PRELIMINARY DESIGN AND CONSTRUCTION OF A PROTOTYPE CANOLA SEED OIL EXTRACTION MACHINE

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ABSTRACT

PRELIMINARY DESIGN AND CONSTRUCTION OF A PROTOTYPE CANOLA SEED OIL EXTRACTION MACHINE

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Growing energy demand in the world force people to investigate alternative energy sources. Unlike coal or other fossil fuels, renewable energy sources are promising for the future. Especially, seed oils are effectively used as energy sources such as fuel for diesel engines. The scope of this study is to develop an oil extraction machine specific to canola seed.

In this study, seed oil extraction methods have been investigated and various alternatives for the extraction machine have been considered. For continuous operation, oil extraction with a screw press is evaluated as the most appropriate solution. Four different prototypes have been designed and manufactured. According to the results of testing of prototypes, they have been modified and gradually improved to increase oil extraction efficiency. The working principle of the selected screw press based on the rotation of a tapered screw shaft mounted inside a grooved vessel. The screw shaft is a single square-threaded power screw having an increasing root diameter from inlet to exit while the outside diameter of the screw shaft is 66 mm. Seeds are taken into the system at

the point where the depth of the screw thread is maximum. Then they are pushed forward by the threads on the rotating screw shaft and pass through inside the vessel. So, the fed seeds are compressed as they move to the other side of the vessel. Recovered oil escapes from high pressure zone and drains back. The oil is drained out from the oil drainage holes that are machined on high pressure zone of the vessel. Besides, the cake is extruded at the end of the vessel and the screw shaft. The cake thickness is adjustable by the axial movement of the screw shaft. By adjusting the cake thickness, different pressures can be obtained.

During the experiments, it is observed that four main features affect the oil recovery rate. These are the geometry of the grooves inside the vessel, the taper angle of the screw shaft, the operating temperature and the rotational speed. With the final prototype, an oil recovery efficiency of 62.5% has been achieved at 40 rpm with 15 kg/h seed capacity. Since the oil content of the seed is taken as 40%, oil recovery rate of the developed oil extraction machine is 3.75 kg/h. This efficiency is determined for a 0.8 mm cake thickness at 1.1 kW motor power.

Keywords: Canola, Seed Oil, Screw Press, Oil Extraction

ÖZ

KANOLA TOHUM YAĞI ÇIKARMA MAKİNASININ PROTOTİPİNİN ÖN TASARIMI VE ÜRETİMİ

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Dünyada gitgide büyüyen enerji ihtiyacı, insanları alternatif enerji kaynakları bulmaya yönlendirmektedir. Bu şartlar altında, kömür ve fosil yakıtlarından farklı olarak yenilenebilir enerji kaynakları gelecek vadetmektedir. Özellikle bunlardan tohum yağı dizel motorlarda yakıt olarak kullanılmaktadır. Bu tezin amacı, kolza bitkisine özel bir tohum yağı çıkartma makinası geliştirmektir.

Bu çalışmada, yağ çıkartma metodları araştırılmış ve çeşitli alternatifler geliştirilmiştir. Değerlendirilen bu alternatiflerin içinden sonsuz vidalı pres seçilmiştir. Dört ayrı prototip üretilmiştir. Bu prototiplerle yapılan testlerin sonucuna göre, prototiplerde değişiklikler yapılmış ve geliştirilmiştir. Geliştirilen yağ çıkartma makinasının çalışma prensibi iç yüzeyi oluklu silindirik bir haznenin içine yerleştirilmiş konik bir sonsuz vidalı şaftın dönmesine dayanır. Sonsuz vidanın dişleri kare profilli ve tek sarımdan oluşup, iç çapı giderek artarken dış çapı 66 mm'de sabittir. Tohumlar sonsuz vidalı şaftın diş derinliğinin en derin olduğu yerden alınırlar. Sonra silindirik haznenin

içinde dönen şafttaki dişler sayesinde ileriye doğru itilirler. Tohumlar ileri doğru ilerlerken sıkışırlar. Ezilen tohumdan çıkan yağ, yüksek basınç alanından geriye doğru kaçar. Yağ, silindirik haznenin üzerine açılmış yağ deliklerinden dışarı çıkar. Bunun yanısıra, posa da silindirik haznenin ve sonsuz vidalı şaftın son kısmında bulunan konik yüzeyler arasından çıkar. Posa kalınlığı ayarlanabilirdir. Çıkış genişliği ayarlanarak, içeride farklı basınçlar yaratılabilir.

Denemeler sırasında, çıkan yağ miktarını etkileyen dört ana faktör saptanmıştır. Bunlar, silindirik haznenin içine açılan oluklar, sonsuz vidanın konik yapısı, sıcaklık ve dönme hızıdır. Geliştirilen makinayla 15 kg/saat tohum işleme kapasitesine ulaşılmıştır. Ayrıca 40 rpm hızındayken, %62.5'luk bir verim elde edilmiştir. Tohumun yağ oranı 40% olarak varsayılmıştır. Bu varsayıma göre çıkarılan yağ miktarı 3.75 kg/saat olarak hesaplanmıştır. Bu verim, system 0.8 mm kalınlığında posa çıkarmaya ayarlanmışken elde edilmiştir. Denemeler sırasında motorun bu verimlilikte harcadığı güç miktarı 1.1 kW olarak ölçülmüştür.

Anahtar Sözcükler: Kolza, Tohum Yağı, Sonsuz Vidalı Pres, Yağ Çıkartma

To My Family,

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TABLE OF CONTENTS

PLAGIARISM iii
ABSTRACT iv
ÖZ vi
ACKNOWLEDGEMENTS ix
TABLE OF CONTENTS x
CHAPTER
1. INTRODUCTION 1
1.1 Renewable Energy 1
1.2 Biomass Energy Potential in Turkey 5
1.3 Balaban Valley Project 5
1.4 Canola 7
1.5 Canola Oil Recovery Process 8
1.6 Scope of the Thesis 10
2. LITERATURE SURVEY ON SEED OIL EXTRACTION 11
2.1 Fundamentals of Fluid Property for the Compressed Seed 11
2.2 Previous Studies for Different Screw Configurations used in Screw Presses 16
2.3 Some Typical Seed Oil Extraction Machines 17
2.3.1 Komet Oil Presses 17
2.3.2 Rosedowns Oil Presses 18
2.3.3 Vincent Screw Presses 20
2.3.4 Strainer Type Screw Presses 21
2.4 Available Patents for Screw Presses 21
2.4.1 Continuous screw press with strainer cage recovering oils under controlled back pressure (1998) (Pub. Num.: DE19715357) 21

2.4.2 Screw press having a plurality of throttle points and at least one cam movable transversely thereto (1994) (Pub. Num.: US5341730) ... 22
2.4.3 Screw press for extracting oil from seeds etc. - has cylinder composed of rings in or between which are passages which can quickly and easily be connected to cooling fluid supply (1992) (Pub. Num.: DE4109229) ... 23
3. CONCEPTUAL DESIGNS FOR OIL EXTRACTION MACHINES ... 25
3.1 Comparison between Oil Extraction Methods ... 25
3.2 Comparison between Screw Shaft Configurations ... 28
3.2.1 Straight Screw Shaft ... 28
3.2.2 Screw with Tapered Shaft ... 29
3.2.3 Screw with Variable Pitch ... 29
3.2.4 Screw with Tapered Shaft and Variable Pitch ... 30
3.2.5 Screw with Reverse Worm ... 31
3.3 Comparison of the Choke Mechanisms for Cake Drainage ... 32
3.3.1 Nozzle Type Choke Mechanism ... 32
3.3.2 Conical Type of Choke Mechanism ... 33
3.4 Comparison of Oil Drainage Systems ... 34
3.4.1 Drilled Holes ... 34
3.4.2 Lining Bars with Spacers ... 34
3.4.3 Fiber Filter Sleeves ... 35
3.4.4 Barrel Rings ... 35
3.5 Conceptual Designs for the Canola Seed Oil Extraction Machine ... 36
4. PRELIMINARY AND DETAILED DESIGN OF THE OIL EXTRACTION MACHINE ... 43
4.1 Preliminary Design ... 43
4.1.1 Design Tree ... 43
4.1.2 Skeleton ... 45
4.1.3 Hopper ... 45
4.1.4 Main Body ... 46
4.1.4.1 Screw Shaft ... 46

4.1.4.2 Vessel 47
4.1.4.3 Flange 48
4.2 Detail Design Calculations 49
4.2.1 Design Specifications 49
4.2.2 Important Design Inputs 50
4.2.2.1 Required Oil Recovery Rate 51
4.2.2.2 Maximum Available Power 54
4.2.3 Design Calculations for the Prototype 54
4.2.3.1 Screw Shaft Design 55
4.2.3.2 Vessel Design 61
4.2.3.2.1 Oil Drainage Zone 61
4.2.3.2.2 Groove Profile Selection for the Inside Vessel 65
5. MANUFACTURING AND TESTING OF PROTOTYPE OIL EXTRACTION MACHINES 68
5.1 First Prototype 68
5.2 Second Prototype 69
5.3 Third Prototype 72
5.4 Fourth Prototype 78
6. DISCUSSION AND CONCLUSION 87
6.1 Discussion on Manufacturing and Assembly Stage of the Prototypes... 87
6.2 Discussion on the Testing of the Prototypes 89
6.3 Conclusion 91
REFERENCES 94
APPENDICES
A. Screw Thread Thickness Calculations 99
B. Solvent Extraction Experiment for Calculation of the Residual Oil Content in the Cake 100
C. Exploded Views and Dimension Views of the Prototypes 102

LIST OF TABLES

Table 3.1: Comparison between solvent and mechanical types of seed oil extraction methods 27
Table 4.1: Volumetric Flow Rates of oil and cake for 50kg/h seed capacity for 85% efficiency 54
Table 4.2: The results of the three unknown parameters 59
Table 5.1: Residual oil contents for two cake thickness samples at 40 rpm 81
Table 5.2: Volumetric flow rate of the contents in the screw press with 50 kg/h seed capacity and 62.5% efficiency 82
Table 5.3: The electric currents and the power consumed by the turning machine at different operating conditions 85
Table 6.1: Technical data for the developed screw press 91

LIST OF FIGURES

Figure 1.1: Renewable Energy Consumption of 1949-2003 [2] 2
Figure 1.2: Schematic Illustration for Balaban Valley Project 6
Figure 1.3: a) Flower of Canola, b) Seed of Canola.. 7
Figure 1.4: World Oil Seed Production 2004 [13] 8
Figure 1.5: Canola Oil Recovery Process [15].. 9
Figure 2.1: Temperature – viscosity performance of rape seed oil [27] 12
Figure 2.2: Schematic Illustration of Permeability [33].................................... 14
Figure 2.3: Rheological Model for Consolidation [33]..................................... 15
Figure 2.4: Compression Test Setup [33]... 16
Figure 2.5: Illustration of principle of single-feed double stage compression used in the developed screw press 17
Figure 2.6: Detailed Picture of Screw Press Manufactured by Oekotec, IBG-Monforts [36]... 18
Figure 2.7: Detailed views of the screw shaft of Rosedowns Screw Presses [37] 19
Figure 2.8: Detailed Drawing of Screw Press Manufactured by Rosedowns [37] 20
Figure 2.9: Screw with Resistor Bars manufactured by Vincent Corporation [38] 20
Figure 2.10: Strainer Type Screw Press [27] 21
Figure 2.11: Drawing of the patent DE19715357 [39] 22
Figure 2.12: Drawing of the patent US5341730 [39].. 23
Figure 2.13: Drawing of the patent DE4109229 [39] 24
Figure 3.1: Basic oil extraction methods.. 25
Figure 3.2: Illustration of a straight screw shaft.. 29
Figure 3.3: Illustration of a screw with tapered inner shaft................................ 29

Figure 3.4: Illustration of a screw with variable pitch 30
Figure 3.5: Pressure vs. Length graphs of the screw with variable pitch and the screw with tapered shaft 30
Figure 3.6: Illustration of a screw with tapered shaft and variable pitch 31
Figure 3.7: Illustration of a screw with reverse worms 31
Figure 3.8: Nozzle Type Choke Mechanism 32
Figure 3.9: Conical Types Choke Mechanisms 33
Figure 3.10: A view of the main press cage of the Rosedowns screw press [37] 34
Figure 3.11: A view of the fiber filter sleeves of the Vincent screw press [38]. 35
Figure 3.12: A view of barrel rings, screw shaft and bearing parts of the Mini 40 screw press manufactured by Rosedowns [37] 35
Figure 3.13: Detailed View of the First Conceptual Design 36
Figure 3.14: Illustration of the flow of the seeds in the first conceptual design 37
Figure 3.15: Orientation and front views of the barrel plates of the first conceptual design 38
Figure 3.16: Detailed View of the Second Conceptual Design 38
Figure 3.17: Illustration of the grinder during cracking of a seed 39
Figure 3.18: The dimensions of the outer and inner grinder teeth 39
Figure 3.19: Detailed View of the Third Conceptual Design 41
Figure 3.20: Detailed View of the Fourth Conceptual Design 42
Figure 4.1: 3D model of the developed screw press 44
Figure 4.2: Design Tree of the Screw Press 44
Figure 4.3: 3D model of the developed skeleton 45
Figure 4.4: 3D model of the developed screw shaft 47
Figure 4.5: 3D model of the developed vessel 48
Figure 4.6: 3D model of the assembly of the vessel and flange 49
Figure 4.7: Pressure, change in volume of cake and oil expressed vs. time graph [32] 52
Figure 4.8: Illustration of force directions on the unwrapped thread while pushing the seeds forward 55

Figure 4.9: Graph of assumed pressure distribution on the screw shaft from the inlet to outlet ... 57
Figure 4.10: Graph of height distribution through the screw shaft ... 58
Figure 4.11: Free Body Diagram of the screw shaft ... 60
Figure 4.12: Illustration of inside and outside pressure for the vessel ... 62
Figure 4.13: $\frac{K_t}{(1-\frac{D_h}{L_h})}$ vs. L_h graph ... 64
Figure 4.14: Illustration of the curvature shaped grooves and its dimensions ... 65
Figure 4.15: Detailed view of a groove from the front view of the vessel at the cake outlet section ... 66
Figure 5.1: First Prototype of Screw Press ... 68
Figure 5.2: Second Prototype of Screw Press ... 70
Figure 5.3: Extruded cake view after the third experiment ... 71
Figure 5.4: 3D model of the third prototype ... 72
Figure 5.5: View of the third prototype after the first experiment ... 74
Figure 5.6: Heating Device mounted onto the third prototype ... 75
Figure 5.7: Cake view with thickness of 0.2 mm ... 75
Figure 5.8: View of oil leaking out from the vessel ... 76
Figure 5.9: View of the recovered oil after the failure ... 77
Figure 5.10: View of the failure on the vessel ... 77
Figure 5.11: 3D model of the fourth prototype ... 78
Figure 5.12: View of the total system after the first experiment ... 79
Figure 5.13: View of the extruded cake ... 80
Figure 5.14: View of the oil and cake recovery after the third experiment ... 81
Figure 5.15: Illustration of the cake drainage section with geometrical dimensions ... 83
Figure 5.16: The temperature change of the screw shaft at 30 rpm for the first 15 minutes and at 40 rpm for the rest ... 85
Figure 5.17: The temperature change of the vessel at 30 rpm for the first 15 minutes and at 40 rpm for the rest ... 86

Figure A.1: Axial force distribution applied on the threads along the thread length 99
Figure B.1: Flow chart of the grinding process of the cake flakes..................... 100
Figure B.2: Soxhlet extraction apparatus 101
Figure C.1: Exploded view of the first prototype..................... 102
Figure C.2: Some important dimensions of the first prototype..................... 103
Figure C.3: Exploded view of the second prototype..................... 104
Figure C.4: Some important dimensions of the second prototype 105
Figure C.5: Exploded view of the third prototype..................... 106
Figure C.6: Some important dimensions of the third prototype..................... 107
Figure C.7: Exploded view of the fourth prototype 108
Figure C.8: Some important dimensions of the fourth prototype..................... 109

LIST OF SYMBOLS

a	: Undetermined coefficient of the third order equation of P(ξ)
$A_{annular}$	: Area between inside wall of the vessel and root diameter of the screw shaft
A_c	: Projection of the annular area of the cake drainage cones
d_1	: Smallest root diameter of the screw shaft
d_c	: Larger diameter on the conical surface at cake drainage
D_h	: Diameter of the oil draianage hole
d_s	: Outside diameter of the screw shaft
f	: Kinetic friction coefficient between the seeds and the machine components
F_a	: Axial unit force on the threads
F_{ts}	: Tangential force on the screw shaft
F_{xs}	: Axial force pushing the seeds forward
H(ξ)	: Function of the thread depth along the thread length
H_1	: Heigth of the thread at the starting point of the turns of the screw shaft
H_2	: Heigth of the thread at the end point of the turns of the screw shaft
h_g	: Depth of the grooves
K_f	: Stress concentration factor for threads
K_t	: Stress concentration factor for holes on the vessel
l	: Pitch of the screw
L_g	: Length of the grooves
L_h	: Distance between two oil drainage holes
L_s	: Length of the threaded portion of the screw shaft

L_t	: Thread length for one turn
L_v	: Length of the vessel
M_{oil}	: Mass flow rate of oil
M_s	: Moment at the most critical cross section arising from the weight of the screw shaft
n	: Factor of safety
N	: Normal force on the thread of the screw shaft
N_h	: Number of oil drainage holes
$P(\xi)$	: Function of the pressure distribution along the thread length
P_1	: Pressure at the inlet of the screw shaft
P_2	: Pressure at the outlet of the screw shaft
P_{max}	: Maximum pressure
P_o	: Outside Pressure
Q_{cake}	: Volumetric flow rate of the cake in the screw press
$Q_{compressed\_seed}$	: Volumetric flow rate of the compressed seeds in the screw press
Q_{oil}	: Volumetric flow rate of the oil in the screw press
$Q_{uncompressed\_seed}$	: Volumetric flow rate of the newly fed seeds into the screw press
R_s	: Reaction forces acting on the screw shaft at two ends
r_{vi}	: Inside radius of the vessel
r_{vo}	: Outside radius of the vessel
SC	: Seed capacity rate of the screw press
S_{total}	: Complex power
S_y	: Yield strength
t	: Tooth thickness
T_s	: Torque of the screw shaft
U	: Fluid pressure
$Volume_R$	: Real swept volume of the seeds

$Volume_T$	: Theoretical swept volume of the seeds
V_{rms}	: Root mean squared voltage
W_s	: Weight of the screw shaft
W_v	: Weight of the vessel
α	: Taper angle of the screw shaft
η	: Efficiency of the screw press
θ	: Taper angle of the cake discharge
ξ	: Axes of thread length
ρ	: Density of canola oil
ς	: Feeding efficiency
σ_i	: Cake pressure
σ_t	: Total applied pressure onto the seeds
$\sigma_{tangential}$ σ_{radial} $\sigma_{longitudinal}$	: Principle stresses occur inside the vessel
τ_{yz}	: The nominal shear stress in torsion in yz plane of the screw shaft
Φ	: Oil content in the seed
ω	: Rotational speed of the screw shaft
$\#_{turns}$	: Number of turns on the screw shaft

CHAPTER 1

INTRODUCTION

1.1 Renewable Energy

Energy is the source of life, however there is a limited supply of energy on earth. Thus, renewable energy utilization must be widespread all over the world; otherwise the end of life would be unavoidable. One other important reason to prefer renewable energy is the environmental pollution depending on the emission of the burning of fossil fuels. These emissions such as CO_2 and sulphur causes greenhouse effect which lead to contamination and warming of the Earth. Therefore, the utilization technologies of the renewable energy resources must be encouraged and developed to increase the demand for renewable energy types. Renewable energy resources are inexhaustible and environmentally friendly, since the energy, which is reversed back, comes from the sunlight, wind, falling water, waves, geothermal heat, or biomass, in other words, the nature. Each type of renewable energy has its own special advantages.

