch diameter of conveyor	y = 0.0237x + 0.012	$R^2 = 0.9891$
Vertical pressure acting downwards	Shaft diameter	y = 0.02x + 0.01	$R^2 = 0.9827$
	Hopper diameter	y = 0.0771x + 0.2467	$R^2 = 0.9613$
	Hopper height	y = 0.0643x + 0.3833	$R^2 = 0.9382$
Jansson pressure equivalent	Shaft diameter	y = 0.02x + 0.01	$R^2 = 0.9827$
	Hopper diameter	y = 0.0771x + 0.2467	$R^2 = 0.9613$
	Hopper height	y = 0.0643x + 0.3833	$R^2 = 0.9382$
Shear stress in the conical section of hopper	Shaft diameter	y = 0.02x + 0.01	$R^2 = 0.9827$
	Hopper diameter	y = 0.0771x + 0.2467	$R^2 = 0.9613$
	Hopper height	y = 0.0643x + 0.3833	$R^2 = 0.9382$
Discharge rate and hopper outlet diameter		y = 207.05x - 28.453	$R^2 = 0.9191$
Power required by screw conveyor andlength of the screw conveyor		$y = 0.0002e^{12.825x}$	$R^2 = 0.9871$
Flow rate of material and operating pressure in the barrel		y = 0.0068x + 0.0061	$R^2 = 0.9315$
Thrust force in the barrel and area of extruder		y = 1.7176x - 3.109	$R^2 = 0.8504$
Tangential force in the barrel and thrust force in the barrel		$y = 0.0027e^{0.8023x}$	$R^2 = 0.9456$
Material hold-up and Reaction volume of the extruder		$y = 0.0112e^{0.7251x}$	$R^2 = 0.9847$
Capacity of screw conveyor in the barrel andnumber screw rotation		$y = 0.0002e^{38.518x}$	$R^2 = 0.998$
Flow rate and the screw diameter of the extruder		$y = 0.006e^{0.5129x}$	$R^2 = 0.81$

Source: Author's prepared.

The prediction model for design of extruder machine. It predicts specifications at different production levels, distinguishing design specifications through linear equations and others derived from interrelated factors through which specifications can be given according to design conditions. As showing Table 2.

Table 1 shows the difference in the costs of extruder screw manufacturing materials according to the productivity of the extruder and the required capacity. The extruder screw manufacturing cost was $80.40 for an extruder with a capacity of 9 kg/hour while it increases to $628 for an extruder with a capacity of 90 kg/hour.

CONCLUSIONS

The possibility of using a Mathematical program based on previously known equations to determine the design specifications for different models of extruder production, as well as a program that can predict through equations calculated from the interconnected relationships to determine the design specifications for different models of extruder production.

The models used in this research provide a suitable tool to unpack this complexity and making the problem solvable.

After giving general definitions for system terminology, model, simulation, prediction and developing appropriate equations to solve the complexities in the design of extrusion machines, especially those used in oil extraction.

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