From the early ages, the energy need of the world has been partially compensated by renewable energy types. Until the mid-1800s, mostly wood was used as an energy source. Also, many large plants and mills were located near the streams to generate electricity during the industrial era in Europe and North America [1]. In the mid-1850s, as the fossil fuel usage, which are mainly coal and oil, increased, production plants were not limited to locate by rivers or streams because instead of water, fossil fuels were started to be used in manufacturing. As a result, industry started to grow up at the locations that are closer to the sources of markets, seaports and raw materials. From 1950's to nowadays, it is shown in Figure 1.1 that the amount of renewable energy consumption has increased. Increase in amount and variety of renewable energy resources is directly proportional with the increase in population, which leads to increase in energy demand. The renewable energy sources are growing in importance, but combined still make up less than 15% of world's energy consumption.

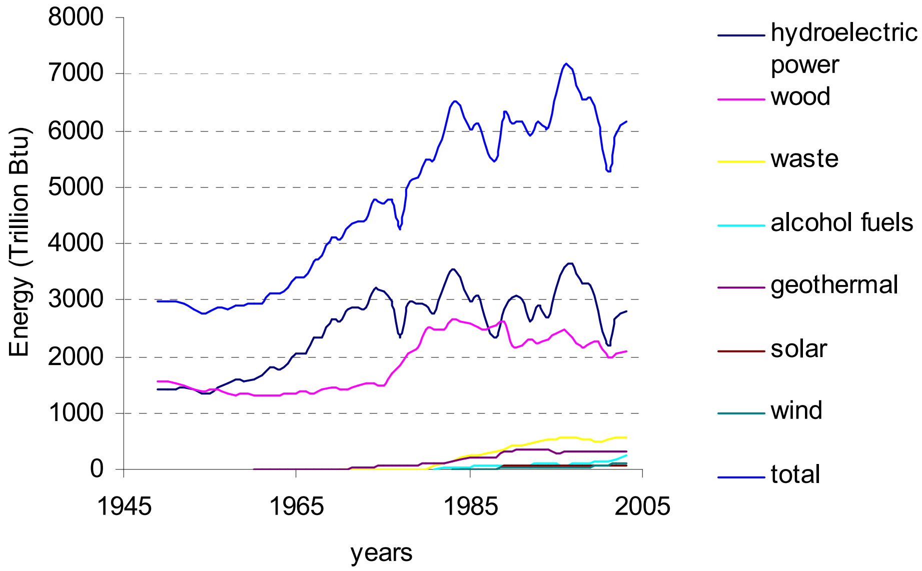


Figure 1.1: Renewable Energy Consumption of 1949-2003 [2]

In the last century, mostly coal and fossil fuel sources have been utilized especially in transportation. According to the current consumption rates, the scenarios about how long the fossil fuels would last for different cases are not promising if sufficient precautions will not be taken [3]. There are basically six types of renewable energies.

- Solar energy

The sun can be used to produce heat, light, hot water, electricity, and even cooling, for homes, businesses, and industry [4]. The two common ways to produce electricity from the sun are the solar cell technologies also called photovoltaic cells, and solar-thermal technology. Photovoltaic systems consist of wafers or other conductive materials. When sunlight hits the wafers, a chemical reaction occurs and electricity is released [5]. They are used in all kinds of equipments, from calculators and watches to roadside emergency phones.

Solar-thermal technologies collect the sun's rays with mirrors or other reflective devices in order to heat a liquid. By heating the liquid, its vapor is used to activate a generator and produce electricity. There is another way to benefit from the sun that is buildings` windows constructions are adjusted according to sunrise and sundown directions. Consequently, consumption of electricity, for cooling in summer and for warming in winter, would be much more cost effective.

- Geothermal energy

The simplest meaning of geothermal is the heat coming from the Earth. An extreme amount of heat is contained in liquid rock called magma that is in the interior of the Earth. These heat zones might be located close to the surface by the help of the convective circulation. Convective circulation is kind of a deep circulation of ground water which meets the heat along the fracture zones of the magma and discharges as hot springs. For direct use applications, the hot water and/or steam is piped to the surface by drillers in order to generate electricity by turning a steam turbine. This electricity is used to heat houses or in various applications for industry.

- Hydroelectricity

Hydropower converts the energy of the flowing water into electricity. The quantity of electricity depends on the volumetric flow rate of the water and the height of water surface from the turbines. Hydropower plants produce about 24 percent of the world's electricity and supply power to more than 1 billion people all over the world [6].

- Wind Energy

The energy from the wind can be collected by wind turbines and windmills to generate electricity. Wind turbines can be used as stand-alone applications, or they can be built close together called wind farm. Electricity acquired from the stand-alone turbines is usually used for water pumping or communications whereas in the wind farms, hundreds of turbines provide electricity to the power grid. Other utilities of the wind turbines are charging batteries, pumping water, and grinding grains of agricultural products [7].

Wind power stations can be constructed quicker than other conventional sources [8]. Further, wind power has no constraints on any other non-renewable energy sources that acquiring process of the electricity from the wind turbines is independent of fuel consumption. The independency on any other type of energy is very advantageous during obtaining electricity from renewable energy in rural areas since transportation and cost of the fossil fuel is sometimes difficult to supply for far villages. For this reason, small turbines can be used effectively in the villages to compensate the energy needs.

- Biomass energy

Biomass is an important source of energy worldwide and is abundantly available on earth. Many other types of biomass energy can be used now which consists of trees, agricultural crops and associated residues like plant fiber, animal wastes, and organic industrial waste [9]. Emission from burning of biomass is carbon dioxide neutral since it absorbs the same amount of carbon dioxide when growing as a plant. Biomass can be used as a solid fuel, or converted into liquid or gaseous forms. It can be used to produce electric power, heat, chemicals, or fuels. There are basically three types of biomass applications:

Biofuels: Biomass can be directly converted into liquid fuels, to be used in transportation such as cars, trucks, buses, airplanes, and trains.

Biopower: Biomass can be burned directly or converted into liquid or gas state to generate electricity or industrial process heat and steam.

Bioproducts: Petroleum based products can be substituted by bioproducts which are not only made from renewable sources also they usually requires less energy for production.

1.2 Biomass Energy Potential in Turkey

Lack of energy for the future is threatening the world, so as Turkey. Turkey is able to compensate the energy need of the country from self natural energy sources. Since Turkey cannot utilize its energy potentials effectively, some precautions must urgently be taken to compensate the future energy need. Renewable energy is one of the most important alternatives to avoid this approaching possible danger.

There are mainly six types of renewable energy sources in Turkey which are: solar, geothermal, hydropower, wave, wind, and biomass. Among them, biomass supplies 10% of the total energy consumption of Turkey [10]. Also, the technology required for the provision of the biomass energy is not as complicated and costly as the other type of renewable energies.

1.3 Balaban Valley Project

Turkey, once producing its agricultural products exceedingly, now imports even some of the major agricultural products. This condition has been developed throughout the years and has some important reasons. In Turkey, there has been a large migration from rural areas to big cities in the last 50 years. Additionally, in 60`s some European countries needed cheap labor, so because of the economical reasons, unequipped people, in rural areas, started to migrate to these countries. Now, nearly 30% of Turkish population lives in villages. As a consequence, the number of the farmers decreased proportionally.

In the last 50 years, high inflation rates, resulted in high cost of fertilizers and pesticides and especially fuel in agricultural areas. This is one other main reason for the insufficient utilization of agricultural potential in Turkey.

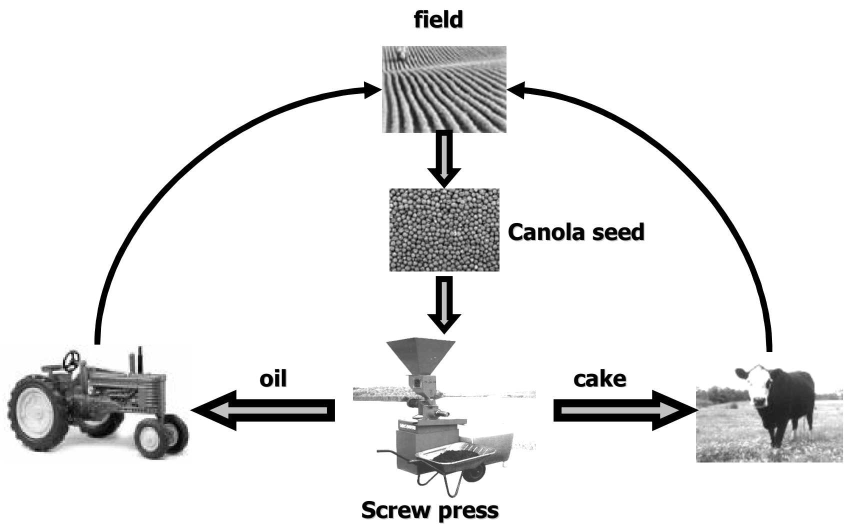


Figure 1.2: Schematic Illustration for Balaban Valley Project

Renewable energy technology can capture natural sources to convert into a usable form. Construction of power grids to far rural areas may not be a wiser solution rather than setting up a renewable energy technology for the same place. In such a case, eco villages should be supported and developed. `Balaban Valley Project` is supported by Middle East Technical University, Ankara University, Ankara Güneşi KOOP (Non Governmental Organization), Türk Traktör Company, Kırıkkale Agricultural Authority. This project is proposed for improving the quality of life in a rural area. For carrying out the project, four villages are selected located 60 km east of Ankara with a population of 1300 people. Expected result is a self-sustaining village, using renewable energies. One of the main operations in the project is substituting the fossil fuel with the biofuel and reducing the cost of the fuel used in tractors.

In the Balaban Valley, there will be biomass energy cycling (Figure 1.2) that the canola crops will be separated into oil and cake by an extraction machine, where cake will be a nutritious food to animals, and oil will be used as biofuel in tractors to plow the fields. The cycle will go on by growing up new canola crops besides the other agricultural foods. Besides, the plowing of the fields will be done by tractors and the animals eating the cake of the canola will supply fertilizer for the field. This thesis study is a part of the Balaban Valley Project which concentrates on achieving a self-sustaining village.

1.4 Canola

Canola (Figure 1.3) is a name given to edible rapeseed [11]. It is from a mustard family which consists of 3000 species. The name comes from “Canadian Oil” since it was registered by the Western Canadian Oilseed Crushers in 1979.

a)

b)

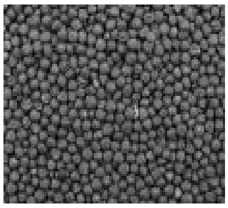


Figure 1.3: a) Flower of Canola, b) Seed of Canola

The relatives of this crop have been cultivated for food since the old ages. Also in the 13th century, Europeans used the rapeseed as a source of fuel and food. During the World War II, rapeseed production increased rapidly due to its use as lubricants for marine engines because of the adhesive property [12].

Rapeseed (Brassica and related species, Brassicaceae) is now the second largest oilseed crop in the world providing 12% of the world’s supply as shown in Figure 1.4 [13]. Seeds of these species commonly contain 40% or more oil and produce meals with 35 to 40% protein [11]. .

In a compression engine, there is a huge amount of heat and pressure. With respect to this situation vegetable oils tend to become crystalline and cannot lubricate effectively on cold days [11]. In 1996, a vegetable based motor oil which has the ability to lubricate on cold days just like the petroleum products was studied [14].

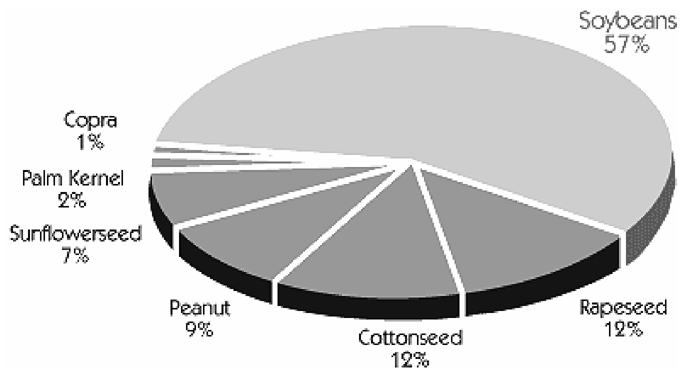


Figure 1.4: World Oil Seed Production 2004 [13]

The uncultivated crop has two harmful properties for human health. The first one, the oil contains less than 2% erucic acid which is a fatty acid leading to heart disease. And the second one, the cake part of the seed contains 3 mg/g of glucosinolates which breakdown products that are toxic to animals [12]. Cultivars which do not provide these conditions are used for non-edible conditions such as industrial lubricants and hydraulic fluids.

1.5 Canola Oil Recovery Process

Canola oil recovery process is a combination of several stages such as cleaning, pretreatment, extraction, filtration and lastly packaging and storage as seen in Figure 1.5.

The first step of the overall process is cleaning process of the seeds. The common cleaning methods are air aspiration, indent cylinder cleaning, sieve cleaning, magnetic separator or a combination of these. By cleaning process, foreign materials like broken stone, sand, or metallic powder are avoided from mixing into seed barrel. This is an important process, because the particles which have high hardness coefficient factors may damage the machine parts.

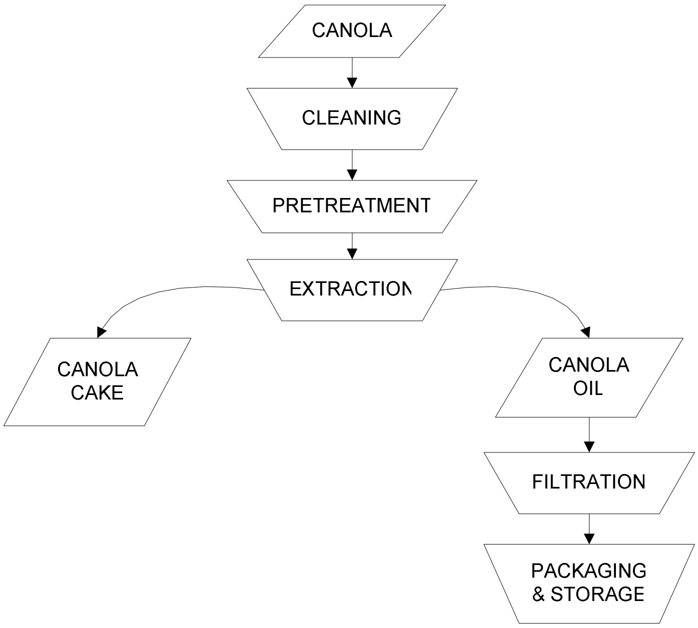


Figure 1.5: Canola Oil Recovery Process [15]

Secondly, pretreatment stage is required for increasing the amount of oil recovery by preconditioning the seed using some methods like heat treatment, moisture adjustment, etc.

At the extraction stage, there are basically two methods which are called mechanical and solvent extraction. They are used in different application areas depending on the desired production property, capacity and economical aspects.

After the extraction process, canola cake can be directly used as animal feeding. Canola oil is applied one more process which is the filtration. Filtration is the clarification of contaminants, such as fine pulp, water, and resins from the oil. Leaving the oil undisturbed for a few days is one of the cheapest and the easiest way of clarification. In case of a requirement for improved purity of the oil, then a fine filter cloth can be used. Furthermore, the oil can be heated to remove the left water particles and kill any bacteria.

After filtration process, the oil can be used directly in diesel engines as a biofuel. Packaging and storage of the oil is one of the most important step, because keeping the oil in dry containers made up of glass or plastic avoids rancidity. Also, colored containers increase the shelf life of the oil since the oil is prevented from sun rays. The shelf life of oil is usually 6 to 12 months, if it is packaged and kept away from heat and sunlight properly [16].

1.6 Scope of the Thesis

The objective of this study is design and manufacture of an oil extraction machine specific to canola seed. The obtained oil will be used in the diesel engines of the tractors on the rural areas. This will eliminate the dependency on diesel fuel for the farmers and contribute to the economy in the rural areas.

Expected seed capacity of the oil extraction machine is 50 kg/h in order to meet the requirements of the selected village. The village is selected within the Balaban Valley Project which has been presented in Section 1.3. Another design constraint is the maximum available power for the developed machine. The maximum power is limited according to the motor powers of the commercial oil extraction machine available in the markets for the same seed capacity.

In Chapter 2, the previous studies and the mechanisms of the developed oil expellers are presented. In Chapter 3, different conceptual designs are investigated and developed. In Chapter 4, in the preliminary design section, functionalities of the components of the selected alternative are explained. In the detail design calculations section, geometrical dimensions, stress analysis and the material selection of the machine components are identified. In Chapter 5, manufacturing of the prototypes and the experiments with these prototypes are presented. In Chapter 6, discussion, conclusion and the future work about this study is presented.

CHAPTER 2

LITERATURE SURVEY ON SEED OIL EXTRACTION

2.1 Fundamentals of Fluid Property for the Compressed Seed

The previous theoretical and experimental studies about the flow behavior of the compressed seeds have provided considerable contributions into understanding of the fundamentals about seed oil extraction process. A mathematical model of oil and cake flow during the compression process requires certain assumptions depending on real application conditions. Thus, the behavior of the flow cannot be explained by only specific theoretical considerations.

Ohlson [17] focused on the optimization of the parameters such as pressure, temperature and moisture content of the seeds in order to optimize the oil recovery rate. Dehulling pretreatment before compression resulted in higher oil recovery rate. The reason for this is that hulls decrease the compressibility of the seeds because they are harder than the inside volume of the seeds, so that more gaps, filled with oil, occur in compressed hulled seeds. Also, resizing into smaller volumes before the compression process has considerable effects on the oil recovery rate. Presizing of the seeds reduces the required force that is used for compressing the seeds. Preheating is one of the most effective one among all pretreatments. Since the viscosity of the canola oil is high at room temperature, separation and leakage of the oil particles is comparatively lower than at higher temperatures. The viscosity specifies the flow velocity of the fluid through porous medium. At higher temperatures, the viscosity of the oil decreases, and oil recovery rate increases. However, there is an important consideration about the maximum allowable temperature which is applied to the seeds because quality of the oil is directly related with the applied temperature. As a consequence, the preheating is allowed in certain ranges of temperature to acquire quality product. Dehulling, resizing, preheating studies, aided to increase the oil recovery rate from 50% to 80% [18-25].

Singh and Bargale [26] studied about the influence of moisture on oil recovery rate. In order to make the experiments they also designed a screw press which is slightly different than the typical conventional types which will be described in Section 2.3. In the experiments, the maximum oil recovery rate of 90.2 % is obtained at moisture content 7.5 % (wet basis). The moisture rise in the seeds has some certain advantages. It decreases the maximum working temperature which must be maintained under 90ºC to conserve the cake and oil quality. Another benefit of the moisture rise is decreasing the specific energy consumption during the compression process.

The flow rate of oil is higher at higher temperatures which means higher oil recovery rate. It is related with the kinematic viscosity of the oil which changes proportionally with the temperature as represented in Figure 2.1. Kinematic viscosity of oil is inversely proportional with temperature. As it can be seen in Figure 2.1, viscosity gradient is very large between -5°C and 30°C [27]. After 30°C, since the slope of the curve is small, temperature increase slightly affects the viscosity.

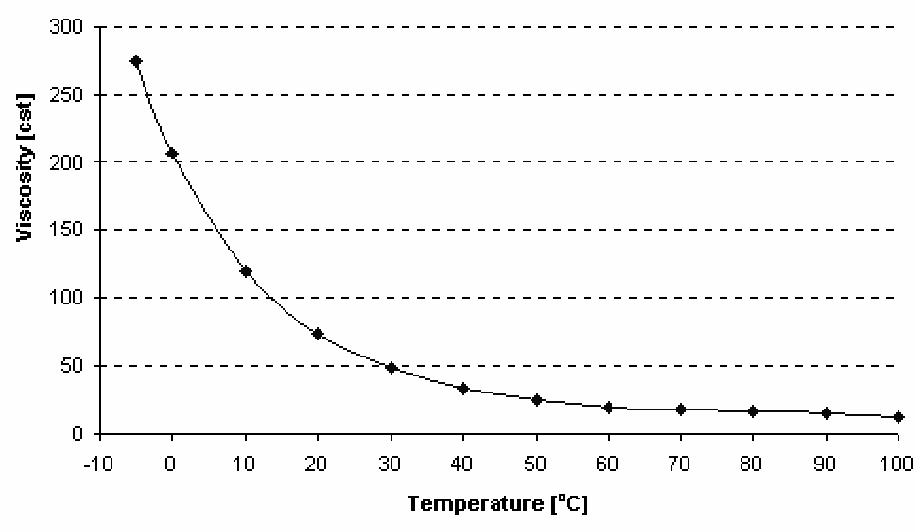
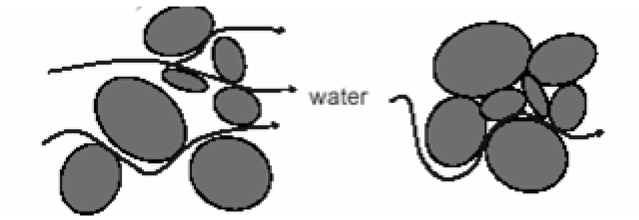


Figure 2.1: Temperature – viscosity performance of rape seed oil [27]

Regarding to Ohlson [28], temperatures above 90°C adversely affect the cake and oil quality. Temperature increase can also occur during the compression process, between the compressed seeds and the machine components. Also, with a temperature rise, not only the oil quality is affected, but also the maximum yield stress of the materials, which are exposed to frictional heat, decrease.

Omobuwajo et al. [29] developed a theory for extrusion pressure and oil flow rate by assuming that the flow of compressed seeds behave like a fluid with a variable density in the annular space. Heat, generated from the friction between compressed seeds and machine components, causes a temperature distribution through the compression module of the extraction machine. Accordingly, the flow is assumed as isothermal variable density flow after the steady state is attained. In this assumption, the fluid (oil and cake) is taken as non-Newtonian, and is applied Ostwald-de Waale model called the power law equation [30]. By using the assumptions and related equations, a simplified mathematical model is studied instead of the actual physical system. The results were determined with a deviation of 16% to 27% between the predicted data and experimental data. The deviations in the results mostly depend on the simplifications in the mathematical model. One of the simplifications is assuming that the temperature distribution attains a steady state after 15 minutes the process starts, however 15 minutes after a temperature gradient can still be observed through the compression module [31]. Thus, energy balance equation would be incorporated into the formulation of the flow behavior in the further studies.

According to Mrema and McNulty [32], the theory behind the mathematical model of the compression of seeds depends on the combination of three basic theories which are firstly Hagen Poiseulle equation for flow of fluids in pipes, secondly Terzaghi's theory for consolidation of the saturated soils and thirdly Darcy's law of fluid flow through porous media for describing the flow of oil through the compressed seeds. They have combined these equations and derived a pressure equation, written in terms of time and height, with certain boundary conditions. These equations are used in predicting the resultant oil recovery rate for certain experiments. Consequently, good agreement was obtained between experimental and theoretical data with minimum error arising from the empirical data and the environmental conditions. The experimental results were closer to the theoretical results for the constant load application and less satisfactorily in the linear increasing load applications. The oil recovery rate depends on the permeability and consolidation property of the seed assuming that other environmental conditions are constant. Permeability is a measure of how easily a fluid can pass through a porous medium as seen in Figure 2.2.



a) Easy to flow, high permeability
b) Difficult to flow, low permeability

Figure 2.2: Schematic Illustration of Permeability [33]

Theoretical equations behind permeability depend on Darcy's law of flow through porous medium where the fluid flow rate is proportional with the area of drainage, coefficient of permeability and hydraulic gradient.

Other determinative constraint for the oil recovery rate is consolidation which is an adjustment of soil particles, in response to compressive stress that results in lower porosity. There is a mechanical analogy between the experimental setup in Figure 2.3 and compressibility of soil called consolidation. The spring is assigned to soil frame, water matches with porosity in soil, volume of cylinder is the volume of soil, tap is the permeability and pressure gauge is the pore pressure in this experimental setup. When Q load is applied onto the top of the spring, fluid pressure increases. However, at this position, no force is applied to spring since whole pressure is carried by water. After tap is opened, water rushes out until the Q load and the back force on the spring are balanced.

Although Q load is increased continuously, the lowering frame will definitely stop at a time at which the spring reaches its minimum length. At the equilibrium point, pressure of water is equal to atmospheric pressure.

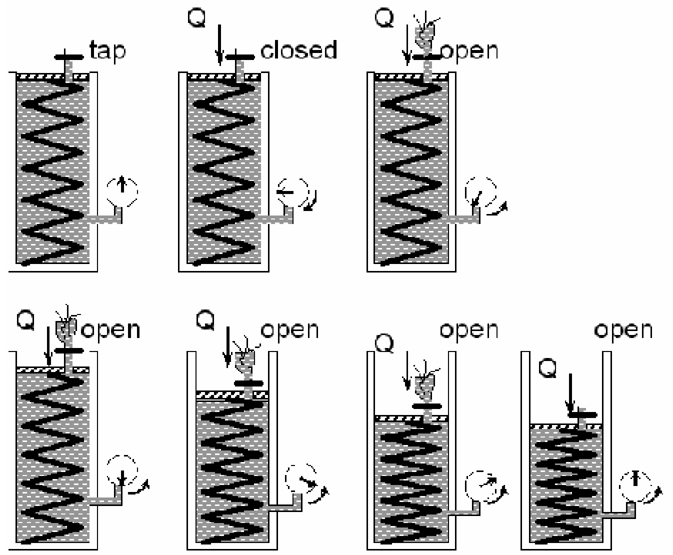


Figure 2.3: Rheological Model for Consolidation [33]

The idea of the experimental setup used by Mrema and McNulty [32] was in accordance with this setup logic. The uniaxial compression test setup is shown in Figure 2.4. Just like the rheological model, seed oil rushes out from the porous stone depending on the applied force. In theory, the compression process continues until any gaps and any oil particles are left inside the compressed cake, however in practice, cake would never be 100 % free from gaps and oil.

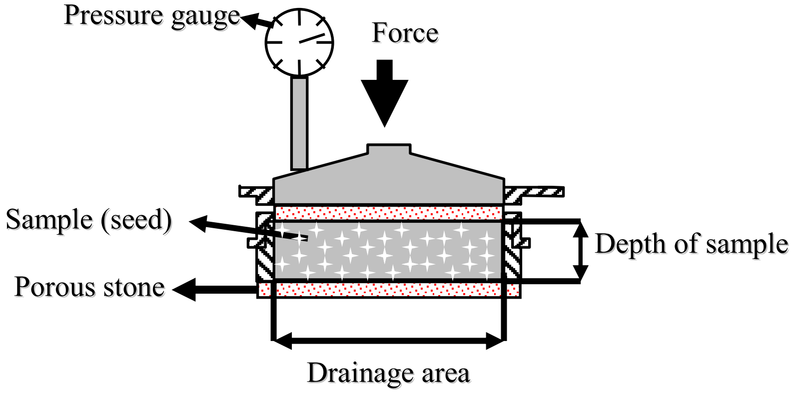


Figure 2.4: Compression Test Setup [33]

Unlike the previous studies that used constant average properties, Bargale et al. [34, 35] developed a mathematical model by using experimentally measured time-varying oilseed properties like coefficient of permeability and coefficient of consolidation. Predictions of oil recovery yields versus time for extruded soy samples were good enough whereas for mechanical pressing of sunflower seeds with hulls were unsatisfactory. Errors mostly depend on the errors in measurement of the coefficient of permeability and the initial sample depths.

2.2 Previous Studies for Different Screw Configurations used in Screw Presses

Singh J. and Bargale P.C. [26] designed a screw press with two tapered screws which are mounted adjacently and concentrically as shown in Figure 2.5. The seeds are compressed in two stages instead of one compression that is prior to exit. In this design, instead of a single stage compression as in the conventional screw presses, a compression ratio of 5:1 in the primary section and 3:1 in the secondary section is used. As a result, the design configurations avoids the possible damages of choking and jamming occurrences, which causes wear and tear of the machine components and results in energy losses. Also, pressure required to recover the oil with 80% efficiency is decreased to the levels at which choking and jamming cannot occur.

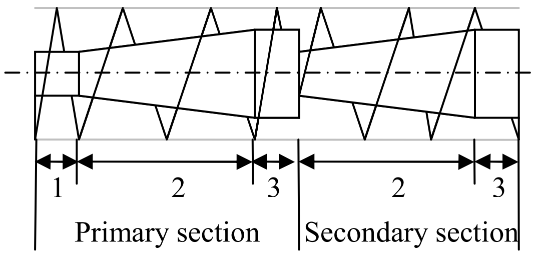


Figure 2.5: Illustration of principle of single-feed double stage compression used in the developed screw press

2.3 Some Typical Seed Oil Extraction Machines

Although the compression is generated by a screw in all types of screw presses, there are several differences in their drainage mechanism principles. Some of the oil presses available in the industry are described in the following subsections.

2.3.1 Komet Oil Presses

In this type of screw press, oil leaks out from the holes as represented in Figure 2.6. The holes are drilled on the vessel [36]. The oil drainage hole has a larger diameter outside the vessel and this diameter continues up to few millimeter thickness of the vessel. This small thickness of the vessel is drilled with a smaller diameter. Most probably, the reason for the short length of the smaller hole is to prevent it from choking with cake. Also, oil drainage zone is far from the cake drainage zone. At the cake drainage zone, cake pressure is maximum. So, if the oil drainage holes were drilled close to the cake drainage zone, then the holes can be choked with cake easily.

Dry cake extrudes from the nozzle. At the cake drainage, there is a heating system. Heat provides higher oil yield and lower residual oil in the cake. In this type of screw presses, different kinds of seeds can be compressed by changing the nozzle and the rotational speed of the screw shaft.

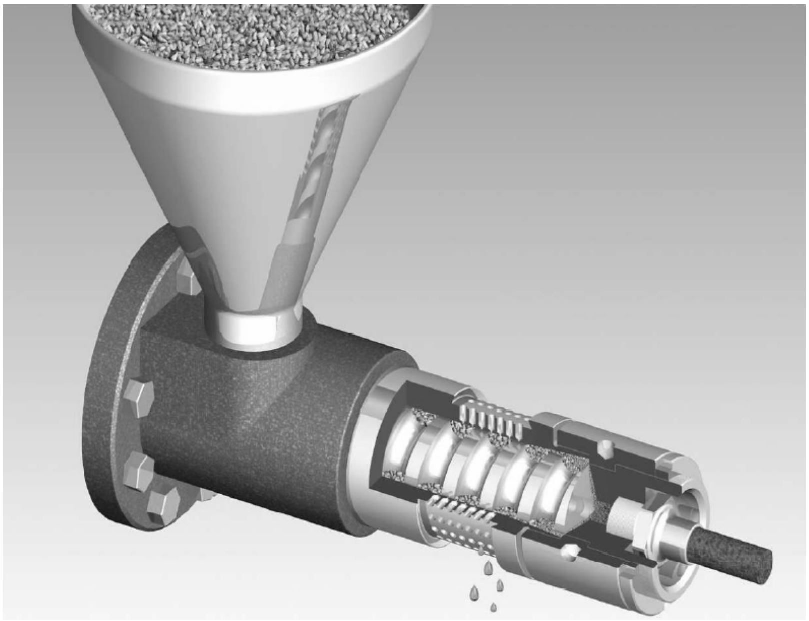


Figure 2.6: Detailed Picture of Screw Press Manufactured by Oekotec, IBG-Monforts [36]

2.3.2 Rosedowns Oil Presses

A complete system of a Rosedowns screw press [37] is represented in Figure 2.8. The system is divided into subgroups as:

1- Main Gearbox: It transmits the power of the motor to the screw shaft. Gearboxes should be separated as far as possible for the hot and dirty environment of the pressing sections. The feeding section of the screw shaft is the cooler and lower pressure end of the press. Therefore the best choice for the drive position is the feeding end of the screw shaft.

2- Feeding Section: It is composed of mainly three parts which are the feed inlet, the horizontal feeder and vertical feeder. Seeds are poured into the feed inlet. Then with the help of the variable speed drive of the horizontal feeder, the flow of feed is controlled. Vertical feeder prevents bridging in the cage inlet and ensures that the seeds pass into the vessel.

3- Bearings: There are two kinds of bearings. One of them is called thrust bearing and it carries the thrust loads generated by the press. The other bearing is the discharge end bearing and it is used for supporting the shaft when there is no load or light load inside the press. Without this bearing, the screw shaft can hit inside the walls of the vessel.

4- Cages: For longer presses, the cage is divided into two parts in order to keep the main cage to a more manageable size for maintenance operations. The inside cage is composed of lining bars separated by spacers. The size of the spacers can be altered for different kinds of seeds by changing the drainage gaps.

5- Screw Shaft: The screw shaft is the key functional part of a screw press. The screw shaft has multi-stage compressions in order to reduce the required pressure. In recent years the multi-stage, lower compression screw shaft has led to significant improvements in performance, wear life and power consumption. As represented in Figure 2.7, at the compression stage, the screw shaft becomes tapered where the inside vessel diameter decreases. Therefore, pressure increases at the decreased annular area which results in compression of seeds.

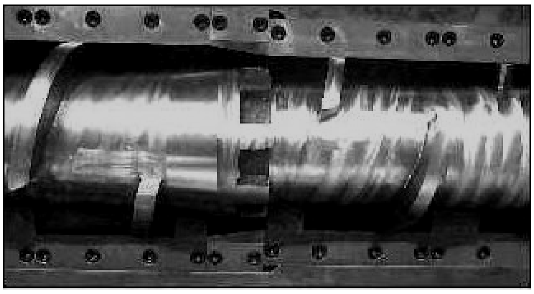


Figure 2.7: Detailed views of the screw shaft of Rosedowns Screw Presses [37]

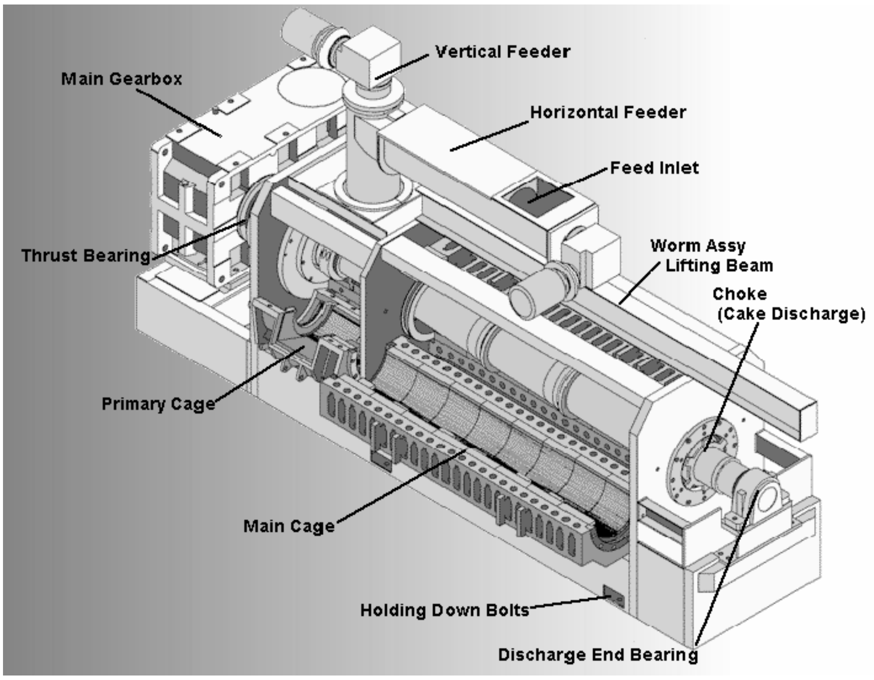


Figure 2.8: Detailed Drawing of Screw Press Manufactured by Rosedowns [37]

2.3.3 Vincent Screw Presses

As represented in Figure 2.9, a screw of progressively reducing pitch rotates inside a cylindrical perforated screen. Material entering the hopper is subjected to gradually increasing pressure as it moves toward the exit end of the press, forcing the liquid phase to extrude through the screen [38]. Two resistor teeth fit in each interruption of the turn as seen in Figure 2.9. This interruption prevents jamming.

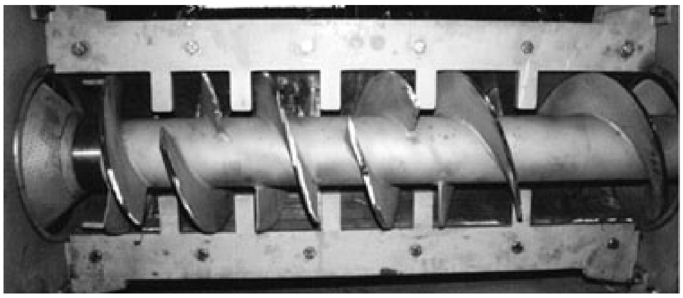


Figure 2.9: Screw with Resistor Bars manufactured by Vincent Corporation [38]

2.3.4 Strainer Type Screw Presses

In strainer type of screw presses [27], oil rushes out from the strainers which are made up of flat plates mounted through the screw shaft. By rotating the arm which is at the right end of the screw press as shown in Figure 2.10, the screw shaft can be displaced forward or backward to adjust the thickness of the cake which is extruded at the left end of the screw press. Accordingly, different kinds of seeds can be compressed also by changing the rotational speed.

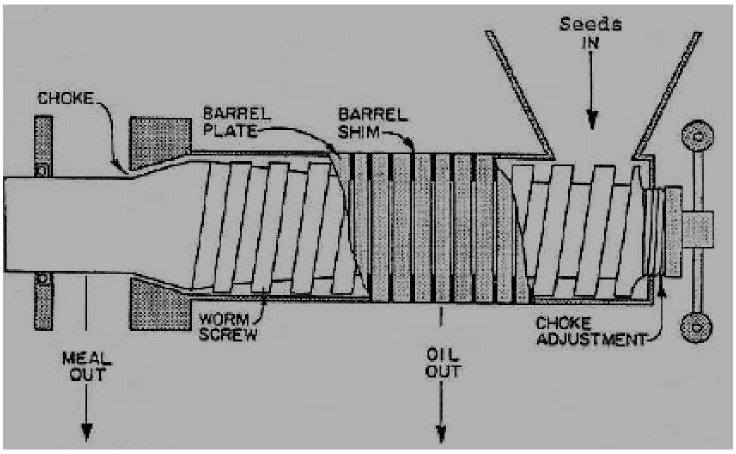


Figure 2.10: Strainer Type Screw Press [27]

2.4 Available Patents for Screw Presses

In general, the patents have a common idea in the design of the screw presses which is the tapered screw shaft. Three of them are represented in Figure 2.11, Figure 2.12 and Figure 2.13 with their bibliographic data.

2.4.1 Continuous screw press with strainer cage recovering oils under controlled back pressure (1998) (Pub. Num.: DE19715357)

In Figure 2.11, the components, their relations and functions are as below:

This unit is screw presses with strainer (1) pressing e.g. oil seeds or other oil containing materials. The straining basket or cage (7), interior (11) includes a wall with passages (12) leading to the exterior. The internal screw (21) is mounted in bearings and rotated. It forms a pressing volume with the straining cage and conveys pressed materials towards the press outlet (27). An adjustment unit (3) controls the back pressure exerted. This comprises a passage with adjustable cross section at the press outlet. It is in fact, comprised of several passages, which can be closed off, individually or in groups [39].

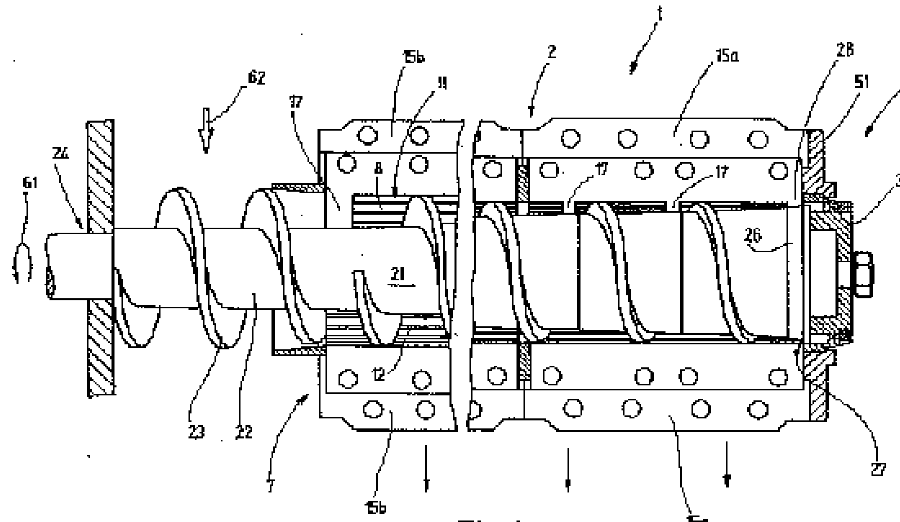


Figure 2.11: Drawing of the patent DE19715357 [39]

2.4.2 Screw press having a plurality of throttle points and at least one cam movable transversely thereto (1994) (Pub. Num.: US5341730)

In Figure 2.12, the components, their relations and functions are as below:

A screw press for pressing off fluids, especially from oil seeds, has a screw (1) and, surrounding this screw (1), a fluid-permeable mantle (2), particularly a screen, whereby the screw shaft (3) and the mantle (2) form between them a screw channel (6) with a cross-section that decreases towards the transport direction of the screw (1), and whereby in the screw channel (6) at least one throttle point (7,8,9) is provided for building up zones of high pressure, and a cross-section expansion is provided in transport direction following the throttle point (7,8,9) for relaxing the high pressure at least partially. In order to achieve a higher efficiency, at least one cam (10) that may be moved transversely to the transport direction of the screw (1) is provided in the area of at least one of the existing throttle points (8,9) in the screw channel (6) [39].

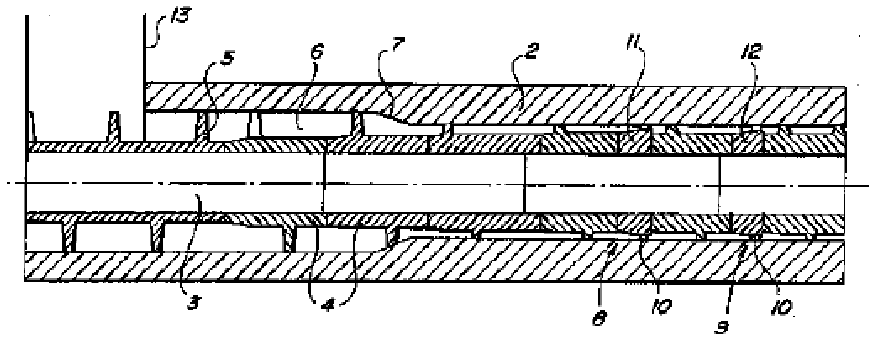


Figure 2.12: Drawing of the patent US5341730 [39]

2.4.3 Screw press for extracting oil from seeds etc. - has cylinder composed of rings in or between which are passages which can quickly and easily be connected to cooling fluid supply (1992) (Pub. Num.: DE4109229)

In Figure 2.13, the components, their relations and functions are as below:

A new screw press for extracting oil from seeds, etc. at low temp., has rings or pairs of rings (10,10a) in the press cylinder (8) which has passages for a cooling fluid. These rings or pairs of rings have grooves (16) which communicate with cooling fluid inlet and outlet points. The pairs of rings have individual rings (11,12) between which are seals, gaskets or O-rings on either side of the grooves (16). The inlet and outlet channels may be formed half in one disc and half in the other, or may be formed centrally in one disc only. Inlet and outlet pipes are connected to these channels by hoses or quick-release couplings, and these may be connected and disconnected either singly.

It is used in extracting oil from flax seeds, sunflower seeds, poppy seeds, etc. The temperature of the oil is prevented from rising above about 38 °C, and the apparatus is suitable for small to medium output systems [39].

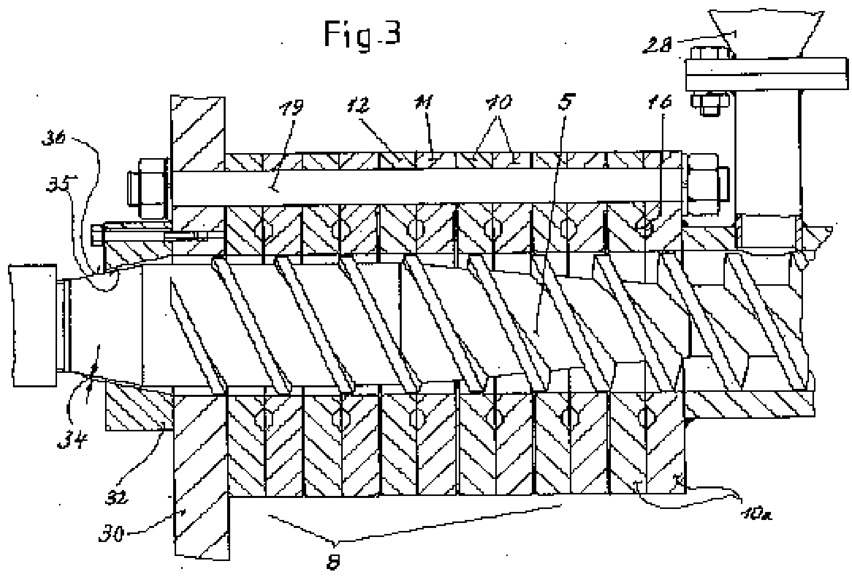


Figure 2.13: Drawing of the patent DE4109229 [39]

CHAPTER 3

CONCEPTUAL DESIGNS FOR OIL EXTRACTION MACHINES

3.1 Comparison between Oil Extraction Methods

There are basically four types of oil extraction methods as represented in Figure 3.1. First one is the chemical extraction method in which enzymes or solvents are used to extract oil. In the solvent extraction type, a solvent is mixed with the ground seed. Grinding process is necessary, because the contact area of the seed with the solvent should be maximized in order to increase the oil yield. In general, hexane is used as solvent which is a petroleum distillate. Then by heating the oil up to 100°C, solvent is separated from the oil. Theoretically, after this process, oil gets free of solvent. However, microscopic portions of solvent remain both in the cake and the finished oil.

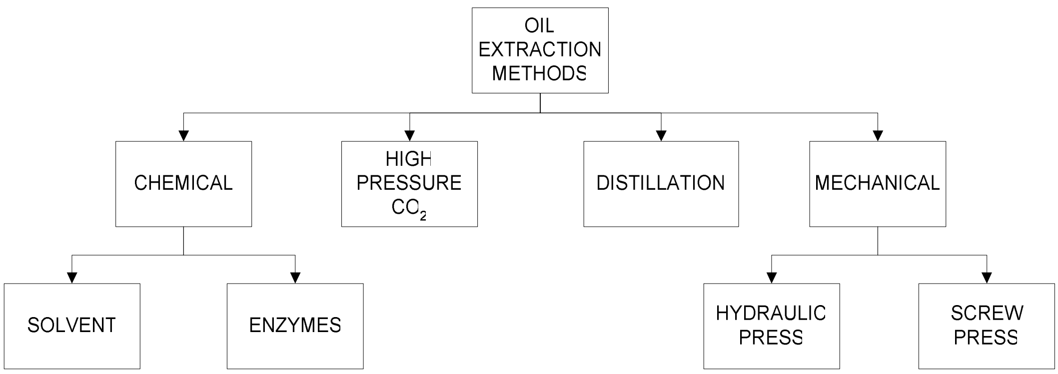


Figure 3.1: Basic oil extraction methods

The oil extraction process by using enzymes is implemented by big vegetable oil companies because the process produces many high value products. The seeds are cooked and put into water. Enzymes are then added which digest the solid material. The basic difference of this type of extraction method from the solvent type is that the residual enzymes in the oil are separated by the use of a liquid-liquid centrifuge.

In the high pressure (super critical, at 31°C and 70 bar) carbon dioxide extraction, seeds are mixed with high pressure carbon dioxide in liquid form. Then oil dissolves in the carbon dioxide. When the pressure is released, the carbon dioxide becomes a gas and the oil is left behind.

Most essential oils are extracted using steam distillation. Essential oils are the highly concentrated essences of aromatic plants used in healing of the body and the mind. As the steam break down the plant, its essential oils are released in a vaporized form. When these pass through cooling tanks, the volatile essential oils return to liquid form and are separated and are easily isolated as pure essential plant oil [41].

Other oil extraction method is a mechanical process. Mechanical extraction method is the oldest known method. It is based on mechanical compression of the seeds. Different mechanisms can be used for compression. There are two well-known mechanisms which are called the hydraulic press and screw press mechanisms.

Methods of high pressure CO_2 extraction and distillation are not included to the comparison stage. The reason is that these methods are used in extraction of essential oil used for aromatherapy. Aromatherapy is the art of using these oils to promote healing of the body and the mind which is beyond the scope of this study.

Table 3.1: Comparison between solvent and mechanical types of seed oil extraction methods

	SOLVENT	**MECHANICAL**
Capacity of Production	High	Medium
Location Near	High Traffic Points	Agricultural Production
Capacities	Large Scale	Small Scale
Oil In Seed Cake	1%	15%
Oil quality	Low	High
Investment Cost	High	Low
Working Cost	Low	High
Energy Consumption	High	Low
Wastes	Chemicals, Water	No Wastes
Security Requirements	High	Low
Transportation Distance	Long	Short

The advantages and disadvantages of the solvent and mechanical extraction methods are presented in Table 3.1 in order to understand which method conforms with the scope of this study most. Despite, solvent extraction method has some superiority on mechanical extraction methods; depending on the conditions and expectations, the mechanical extraction method is better especially for small scale production. For example, in mechanical extraction method, residual oil in the cake is high; however it is an advantage in the villages since it is used as nutritious animal feeding. Also, the production of oil in mechanical extraction methods is in smaller scales; however it may be sufficient to compensate a village need.

Other advantages of mechanical extraction methods are that the investment cost is lower than the solvent extraction set up. Further, the equipment can be easily constructed, maintained and operated by semi-skilled labor. Also, it can be adapted quickly for different kinds of seeds. Furthermore, the mechanical extraction process is more safe and simple compared to solvent extraction method.

After deciding that mechanical extraction method is more suitable for the scope of this study, then a further comparison step between different mechanical press systems is to be discussed. For the mechanical extraction methods, two types of presses are generally used which are called hydraulic press and screw press. The superiority of screw press system is based on the continuous flow of seeds. Also, hydraulic presses are slow and not efficient in oil recovery rates whereas the screw presses are more preferable since they are more efficient [42]. Results of the previous studies about comparison of hydraulic and screw press systems show that screw presses are more advantageous. Owolarafe et al. [43] compared the performance of the digester screw press and a hand-operated hydraulic press. The throughput of the screw press system was four folds of the hydraulic press system with a higher oil extraction efficiency of 89.1%. Result of the comparison between the two different mechanical extraction systems shows that screw press system is more advantageous for this particular.

3.2 Comparison between Screw Shaft Configurations

During the study, various types of screw shaft configurations have been developed and considered. Some of these configurations are used in conventional screw presses which have already been discussed in Section 2.3. Some basic configurations of screw shafts are presented in the subsections.

3.2.1 Straight Screw Shaft

The type of screw shaft configuration which is represented in Figure 3.2 is commonly used in screw presses, because the manufacturing process is easy. In Komet Oil Presses, this type of screw shaft configuration is used [36]. The pitch and the root diameter are constant through the screw shaft. The rate of pressure increase in this type of a screw press is analogues to the rate of pressure increase in hydraulic presses. In both of them, pressure increases linearly. However, seed flow in the screw press is continuous whereas the compressed seeds must be replaced after each stroke in a hydraulic press.

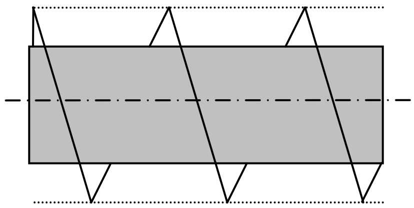


Figure 3.2: Illustration of a straight screw shaft

3.2.2 Screw with Tapered Shaft

In this type of screw shaft (Figure 3.3), the pitch is constant, where the annular area is decreasing through the length of the screw and takes its minimum value at the end of the screw. The volume swept by the screw thread in each turn is the multiplication of the annular area and the pitch distance. In this type of screw shaft, the rate of pressure increase is higher than straight screw shaft. Besides, machining of this part requires a CNC machine.

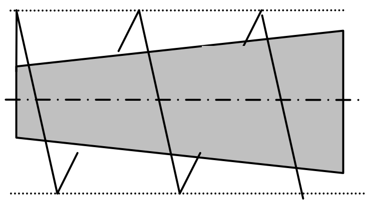


Figure 3.3: Illustration of a screw with tapered inner shaft

3.2.3 Screw with Variable Pitch

This is a screw type with decreasing pitch as represented in Figure 3.4. This type of a screw thread can only be machined with a 5-axes CNC machine tool. So, in order to reduce the cost, total shaft is separated into several sections. Each section has a constant pitch, but different from the other's pitch. The screw, through which the seeds are fed, has the maximum pitch in order to increase the seed capacity.

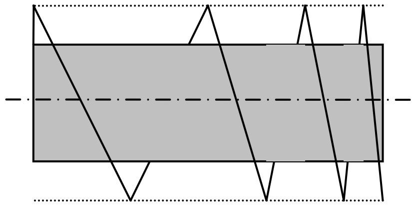


Figure 3.4: Illustration of a screw with variable pitch

Similar to the tapered shaft system, in this type of screw shaft system, volume is decreased by an amount in each turn. The main difference between them is the rate of pressure increase through each thread. In tapered screw, pressure increase linearly through the screw shaft whereas in screw with variable pitches distance, pressure is constant through each thread and increase at the transitions as shown in Figure 3.5.

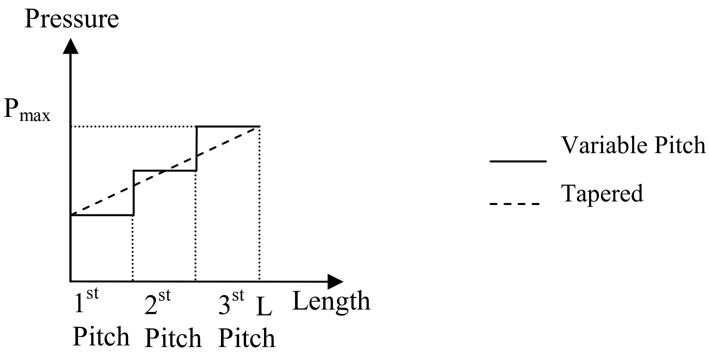


Figure 3.5: Pressure vs. Length graphs of the screw with variable pitch and the screw with tapered shaft

3.2.4 Screw with Tapered Shaft and Variable Pitch

This is the combination of the screw types with variable pitch and tapered shaft as represented in Figure 3.6. Rate of pressure increase in this type of screw is higher when compared with the other type of screws. The same pressure can be determined in a shorter time because the pressure attains its maximum value in fewer revolutions when compared with the same sized screw types.

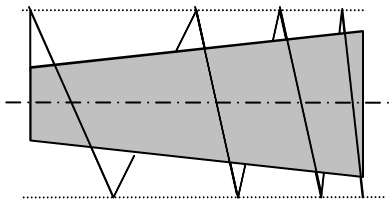


Figure 3.6: Illustration of a screw with tapered shaft and variable pitch

3.2.5 Screw with Reverse Worm

Screw with reverse worm configuration (Figure 3.7) is different than the previous ones, screw is composed of more than three pieces depending on the number of reverse worms. In Tinytech Tiny Oil Mills, this type of screw shaft configuration is used [44]. Reverse worms are generally used to reduce the total compression ratios, in other words, the same amount of oil can be obtained at lower pressure values by using reverse worms at different locations. Maximum required pressure is decomposed into smaller values by compressing the seeds at more than one stage.

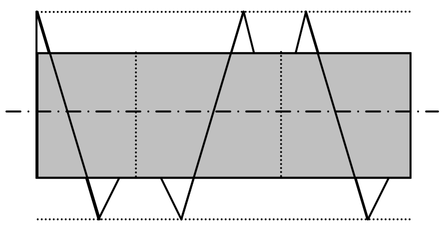


Figure 3.7: Illustration of a screw with reverse worms

3.3 Comparison of the Choke Mechanism Alternatives for Cake Drainage

The common property of cake drainage systems in screw presses is the adjustability of the cake drainage opening. Narrower openings result in low residual oil content in the cake. Also, the opening size depends on the type of the seed.

During the study, various types of cake drainage systems are considered. Some of them are used in conventional screw presses as presented in Section 2.3. Working principles of these cake drainage systems are presented in the subsections.

3.3.1 Nozzle Type Choke Mechanism

Generally, in small types of screw presses, nozzle type choke mechanism is used. In Komet Oil Presses, this type of a choke mechanism is used [36]. In nozzle type choke mechanisms (Figure 3.8), one end of the screw shaft is free and the other end has two bearings. The screw shaft is short enough to compensate any deformation arising from buckling.

Seeds continue to accumulate at the end of the screw until the maximum pressure has been reached. During compression, oil part of the seeds leaks from the filter and the left cake starts to extrude out from the nozzle, at the end of the screw. Besides, the required maximum pressure can be provided by adjusting the nozzle diameter.

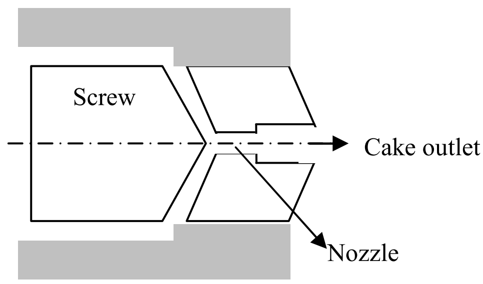


Figure 3.8: Nozzle Type Choke Mechanism

In this type of choking mechanism, the maximum pressure at the end of the screw pushes the screw backward. The resultant force is the multiplication of the axial component of the maximum pressure and the circular area of the screw. Since the application area of the back force is comparatively larger than in conical type of choke mechanisms, bearing which carries the axial back force should be larger in this type of systems. Another disadvantage for this choking system is the probability of a blockage at the entrance of the nozzle.

3.3.2 Conical Type of Choke Mechanism

This type of a system (Figure 3.9) is both practical and economical when compared with the equivalent systems. In Tinytech Tiny Oil Mills, this type of a choke mechanism is used [44]. The maximum pressure and the cake thickness can be changed by adjusting axial displacement of the screw shaft forward and backward in order to achieve the required pressure. The force pushing the screw backward is relatively less here when compared with the nozzle type choke mechanism since the effective pressure area is less than the normal cross-section.

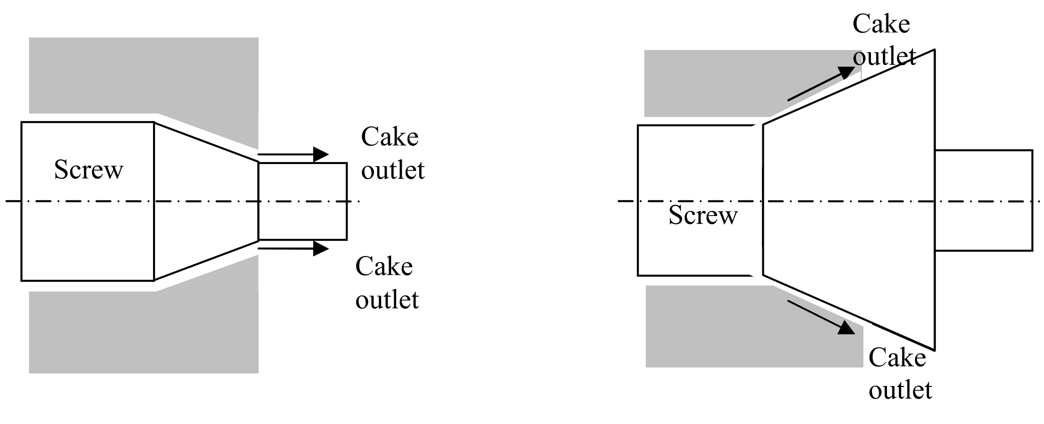


Figure 3.9: Conical Types Choke Mechanisms

3.4 Comparison of Oil Drainage Systems

There are three typical systems used in commercial screw presses for oil drainage which are presented in the subsections.

3.4.1 Drilled Holes

In Figure 2.6, Komet oil press has holes on the vessel for oil drainage. The main advantage of this system is no extra parts for oil drainage system is required. However the oil drainage openings in this system are not adjustable.

3.4.2 Lining Bars with Spacers

In this type of oil drainage system (Figure 3.10), lining bars are fixed inside surface of the vessel cage. Spring type metal spacers are placed between two bars. Different sizes of gaps can be obtained by using spacers in different thicknesses. Also, in this system, lining bars canalize the compressed seeds to forward. They prevent jamming by creating obstacles to the rotating compressed seeds, so they are pushed forward more strongly.

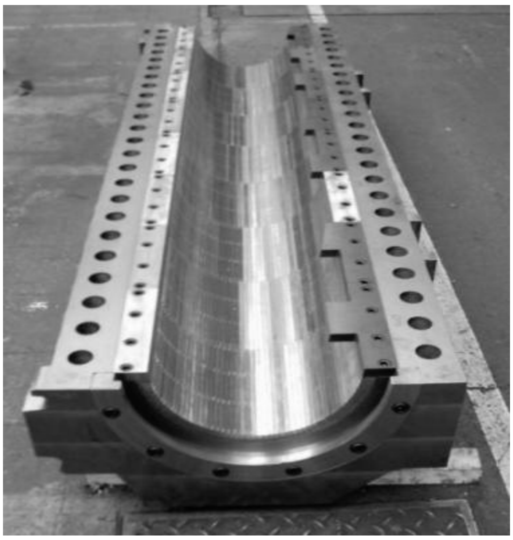


Figure 3.10: A view of the main press cage of the Rosedowns screw press [37]

3.4.3 Fiber Filter Sleeves

This kind of liquid drainage system (Figure 3.11) is generally used for the substances which do not require high pressure. Since the fiber is a deformable material, high pressures would result in expansion of the fiber.

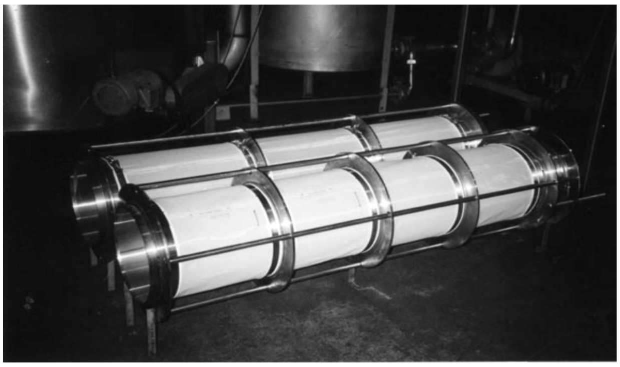


Figure 3.11: A view of the fiber filter sleeves of the Vincent screw press [38]

3.4.4 Barrel Rings

The vessel is made up of barrel rings as shown with triangular barrels in Figure 3.12. The barrel rings are separated by circular spacers, that slide onto the tie bars to form the drained barrel of the press. This arrangement offers greater flexibility to adjust the drainage gaps of the press and forms a very simple assembly that can be easily maintained [37].

Figure 3.12: A view of barrel rings, screw shaft and bearing parts of the Mini 40 screw press manufactured by Rosedowns [37]

3.5 Conceptual Designs for the Canola Seed Oil Extraction Machine

During the study, four different conceptual designs have been developed by using the previously defined machine part alternatives. The exploded view and some dimensions of the four designs are represented in Appendix C.

- First Conceptual Design for the Canola Seed Oil Extraction Machine

In Figure 3.15, first conceptual design for the seed oil extraction machine is represented. The screw press is composed of mainly three modules which are compression module, oil and cake drainage module.

This compression module involves screws with variable pitch as explained in Section 3.2.3. The complete system contains two inlets for seed feeding and one outlet for cake drainage as represented in Figure 3.16. The reason for using two inlet feedings depends on achieving a double seed capacity screw press.

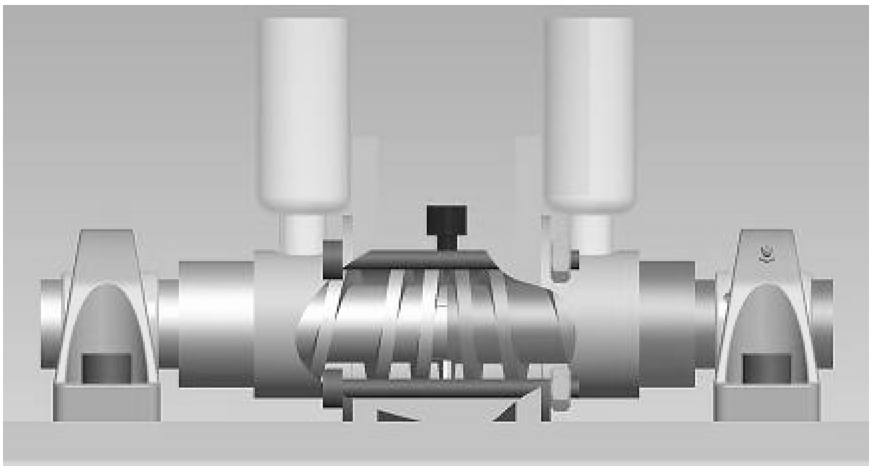


Figure 3.13: Detailed View of the First Conceptual Design

There are two screw shafts which are rigidly connected to each other with a threaded rod and a nut. One of the screw is right handed, and the other is left handed. There are three turns in each screw shaft, and pitch of each turn is in decreasing order from the seed inlet to cake outlet. The highest pitch is at the seed inlet in order to maximize the seed capacity rate of the screw press. The seeds fed into inside of the cage, pass through screws and meet at the middle. Maximum compression occurs on the mating face of the two screw shafts. Then, cake of the compressed seed is extruded out from the nozzle, which is mounted at the middle upon the cage. Cake is transferred to a cake cap which has been connected to the cake nozzle.

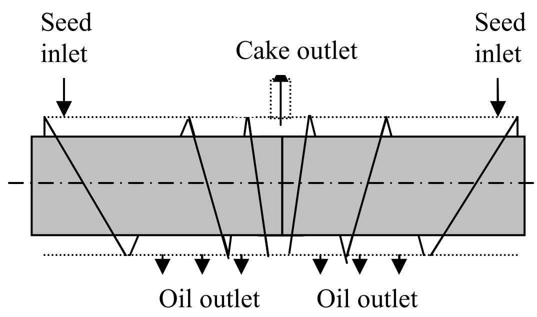


Figure 3.14: Illustration of the flow of the seeds in the first conceptual design

As represented in Figure 3.16, cake, which is subjected to maximum pressure, extrudes out from the nozzle. The pushing force is applied by the reversely mating threads during rotation. Also, different seeds can be fed into the screw press only by adjusting the diameter of the nozzle.

For oil drainage, barrel plates (Figure 3.17) are used. Barrel plates are connected to each other and side barrel plates are connected to the platform. Similarly, barrel rings as an oil drainage system are used in Rosedowns Oil Presses [37] which is presented in Section 3.5.4. Grooves are machined onto the mating surfaces of the rings barrel. Then oil can leak out from these gaps.

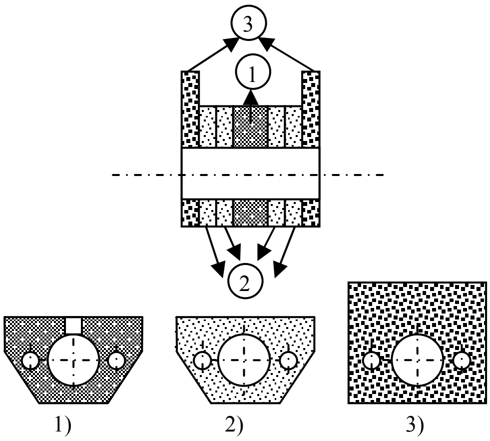


Figure 3.15: Orientation and front views of the barrel plates of the first conceptual design

➢ Second Conceptual Design for the Canola Seed Oil Extraction Machine

In this design, the compression system is composed of three main parts (Figure 3.18) which are the feeding screw, the grinder and the compression screw. First, the feeding screw which has a larger diameter pushes the seeds forward. Then, seeds pass through the grinding part. At this stage, husks of the seeds are cracked and the seeds are broken into pieces. Resized seeds pass to the last stage which is the compression screw and has a smaller diameter. There, the resized seeds are compressed and cake is discharged from the discharging cones. These three features are connected to each other and they rotate together. The compression screw shaft can be moved into the feeding screw shaft in order to adjust the cake thickness. And the grinder is rigidly connected to the feeding screw shaft.

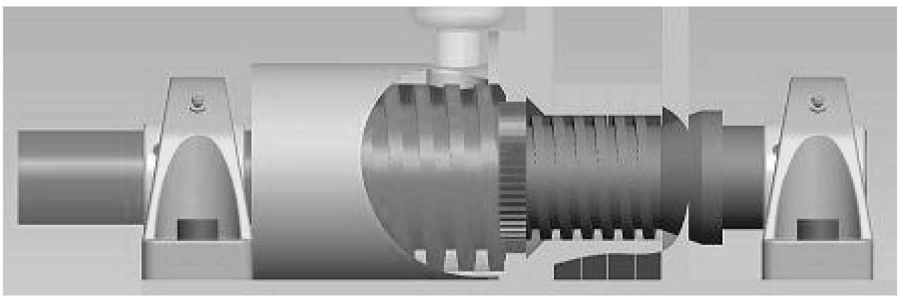


Figure 3.16: Detailed View of the Second Conceptual Design

In the resizing process, an inner shaft which the teeth are machined on its surface rotates inside a stationary cage as shown in Figure 3.19. When the seeds are between the teeth gaps, as the inner grinder rotates, the seeds are cracked by the cutting edges of the teeth which are machined inside the cage. All the tangential force at the cutting edge of the tooth can be applied to the seed if the direction of the tooth wall passes through the center of the grinder.

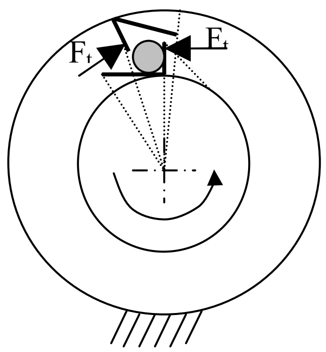


Figure 3.17: Illustration of the grinder during cracking of a seed

The dimensions of the grinder are shown in Figure 3.20.

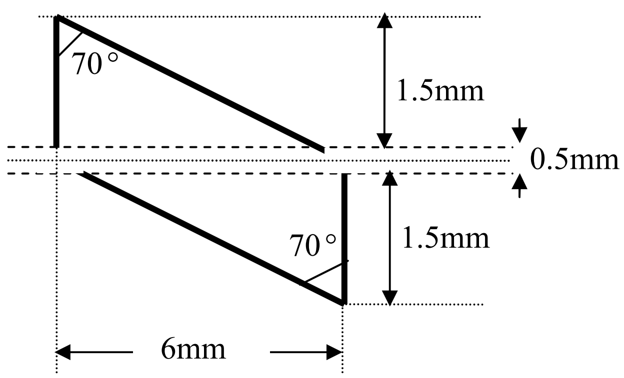


Figure 3.18: The dimensions of the outer and inner grinder teeth

Oil leaks out through the small gaps between the barrel plates. On the barrel plates, grooves are machined in the radial direction for oil drainage. The barrel plates are rigidly connected to each other and the two side barrel plates are connected to the platform. Mating of the grinder and the feeding tube are also connected to the barrel plates. Inside the barrel plates, grooves are present longitudinally. These grooves prevent jamming of the compressed cake and canalize them through the cake drainage.

- Third Conceptual Design for the Canola Seed Oil Extraction Machine

In this prototype (Figure 3.21), the machine components are composed of mainly two parts which are the screw shaft and the vessel. Screw shaft has a tapered root diameter and a constant pitch. Vessel is composed of two parts which are the feeding tube and the compression vessel. The compression vessel is connected to the platform and the feeding tube is connected to the compression vessel. The seeds are fed into the system at the point where the thread depth is maximum. Then they are pushed forward and compressed between the inside surface of the vessel and inside surface of the screw shaft since thread depth decreases through the cake drainage.

Vessel has a special profile at inside surface to canalize the compressed seeds to the cake drainage. This is a curvature shaped groove profile which can be machined in CNC WEDM (Wire Electrical Discharge Machining). The grooves inside the vessel prevent the compressed seed from rotating with the screw shaft, so the compressed seeds can be directed to the cake drainage. And by rotation of the screw shaft the compressed seeds are pushed forward by the turns on the screw. Besides, oil drainage is provided by the slits that are machined on the inside surface of the vessel in the outward radial direction. The slits are machined in CNC WEDM all through the length of the inside vessel.

Also, a heating mechanism is available in this type which is mounted around the shaft adjacent to the cake drainage cones. Gap thickness for the cake drainage can be adjusted by moving the screw shaft in the longitudinal direction.

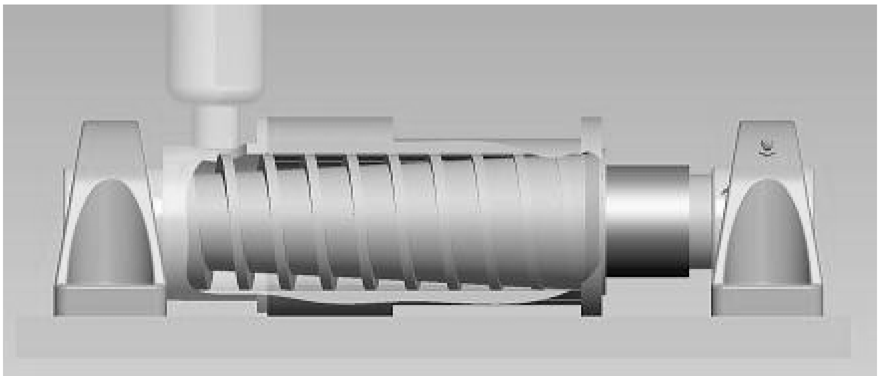


Figure 3.19: Detailed View of the Third Conceptual Design

- Fourth Conceptual Design for the Canola Seed Oil Extraction Machine

In this design, again tapered screw press is used (Figure 3.22). However, different than the previous design, the vessel is one piece and the oil drainage is provided with holes which are machined on the vessel. The vessel is rigidly connected to a flange and the flange is connected to the platform. Since the height of the vessel is increased with the flange, an elevation block is placed under the free end of the vessel to balance the weight of the vessel and eliminate the misalignment. Seeds are fed from one end of the screw shaft at where the thread height is maximum. Then by the rotation of the screw shaft, seeds are pushed forward. Since the thread height is reduced linearly, the seeds are compressed between the inside walls of the vessel and the screw shaft. The thread profile is rounded at the edges unlike the screw in the third conceptual design. The rounded edge is used to decrease the frictional losses. Inside the vessel, grooves with a different geometry are machined. In this type the geometry of the grooves are triangular in order to ease the manufacturing process.

Gap for cake drainage can be adjusted by moving the screw shaft in longitudinal direction and lock the movement at that position. Screw shaft is locked at the desired position with set screws available at the bearings. Oil is recovered from the holes which are machined on the mid zone of the vessel. The screw shaft and vessel are one piece in order to prevent eccentricity problems.

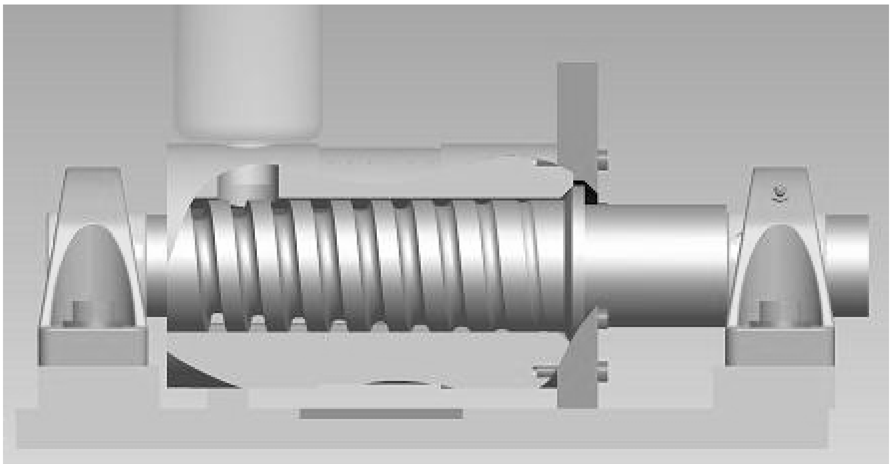


Figure 3.20: Detailed View of the Fourth Conceptual Design

CHAPTER 4

PRELIMINARY AND DETAILED DESIGN OF THE OIL EXTRACTION MACHINE

4.1 Preliminary Design

In this section, design tree and block diagram of the selected system, separation of the system into subsystems and specifications of these subsystems are given (Figure 4.1).

4.1.1 Design Tree

In the design tree of the screw press, the system is separated into its subsystems to analyze the design from top to bottom. In Figure 4.2, components of the screw press are represented. The screw press is composed of skeleton, hopper, main body, connection elements and drive system. Skeleton carries the main body. Hopper is mounted onto the vessel. Drive system is connected to the end of the screw shaft. And connection elements are used to connect the bearings to the platform and flange to the vessel. Assigned numbers to the machine components are represented in Figure 4.1.

Seeds are fed into the system from the hopper (3), and pass through the screw shaft (4) to the end of the vessel (5) where the cake is drained out. Oil leaks out from the holes which are machined on the vessel. Screw shaft is mounted between two bearings (1) at each end. Flange (6) is mounted to the vessel with connection elements (7).

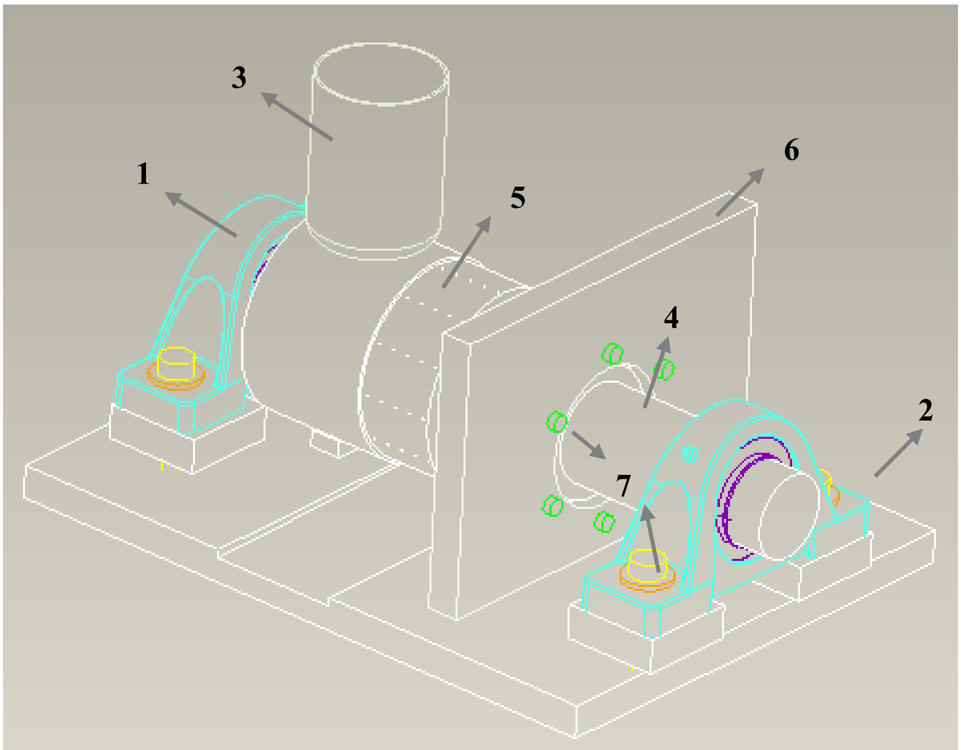


Figure 4.1: 3D model of the developed screw press

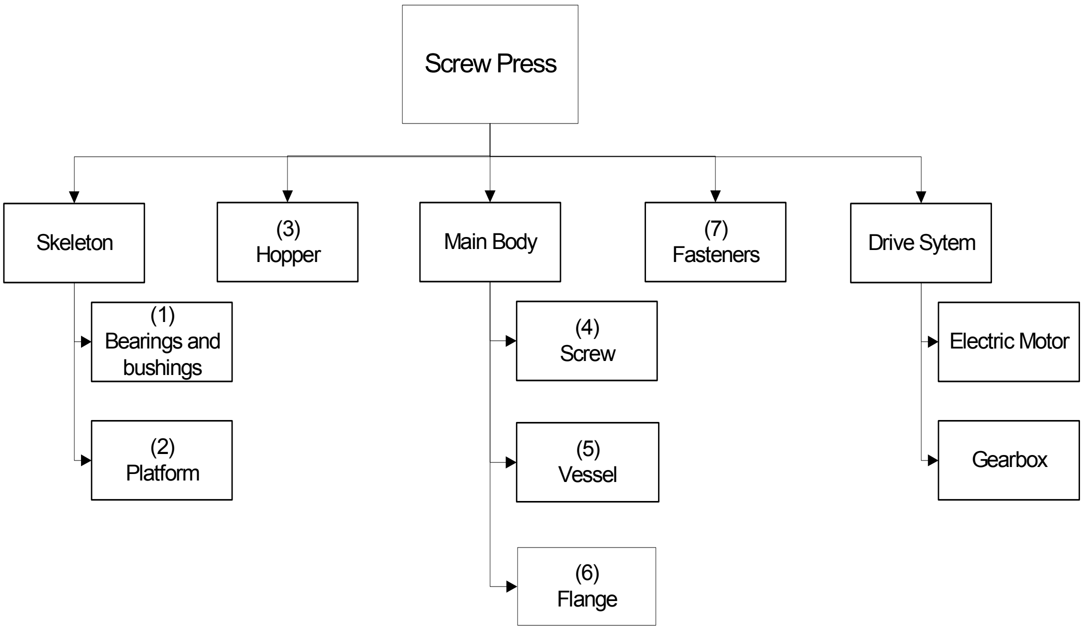


Figure 4.2: Design Tree of the Screw Press

4.1.2 Skeleton

Skeleton (Figure 4.3) is composed of the platform and the bearing bushings. It carries the main body. The screw shaft is bedded with the bearings. The bearing bushings are elevated to a height where the screw shaft can rotate concentrically inside the vessel.

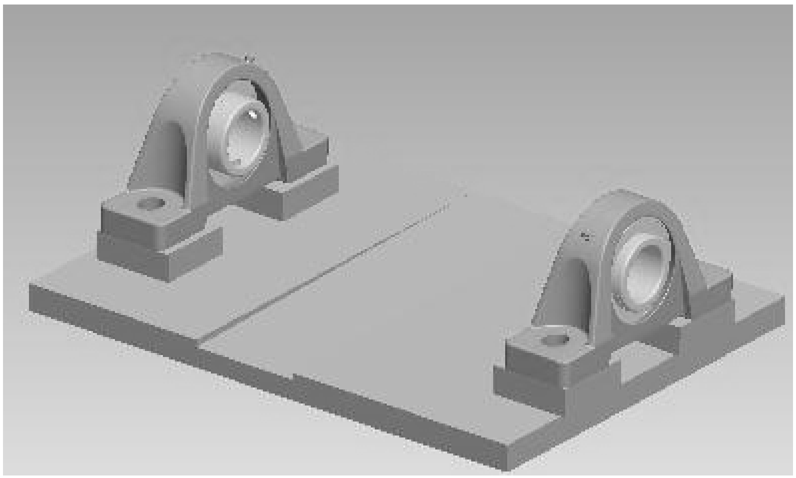


Figure 4.3: 3D model of the developed skeleton

The platform is the basement of the screw press on which bearing bushings are mounted. Also, flange of the main body is connected to the platform in order to carry and elevate the main body upper from the platform. Just under the oil drainage zone of the vessel, the floor is inclined to canalize the oil to the oil container.

4.1.3 Hopper

Hopper is used to carry and canalize the seeds into the screw press. Feeding does not need any energy; gravity is sufficient for feeding. It is a stationary part and mounted onto the vessel. The passage hole of the hopper should be large enough in order to prevent choking of the seeds. In some conventional screw presses, it has a vibration unit to overcome such situations. But, in this design no vibration unit will be used to reduce the cost.

4.1.4 Main Body

The main body is composed of three parts which are the screw shaft, the vessel and the flange. Their functionalities are described in the subsections.

4.1.4.1 Screw Shaft

As represented in Figure 4.4, a screw with tapered root diameter type is used in the design. As mentioned in Section 3.2.2, when compared to straight screw shafts, rate of pressure increase is higher in this type of screw shaft configurations depending on the taper angle of the shaft. The seeds are compressed in two ways. First way of compression occurs by the continuous feeding of the seeds into the system. Newly fed seeds compress the seeds which are already present in the system. Other way of compression takes place between the inside surface of the vessel and inside surface of the screw shaft. As the depth of the thread decreases continuously, the distance between these two surfaces decrease. Then, forwardly pushed seeds are applied compression between these two surfaces. For these reasons, this type of screw shaft configuration is evaluated as the most appropriate one for this study.

Screw shaft rotates inside the vessel. There is a small clearance between the vessel and the screw shaft. This small clearance is necessary for avoiding the seeds penetrating between the outside diameter of the screw shaft and the inside surface of the vessel. In such a case, friction force between the screw shaft and vessel increases, and required torque becomes higher.

Screw shaft is a tapered shaft. The outside diameter is constant whereas the root diameter is inclined through the screw. Thread depth disappears at the end of the screw. In this type of screws, pressure increase is much higher compared to straight screws as explained in Section 3.2.2.

The seeds are fed at where the thread depth is maximum. As the seeds pass through the screw, swept volume of each turn decreases. Under high pressure, oil is separated from the compressed seeds and drains back to the previous turns at where the pressure is lower. Since cake has no such a fluidity property like oil, it continues to the end of the screw shaft and drained out as flakes. At the end where the cake is drained, the screw shaft and the vessel have conical features which are concentric. Cake drains out radially between these two conical features. By adjusting the screw shaft in the longitudinal direction, the gap size of the cake drainage can be reduced or increased. As the gap size is smaller, the residual oil content of the cake becomes lower, because the compressed seed is applied higher pressure.

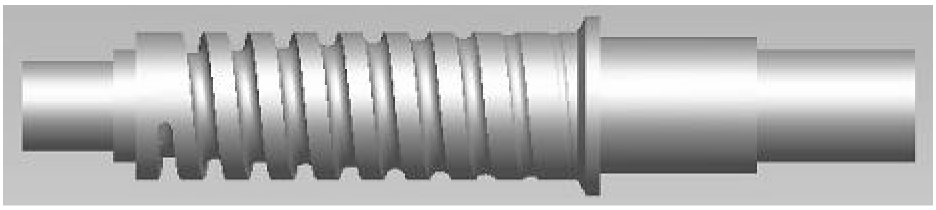


Figure 4.4: 3D model of the developed screw shaft

4.1.4.2 Vessel

Vessel shown in Figure 4.5 is the cage of the screw shaft. It has a big hole for seed feeding. This feeding hole is machined at the beginning of the screw shaft at where the thread depth is maximum.

On the mid zone of the vessel, there are oil drainage holes as shown in Figure 4.6. This type of oil drainage system is used in Komet Oil Presses as explained in Section 3.5.1. The oil drainage zone is slightly far from the cake drainage zone or in other words, the maximum pressure zone. The reason is that, these small holes are filled and choked with compressed cake at high pressure levels.

However, on the mid zone of the vessel, pressure of the cake is not that much high and oil can easily pass through these holes.

As represented in Figure 4.5, there are grooves through inside the vessel. These grooves are necessary for preventing jamming. At high pressure levels, friction force between the compressed seeds and the surface of the screw threads increases, and compressed seeds start to rotate with the screw shaft without any movement forward. Then flow stops. However, grooves act as obstacles to the rotating compressed seeds and canalize the compressed seeds forward.

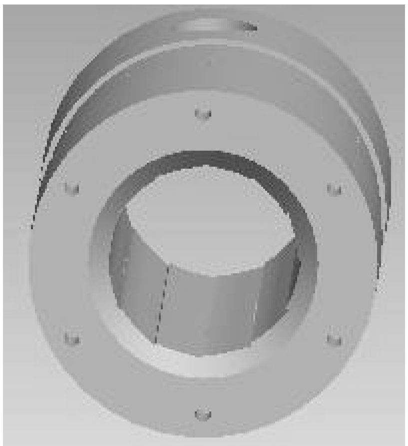


Figure 4.5: 3D model of the developed vessel

4.1.4.3 Flange

Flange is connected to the vessel at the cake drainage end as shown in Figure 4.6. It is necessary for elevating the vessel upper from the platform. Then, oil can easily flow under the vessel. Also it separates the drained cake and recovered oil from each other.

Flange is mounted to the platform. As seen in Figure 4.1, in order to avoid buckling of the vessel, the same elevation is provided to the other end of the vessel by using additional support. But, this support has only contact relation with the vessel, not connected with fasteners.

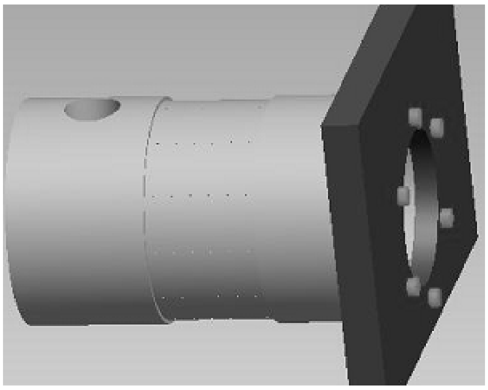


Figure 4.6: 3D model of the assembly of the vessel and flange

4.2 Detail Design Calculations

In this section, the geometrical dimensions of the machine components are determined. Stress analysis of the parts subjected to static and/or dynamic loads are performed.

4.2.1 Design Specifications

First design specification is the required seed capacity rate which is selected as 50 kg/h. The design calculations will mostly based on this specification.

There are some pretreatments that directly affect the oil recovery rate such as the moisture content and temperature of the seeds. According to the study of Singh and Bargale [26], the maximum oil recovery was obtained at a moisture content of 7.5% (wet basis) for rapeseed with a double stage compression screw press as discussed in Chapter 2. Also temperature of the oil should not be higher than $90\,^{\circ}C$ according to Ohlson [28].

Manufacturability of the designed machine components is a very important step for the design methodology. The manufacturing capabilities of the production plant, in which the designed prototype will be produced, must be evaluated and implemented into design steps before release for production. For ease of the manufacturing process, below steps are concerned in this study.

1. Designing parts with simple geometries and few numbers
2. Using standard parts
3. Fool proof mounting and dismounting of the machine parts
4. Avoiding tight tolerances that are beyond the natural capability of the manufacturing process

All these steps definitely reduce the manufacturing and assembling process time, reduce cost and increase the quality of the product.

Weight and volume of the designed machine should be reduced as possible for ease of transportation and construction of the machine.

Safety of these kinds of machines in a rural area has a considerable importance. Since in the rural area, people are not as familiar to technology as the people living in the urban areas, certain precautions must be taken to prevent any possible accidents. Taking power from the PTO shaft eliminates the possible accidents causing from electricity. Further, in order to avoid getting caught in the machine, the machine should be covered by a casing and some illustrative warnings should be attached on it.

4.2.2 Important Design Inputs

Required oil recovery rate and the maximum available power are determining factors in this study. The details of these two design inputs are explained in detail in the subsections.

4.2.2.1 Required Oil Recovery Rate

According to economical and environmental conditions of the village included in “Balaban Valley Project”, required seed capacity of the oil expeller is calculated as 50 kg/h.

The seed capacity is given in terms of mass flow rate; however it should be converted into the unit of the volumetric flow rate, since one of the important inputs to the design calculations is the volumetric flow rate of the seeds.

Weight of the 100 mL uncompressed canola seed is measured as 72 grams. According to this data, 50 kg/h seed is equal to approximately 70 L/h ($Q_{uncompressed\_seed}$) as given in Equation 4.1.

$$50000 g/h . \frac{100 mL/h}{72 g/h} = 69444 mL/h \approx 70 L/h \tag{4.1}$$

Theoretically, the volume swept by the feeding turns of the screw shaft is assumed to be equal to this seed capacity. However, the feeding screws would never be able to push forward the complete volume of seeds that they swept, this assumption is not realistic. So an efficiency rate is assumed between the swept volume by the feeding turns and the volume of the seeds which are transferred forward. $Volume_T$ is the theoretical volume which is the swept volume by the feeding turns. $Volume_R$ is the real volume that is transferred forward by the feeding screws. Feeding efficiency, ς, is taken as 90%.

$$\frac{Volume_T}{\varsigma} = Volume_R \tag{4.2}$$

According to this, the volumetric flow rate, which will be used in the design calculations, should be taken as approximately 77.8 L/h by using Equation 4.2.

According to Mrema and McNulty [32], under sufficient pressure and no drainage conditions, the total volume of a certain amount of seeds drops half of it as given in Figure 4.7. σ_t is total applied pressure, σ_i is seed cake (kernel) pressure and U is fluid pressure in Figure 4.7.

According to Figure 4.7, the volumetric flow rate at the inlet section of the oil expeller will drop to half of it at the outlet section. After compression without a drainage, the total volumetric flow rate, $Q_{compressed\_seed}$, which is composed of the flow rate of the compressed cake, Q_{cake}, and the oil content, Q_{oil}, becomes 38.9 L/h as given in Equation 4.3. In this equation, oil is assumed as incompressible throughout the compression process.

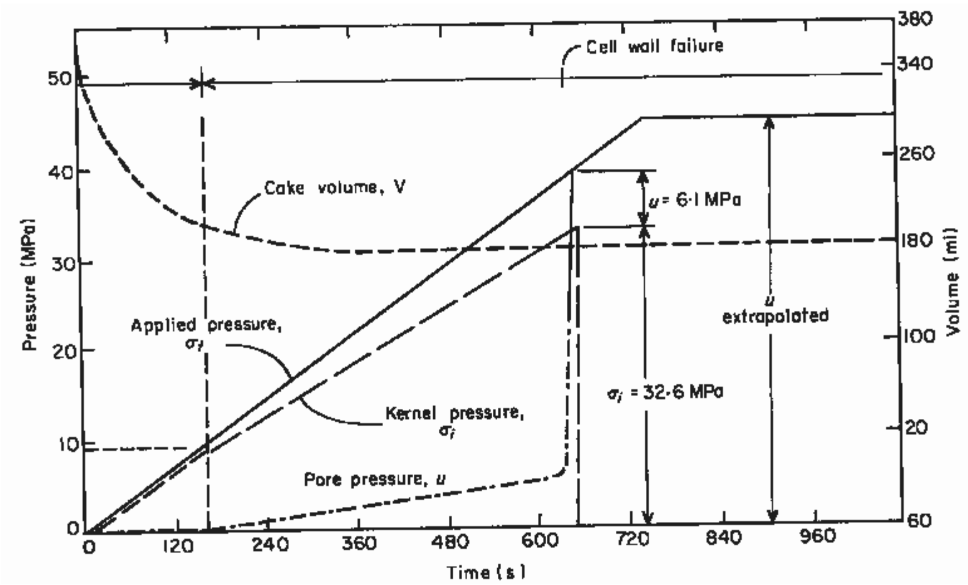


Figure 4.7: Pressure, change in volume of cake and oil expressed vs. time graph [32]

$$Q_{compressed\_seed} = Q_{oil} + Q_{cake} \quad (4.3)$$

Then volumetric flow rate of the cake can be determined by using Equation 4.4.

$$Q_{cake} = Q_{compressed\_seed} - Q_{oil} \quad (4.4)$$

To determine Q_{cake}, first Q_{oil} should be determined.

Since oil content of canola is nearly 40% of the total weight of seed [11], and then expected oil recovery rate is given in Equation 4.6. In this study, residual oil content in the cake is assumed as 15% of the total oil. Oil recovery efficiency of the system, η, is given in 4.5.

$$\eta = \frac{\text{Recovered Oil}}{\text{Total Oil Content}} \tag{4.5}$$

Oil recovery rate (kg/h) is determined by multiplying seed capacity (kg/h), oil content and efficiency. Seed capacity, SC, is 50 kg/h, however it is assumed that more than 50 kg seed is fed into the system in order to allow a margin for errors. Errors may depend on slippage of the seeds inside the system. The seeds may not be effectively pushed forward. So, seed capacity is divided by a correction factor, named feeding efficiency, ς, which is assumed as 90% in the previous calculations. Then the corrected seed capacity becomes 55 kg/h. In Equation 4.6, oil content, ϕ, is 40%, efficiency, η, is 85%. Then, oil recovery rate, M_{oil}, is calculated as 18.7 kg/h.

$$M_{oil} = SC.\phi.\eta \tag{4.6}$$

Volumetric oil recovery rate, $Q_{oil}(m^3/h)$, is determined by dividing the mass flow rate to the density of canola oil, $\rho(kg/m^3)$, as given in Equation 4.7. Density of canola oil is between $0.914 g/cm^3 - 0.917 g/cm^3$ at $20°C$ [51].

$$Q_{oil} = M_{oil} / \rho \tag{4.7}$$

$$Q_{oil} = 0.02 m^3/h = 20 L/h$$

Then, volumetric flow rate of the cake, containing residual oil, can be determined by using Equation 4.8.

$$Q_{cake} = Q_{compressed\_seed} - Q_{oil} \tag{4.8}$$

$$Q_{cake} = 18.9 L/h$$

Table 4.1: Volumetric Flow Rates of oil and cake for 50kg/h seed capacity for 85% efficiency

	Volumetric Flow Rate (L/h)
$Q_{uncompressed\_seed}$	70
$\frac{Q_{uncompressed\_seed}}{\varsigma}$	77.8
$Q_{compressed\_seed}$	38.9
Q_{oil}	20
Q_{cake}	18.9

4.2.2.2 Maximum Available Power

In this study, the maximum available power is taken as 4 kW which is the motor power of some of the commercial screw presses with 50 kg/h seed capacity [36]. Also, required power for the developed screw press should be reasonable, because for higher power requirements, both the size and the cost of the gearbox increase.

In most of the conventional oil expellers, the rotational speed of the screw shaft varies from 15 rpm to 90 rpm. In the design calculations, the rotational speed of the shaft is taken as 30 rpm.

4.2.3 Design Calculations for the Prototype

In this study, the design calculations mainly depend on the seed capacity rate and the maximum available power. The detailed design calculations of the components of the developed machine are given in the following subsections.

4.2.3.1 Screw Shaft Design

The determined volumetric flow rates which are discussed in Section 4.2.2.1 are used to calculate the unknown parameters as the thread depth, pitch and the radius of the screw shaft.

Initially, torque on the screw shaft is determined. The screw shaft is a single square-threaded power screw having an increasing root diameter. In Figure 4.8, l is the pitch, f is the coefficient of friction between the seeds and the screw shaft and taken as 0.3 [57], N is the normal force, F_{xs} is the axial force that pushes the seeds forward and F_{ts} is the tangential force. If pressure is assumed to apply on the surface of the threads as perpendicular, then F_{xs} and F_{ts} are the two components of the overall pressure on the screw shaft.

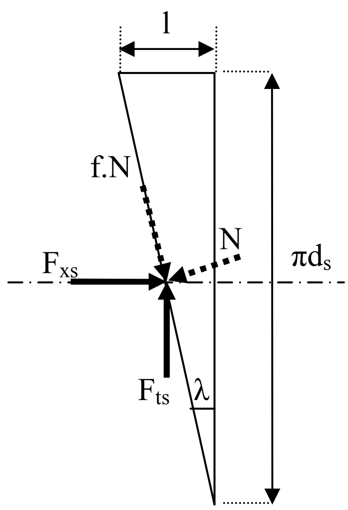


Figure 4.8: Illustration of force directions on the unwrapped thread while pushing the seeds forward

The relation between F_{xs} and F_{ts} is given in Equation 4.9. λ is the lead angle which is equal to $\frac{l}{\pi . d_s}$.

$$F_{ts} = \frac{F_{xs}(f.\cos\lambda - \sin\lambda)}{\cos\lambda + f.\cos\lambda} \quad (4.9)$$

The torque can be written as:

$$T_s = F_{ts}.\frac{d_s}{2} \quad (4.10)$$

Although pitch diameter increases through the length of the screw shaft, d_s is taken as the outside diameter of the screw shaft which is constant in order to be on the safe side. The reason is that α is a very small angle as $2.5°$ [52] so the difference between the initial and final radius is negligible.

F_{xs} can be determined by integrating the pressure distribution along the thread length as given in Equation 4.11.

$$F_{xs} = \int_0^{L_t.\#_{turns}} P(\xi).H(\xi).d\xi \quad (4.11)$$

As shown in Figure 4.9, L_t is the thread length of the screw for one turn which can be determined by using Equation 4.12.

$$L_t = \sqrt{(\frac{d_s}{2})^2 + l^2}.2.\pi \quad (4.12)$$

To calculate the total thread length, L_t should be multiplied with the number of the turns of the screw. The number of the turns of the screw can be calculated by dividing the pitch distance to the axial length of the screw as given in Equation 4.13.

$$\#_{turns} = \frac{L_s}{l} \quad (4.13)$$

$L_t.\#_{turns}$ is the total thread length which can be calculated by using Equation 4.12 and Equation 4.13. $P(\xi)$ is the function of the pressure distribution along the thread length as represented in Figure 4.9.

$H(\xi)$ is the function of the thread depth which is linearly decreasing along the thread length and becomes zero at the cake drainage as represented in Figure 4.10.

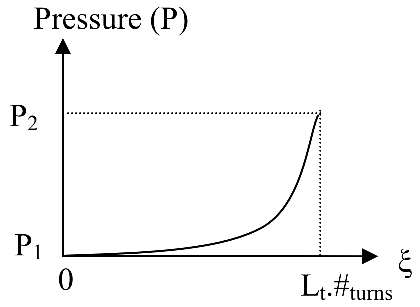


Figure 4.9: Graph of assumed pressure distribution on the screw shaft from the inlet to outlet

In order to calculate $P(\xi)$, pressure is assumed to increase along the helix length of the screw in the third order as represented in Figure 4.9. The general equation of the pressure distribution is given in Equation 4.14.

$$P(\xi) = a\xi^3 \tag{4.14}$$

P_2, which is the highest pressure occurring at the cake drainage zone, is taken as 60 MPa (Figure 4.7) and P_1 which is the atmospheric pressure (1 atm) is assumed as 0 MPa since it is negligible.

For $\xi = L_t.\#_{turns}$, $\quad P(\xi) = P_2 = a.(L_t.\#_{turns})^3$

Then a is equal to $\dfrac{P_2}{(L_t.\#_{turns})^3}$ that Equation 4.14 can be written as:

$$P(\xi) = \frac{P_2}{(L_t.\#_{turns})^3}.\xi^3 \tag{4.15}$$

The linear change in the thread depth along thread length is shown in Figure 4.10.

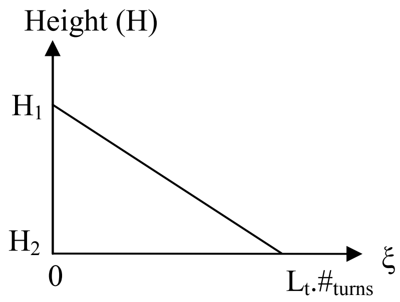


Figure 4.10: Graph of height distribution through the screw shaft

Linear equation of the height of the thread through the thread length is given in Equation 4.16. H_2 is equal to zero since the thread depth becomes zero at the last point of the screw as shown in Figure 4.10.

$$H(x) = \frac{H_2 - H_1}{L_s}.x + H_1 \tag{4.16}$$

L_s can be written in terms of α and H_1 as represented in Equation 4.17.

$$L_s = \frac{H_1 - H_2}{\tan \alpha} \tag{4.17}$$

The extended for of the Equation 4.10 is given in Equation 4.18.

$$T_s = \left(\int_0^{L_h.\#_{turns}} P(\xi).H(\xi).d\xi \right).\left(\frac{d_s}{2}\right).\left(\frac{1 + \pi.f.d_s}{\pi.d_s - f.1}\right) \tag{4.18}$$

The unknown parameters in Equation 4.18 are H_1, d_s, l.

Second equation is the volumetric flow rate of the uncompressed seed with a correction factor as given in Equation 4.19. It is equal to the swept volume by the first turn of the screw in one second.

Tooth thickness, t, is taken as 7 mm according to maximum shear strength calculations in Appendix A. And l is the pitch of the screw. If the thickness of the tooth is subtracted from the pitch, then the gap distance between the first and the second turn of the screw can be determined. The area of this gap is equal to

$H_1.(l-t)$. Decrease in height of the tooth between first and second turns can be neglected since the tapered angle is small. So, it is assumed that the height is constant along the first pitch.

The gap area should be multiplied by the helix length for one turn in order to determine the volume swept by the first turn of the screw in one revolution. One revolution is completed in 2 seconds since the rotational speed of the screw shaft is taken as 30 rpm. So, in order to calculate the volumetric flow rate of the seeds, the swept volume should be divided into 2 seconds.

$$\frac{Q_{uncompressed\_seed}}{\varsigma} = \frac{H_1.(l-t).L_t}{2\sec} \qquad (4.19)$$

Then there are three unknowns in Equation 4.19 which are H_1, d_s, l. However there are two Equation 4.18 and Equation 4.19. In order to determine the unknowns, a reasonable value should be assigned to one of the unknowns such as "d_s". One of the criteria while assigning the value of d_s is concerning the capacity of the manufacturing machine which will be used in production of this part and the expected size of the overall machine. After assigning a value to d_s, the other unknowns can be calculated. Also, calculated torque should be checked if it is reasonable or not as discussed in Section 4.2.2.2. The required power should be below 4 kW. Accordingly, the required torque should be below 1430 Nm if the rotational speed is 30 rpm.

Table 4.2: The results of the three unknown parameters

d_s	l	H_1
66mm	22mm	11mm

From Equation 4.19 and Equation 4.18, the required torque becomes 1286 Nm and the required power is calculated as 4 kW for 30 rpm rotational speed. Also, length of the screw is calculated as 250 mm.

Although thread depth at the end of the screw is zero, cake will extrude from the grooves which are machined inside the vessel for canalizing the seeds.

Stress Analysis at the Most Critical Section of the Screw Shaft

In Figure 4.11, directions of moment, torque, reaction forces and pressure of the seeds applied on the screw shaft is represented.

W_s is calculated as 10 kg by using ProENGINEER. Moment originated from Ws is negligible.

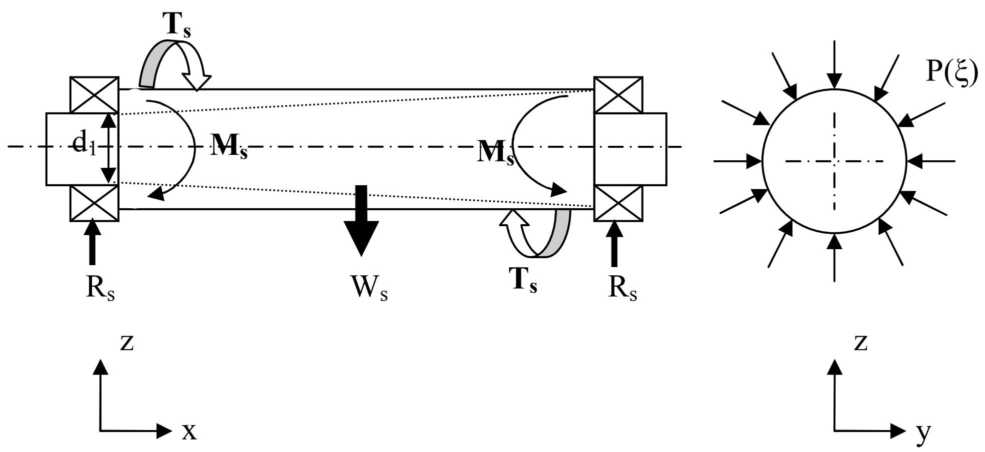


Figure 4.11: Free Body Diagram of the screw shaft

The maximum critical section is at the cross-section of the screw shaft where the diameter is minimum (d_l). The nominal shear stress in torsion at this cross-section of the screw body can be calculated by using Equation 4.20.

- According Unified and American Thread Design, stress concentration factor, K_f, for threads is taken as 3 for this design.

$$\tau_{yz} = K_f \frac{T_s.(d_1/2)}{\frac{\pi}{32}.d_1^{\,4}} \tag{4.20}$$

Then $\tau_{yz} = 230\text{MPa}$ where $\tau_{xy} = \tau_{zx} = 0\text{MPa}$. The stress originated from the moment due to the weight of the shaft, M_s, is negligible compared to the shear stress calculated in Equation 4.20.

According to Maximum Shear Stress (Tresca or Guest) Hypothesis, yielding will occur if $(\tau_A)_{yz} \geq \frac{S_y}{2}$. The yield strength of the material, AISI 1045, is 505 MPa. Since $230\text{MPa} \leq 253\text{MPa}$, then AISI 1045 can be used as material of the screw shaft.

4.2.3.2 Vessel Design

Choking and jamming mostly depend on the vessel geometry. 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 or jamming. 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. Details of the oil drainage holes and grooves are explained in the subsections.

4.2.3.2.1 Oil Drainage Zone

For oil drainage, holes are machined onto the vessel. These holes 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 as shown in Figure 4.12. Oil flows from the high pressure zone to the low pressure zone until it finds an opening to rush out.

Whole seeds are present at the low pressure zone. Here oil can easily leak out from the openings, because whole seeds cannot choke these openings. In order to prevent any choking, the diameter of the hole, D_h, is assumed as 1 mm, because minimum diameter of canola seed is measured as 1.5 mm among the 100 unit of samples. Determination of the locations of the holes is evaluated with experiments. In the experiments, equally distant holes are machined onto the vessel in the longitudinal direction. It is seen that the holes are not choked with cake which are 50 mm or more far from the cake drainage.

Since the velocity of the leaking oil is unknown; the number of the holes will be increased gradually during the experiments. However, depending on the maximum stress which occurs inside the vessel, maximum number of holes at a cross-section can be determined. The inside pressure at the oil drainage zone should be determined in order to calculate the maximum stress inside the vessel. The pressure can be taken as $P(L_t(\#_{turns} - \frac{50mm}{22mm}))$ which is equal to 30 MPa according to Equation 4.15. High pressure develops in tangential directions as shown in Figure 4.12. The tangential stresses can be determined by using Equation 4.21. σ_{radial} is negligible compared to $\sigma_{tangential}$. Longitudinal stress exists when the end reactions to the internal pressure are taken by the pressure vessel itself. In this design, the end reactions are not taken by the pressure vessel itself. They are carried by the bolts which are used in fastening the frame and the vessel. Then, $\sigma_{longitudinal} = 0MPa$.

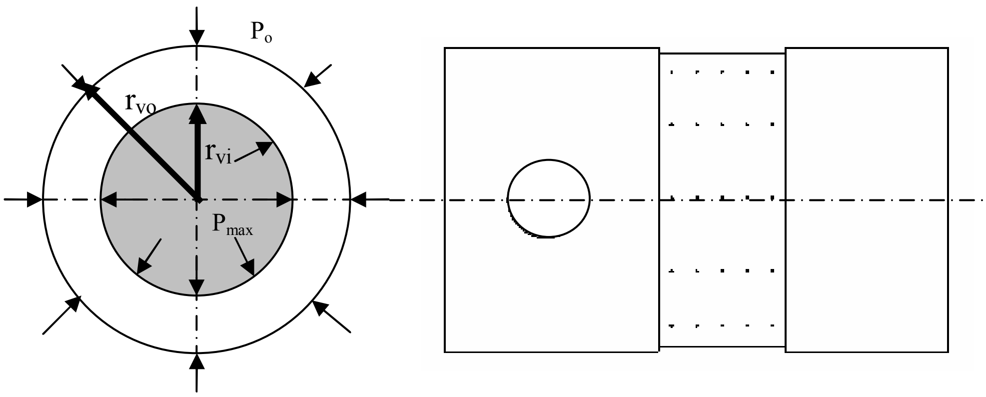


Figure 4.12: Illustration of inside and outside pressure for the vessel

$$\sigma_{tangential} = \frac{P_{max}.r_{vi}^{2} - P_{o}.r_{vo}^{2} - r_{vi}^{2}.r_{vo}^{2}.\dfrac{(P_{o} - P_{max})}{r^{2}}}{r_{vo}^{2} - r_{vi}^{2}} \tag{4.21}$$

In Equation 4.21, r_{vi} is the root diameter of the vessel and r_{vo} is the ouside diameter of the vessel. r is taken as the root diameter of the vessel, since the maximum stress will develop inside the vessel. The tangential stress can be converted into nominal stress by using Equation 4.22. However, this value should be multiplied with the stress concentration factor which is shown in Equation 4.23. L_h is the distance between two holes [63].

$$\sigma_{nom} = \frac{\sigma_{tangential}}{(1 - \dfrac{D_h}{L_h})} \tag{4.22}$$

$$\sigma_{max} = K_t.\sigma_{nom} \tag{4.23}$$

Stress concentration factor can be calculated by using Equation 4.24 for $0 \le \dfrac{D_h}{L_h} \le 1$.

$$K_t = 3 - 3.095(\frac{D_h}{L_h}) + 0.309(\frac{D_h}{L_h})^2 + 0.786(\frac{D_h}{L_h})^3 \tag{4.24}$$

If Equation 4.22 is substituted into Equation 4.23, then the relation between $\sigma_{tangential}$ and σ_{max} is given in Equation 4.25.

$$\sigma_{max} = K_t \frac{\sigma_{tangential}}{(1 - \dfrac{D_h}{L_h})} \tag{4.25}$$

In Figure 4.13, $\dfrac{K_t}{(1 - \dfrac{D_h}{L_h})}$ is constant, 3, after L_h >4mm. To be on the safe side, L_h is assumed as 5mm.

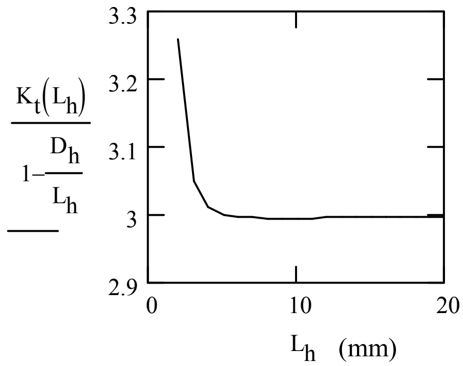


Figure 4.13: $\frac{K_t}{(1-\frac{D_h}{L_h})}$ **vs. L_h graph**

For the ease of manufacturing, the vessel material is selected as Al 7075 for the prototype. Also Al 7075 is selected since cost and yield strength of this material is suitable for this stage of the design. 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. Then if σ_{max} is 300 MPa, from Equation 4.25, $\sigma_{tangential}$ is calculated as 120 MPa.. By using Equation 4.21, thickness of the vessel is calculated as 25 mm where the outside pressure, P_o, is taken as 101.325 kPa.

Circumference of the inside vessel is equal to $2.\pi.r_{vi}$ where 66 mm is the diameter of the inside vessel. The maximum number of holes at one cross-section can be determined by using Equation 4.26.

$$N_{h_i} = \frac{2.\pi.r_{vi}}{L_h} \approx 40 \text{ holes} \tag{4.26}$$

During the experiments, the number of the row of holes can be increased and there should be at least 5 mm distance between the rows.

4.2.3.2.2 Groove Profile Selection for the Inside Vessel

Machining longitudinal grooves from inside the vessel is one of the most essential steps for this design. The grooves are very effective in preventing jamming and choking during the compression process. They serve as obstacles to prevent the rotation of the seeds together with the screw. Consequently, the cake extrudes out more efficiently.

In order to increase the effect of stopping the seed rotation, the applied tangential force should be maximized. The direction of the back of the groove should be radial as shown in Figure 4.14.

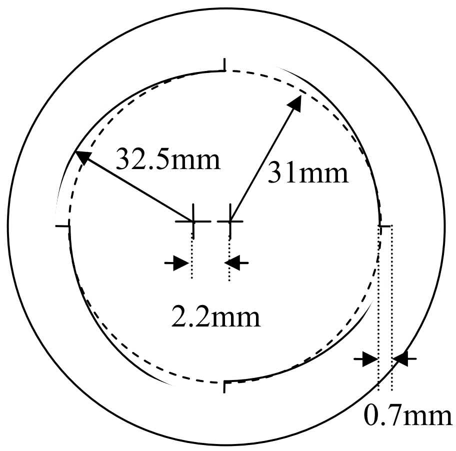


Figure 4.14: Illustration of the curvature shaped grooves and its dimensions

The adjacent wall of the groove should decrease until to the next root of the back wall. By this, choking arising from the density of the accumulation at the root of the back wall is reduced. Although the effective area which the tangential force is applied is very small, a very large pressure is applied onto the back walls of the grooves. Although the effective area which the tangential force is affected is very small, a very large pressure is applied onto the back walls of the grooves.

The oil drainage holes start from 50 mm far from the cake outlet section of the vessel. The number of the rows of the holes is not known, however the length of the grooves should reach the oil holes because they also serve as oil channels. Also, the length of the groove should not reach the feeding inlet in order to prevent the oil passing beyond the oil drainage holes, because oil can choke the feeding inlet. So, the length of the groove should be larger than 50 mm and shorter than 190 mm. As an initial value, the length of the grooves, L_v , is taken as 150 mm.

The depth of the grooves should be in a range of 0mm$<h_g<$1.5mm. 1.5mm is the diameter of a small canola seed. As the depth decrease, compression process results in jamming that the compressed seeds fills the groove gaps and makes the inner surface smoother. As the depth increase, efficiency of the compression decrease that the seeds are not compressed effectively. Experimentally, 0.7mm is determined as reasonable for this depth. Experiment depends on observing the jamming phenomena by increasing the depth of the groove step by step.

The number of the grooves, N_g, is taken as 4 as an initial value.

Although this type of groove has worked successfully during the tests, because of the manufacturing difficulties of this groove shape, another groove shape, which is easier to manufacture, has been developed in this study. This new type of groove has a triangular shape as shown in Figure 4.15.

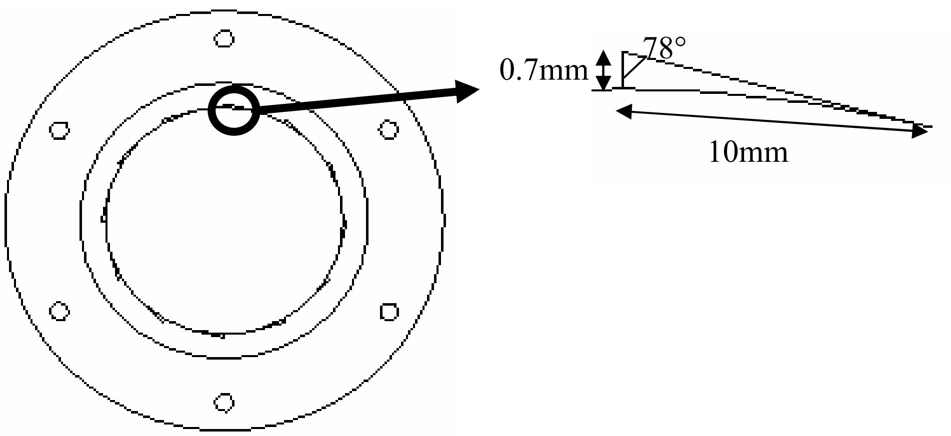


Figure 4.15: Detailed view of a groove from the front view of the vessel at the cake outlet section

A triangular groove is not as effective as a circular groove in stopping the rotation of the seeds and canalizing them through the cake outlet. Its influence area between the two edges of the groove is small compared to the circular type of groove. In a circular type of groove design, the influence area can be enlarged by increasing the diameter of the curvature of the long edge of the groove. However, in triangular type of groove, the length of the long edge completely depends on the depth of the short edge of the groove because of the tangential constraints. So, it is assumed that stoppage effect of one circular groove can be provided with three triangular grooves depending on the proportions of the lengths of the long edges. Then the number of the triangular grooves inside the vessel is determined as 12.

CHAPTER 5

MANUFACTURING AND TESTING OF PROTOTYPE OIL EXTRACTION MACHINES

5.1 First Prototype

The idea behind the first prototype was to develop a double feeding screw press in order to double the seed capacity rate with a one cake drainage system as seen in Figure 5.1. In the system, the seeds are fed into the system at the top of the first turns which have the highest pitch. The seeds coming from both left and right hands of the shaft meet at the middle. Also, for cake extrusion, a nozzle is mounted just above the meeting section of the seeds.

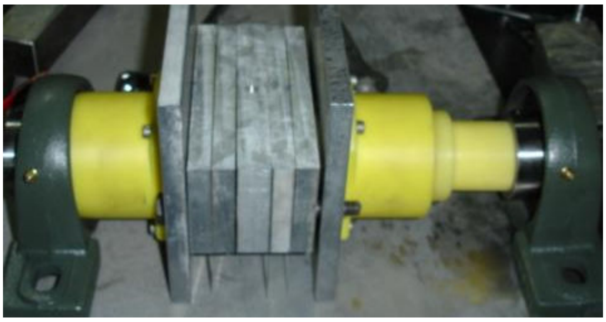


Figure 5.1: First Prototype of Screw Press

The machine components were manufactured and assembled in METU BİLTİR Center.

During the tests of this prototype, after reaching a certain compression pressure at the inside, the seed feeding stopped. Accordingly, no cake extrusion and no oil recovery are obtained. Small amount of seeds compressed at the intersection. But no penetration to the nozzle is observed.

One of the possible reasons for the unsuccessful attempt may be that insufficiency in pushing the seeds forward. This may depend on the low friction force between the seeds and the inner surface of the vessel. During rotation of the screw shaft, the seeds did not face with any obstacles at the inner surface of the vessel. After some compression, seeds positions become stationary relative to screw shaft that they were rotating together with the screw shaft.

Even if the required pressure had been reached in this system, most probably the cake will not be able to extrude from the nozzle, because the thread walls were perpendicular to the root diameter of the screw shaft (pressure angle is 0°). As a consequence, there would be no radial force which is supposed to push the seeds through the nozzle.

In order to overcome the problems, possible modifications can be developed on the prototype. Resizing process before the compression would increase the compression efficiency. By resizing, the maximum required pressure for oil recovery would be decreased. Also, cake extrusion nozzle should be substituted with a new design which should have adjustable opening. Because during any choking situation, by enlarging the extrusion area, choking would be overcome. Furthermore, lead angle of the screw thread should be decreased to increase the pushing force in the axial direction.

5.2 Second Prototype

The system is composed of three main parts which are the feeding, grinding and compression sections as seen in Figure 5.2. First, seeds are fed into the system from the feeding screw which has a larger diameter. Afterwards, seeds pass through the grinding part. At this stage, husks of the seeds are cracked and the seeds are broken into pieces. Then, resized seeds pass to the last stage where they are pushed forward to the discharge. At the cake discharge there is a conical part which is used in adjusting the area of the cake extrusion.

Similar to the first prototype, all the machine components are produced in METU BİLTİR Center.

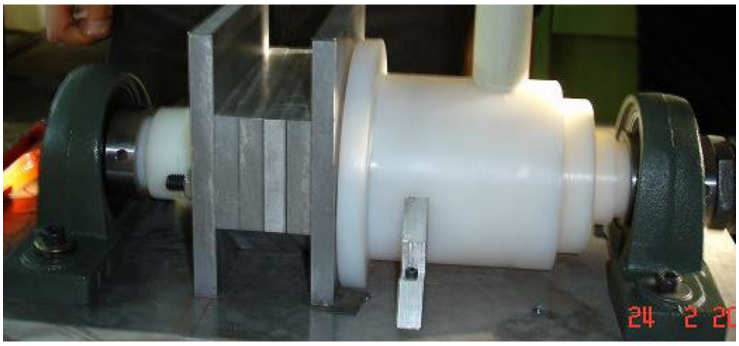


Figure 5.2: Second Prototype of Screw Press

In the first experiment, main body of the screw press was wrapped up with the heating bands adjusted to 70 ° C. There was no thermocouple to limit the maximum temperature of the main body. So, the highest temperature is unknown at the last stage of the experiment. It was observed that the feeding stopped after some time (3-4 minutes). The system choked. After opening the machine inside, it was seen that ground seeds sticked to the grinder teeth so that the passage from the feeding stage to the compression stage has been blocked. And the system choked. Most probably, the reason was the temperature increase. With the high temperature, viscosity of the oil in the ground seeds decreased and behaved as an adhesive substance.

In the second experiment at room temperature (24°C), it was observed that the feeding again stopped after some time (4-5 minutes). The system choked. However, in this experiment, the choking did not occur at the grinder, instead, it had occurred at the cake drainage. After reaching certain pressure value, the compressed seeds sticked to the screw shaft and started to rotate together. So, the feeding was blocked since no drainage occurred.

It can be stated that there are mainly two reasons. Firstly, plastic material of the screw shaft doubles the sticking effect of the compressed seeds onto the thread wall. And secondly, at the inside surface of the cage, there should be obstacles to prevent the rotation of the compressed seeds together with the screw shaft and canalize the compressed seed to the drainage.

In this experiment, grooves were machined inside the ring barrel surface in order to canalize the compressed seeds.

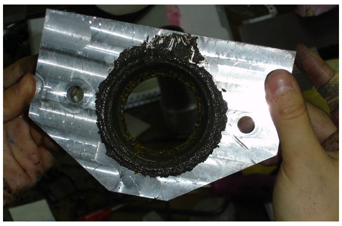


Figure 5.3: Extruded cake view after the third experiment

In the test results, cake extrusion occurred in small amount as shown in Figure 5.3. Also, oil recovery occurred for about 5 drops. After that, system jammed. The grooves partially prevented the rotation of the seeds and helped them to be pushed forward to the drainage. However, the system again jammed and choked, because the depth of the grooves was very small (0.1mm) and the sticky property of the plastic material decreased the obstacle effect of the grooves. As a solution, the depth of the grooves should be deepened. Also, the material property of the screw shaft should not be sticky.

In the fourth experiment, material and configuration of the screw at the compression stage were adjusted. An aluminum and tapered screw shaft was produced. Also grooves inside the barrel rings were deepened.

The system stopped after five or six revolutions that the torque of the motor was insufficient. The main reason for the stoppage of the system depends on the eccentric assembly of the machine components. Wear occurred between the aluminum parts and the mechanism was locked. However, seeds that reached to the cake drainage were dry that their oil was extracted before.

The tapered screw configuration was working, but the eccentricity problem should be overcome. In order to overcome this problem, screw shaft should be one piece, ring barrels should be one piece and the clearance between the screw shaft and the ring barrels should be smaller.

5.3 Third Prototype

The manufacturing step for the third prototype (Figure 5.4) depends on mainly manufacturing of two parts.

The first part is the screw shaft which was machined by using 4 axes CNC turning machine located in METU BİLTİR Center. The code input is written for a tapered screw machining.

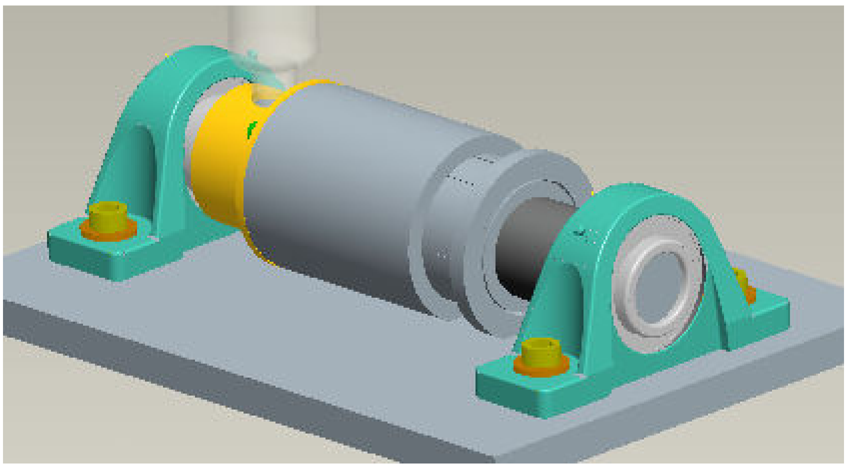


Figure 5.4: 3D model of the third prototype

There were mainly two problems occurred during the machining process of the cylindrical aluminum which were the buckling and the eccentricity problems.

The problems totally depend on the center which was out of use for the CNC machine.

The height of the thread approximates to zero at one end of the screw shaft whereas at the other side of the screw shaft, the thread height is maximum. So the cutting tool penetrates deeply to the shaft during the machining process at where the height of the thread is maximum. This may probably result in a large moment at the other end. This moment would result in larger buckling of the aluminum if it is applied at the very far end. In order to overcome this buckling problem, the CNC codes are adjusted in such a way that the deep thread side of the shaft is mounted closest to the jaw.

Solution to the eccentricity problem was developed by using two center, during the finishing process. The diameter of the screw shaft was machined slightly larger than the calculated diameter (+1 mm). So, at the last machining stage, where the ends of the shaft were reduced to bearing diameters, the shaft became concentric.

The second part is the vessel. The material of the vessel was cast aluminum. The reason for the selection of the material totally depended on cost and time. Cost of such a material has a lower price compared to the extruded aluminums. Time is related with the machining duration. Machining of aluminum is both easier and requires less time when compared to steel. The main feature of the vessel was the grooves inside. The grooves had such a shape that for machining these forms, using CNC WEDM (wire electrical discharge machining) was the most suitable way. Usage of CNC machines were not suitable, because machining the radius of the grooves requires cutting tools with very small diameters (0.5mm). And such a tool cannot have a length of 165 mm which is the length of the vessel. The total time when machining inside the vessel was about 15 hours. It is because cutting feed rate of the wire was 0.2mm/min in the CNC WEDM for such a long part.

After completing the inside profile of the vessel, several slits were machined starting from the inside surface through the outside in the radial direction for nearly 10 mm length. The width of the slit was the same with the diameter of the wire which was 0.2 mm. In order to open the ends of these slits to outside, the outside diameter of the vessel was reduced to a diameter until the ends of the slit appeared. This diameter reduction process was applied to 30 mm length of the vessel's total length, and this 30 mm interval starts 10 mm beyond the end of the vessel. The oil drainage slits were very close to the maximum pressure zone inside the vessel. However, it was seen that the oil drainage openings should not be so close to the maximum pressurized zone, because the compressed cake can fill the oil drainage openings because of the high pressure.

First experiment with this prototype was carried on at room temperature of 24°C. As represented in the Figure 5.5, the compressed seeds extruded out from the cake drainage module as flakes. The problem here was the oil content of the cake was high in amount. One of the reasons for this depends on the cake thickness was adjusted to 4 mm. So, high pressure could not be obtained.

Figure 5.5: View of the third prototype after the first experiment

In the second experiment, a heating device at 80 ° C was used to increase the oil recovery rate. Cake thickness was adjusted to 0.2 mm in this experiment. The heating mechanism (Figure 5.6) was composed of a thermocouple of maximum 90°C and a heater unit of 400 Watt as shown in Figure 5.6. Thermocouple was adjusted up to 80 ° C. The temperature sensing unit was touching to the surface of the vessel. At 80 ° C, than the sensor opened the circuit of the heater system and stopped the heater until the temperature decreases below 80 ° C. Afterwards, it closed the circuit and heater increased the temperature up to 80 ° C again.

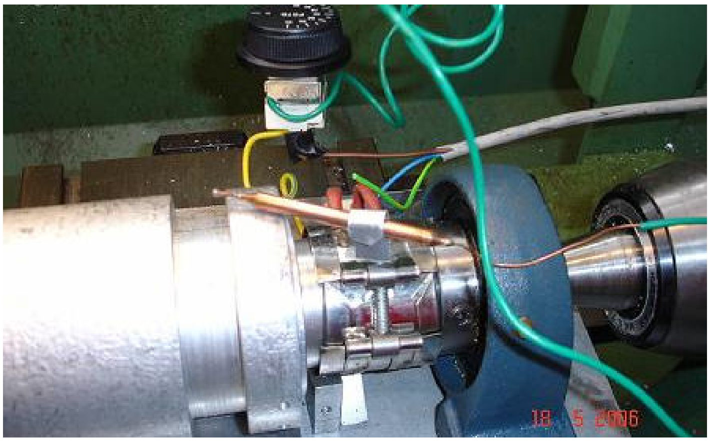


Figure 5.6: Heating Device mounted onto the third prototype

This experiment resulted more successfully with a heating mechanism. The extruded cake had a thickness of nearly 0.2 mm as shown in Figure 5.7. So the oil content of this cake was very low.

Figure 5.7: Cake view with thickness of 0.2 mm

In this experiment, initially oil came from the slits on the vessel. However, after some time (10 revolutions), the slits were filled with cake, and oil had no where to rush out. So, after the inside vessel was saturated with oil, oil leaked out from the cake drainage and feeding side of the vessel.

It was concluded that the oil drainage openings should not be so close to the maximum pressure zone. They should be at a place where the cake pressure is low. So, cake would not be able to fill the openings which are machined for oil drainage.

In the third experiment, 9 holes were machined for oil drainage with equally distant in the longitudinal direction of the vessel. The reason for this was to understand from which hole, the oil would leak out steadily without choking. Oil started to come from the hole which was at the nearest point to the maximum pressure zone. Then oil came from the second, and the third holes (Figure 5.8). Afterwards, oil leakage stopped because of the failure.

Figure 5.8: View of oil leaking out from the vessel

Failure occurred on the vessel (Figure 5.10), that it was separated into two because of the high pressure. A crack initiation was started at the slits after reaching a high pressure value. From this crack, both cake and oil were extruded out as shown in Figure 5.9.

Figure 5.9: View of the recovered oil after the failure

Figure 5.10: View of the failure on the vessel

Oil recovery was really effective with the help of the heating mechanism. By using a heating mechanism, oil viscosity decreased and leakage of the oil became easier. Also, cake extruded from the end of the vessel was seemed to be dry.

5.4 Fourth Prototype

In the fourth prototype (Figure 5.11), the basic differences from the third prototype are based on the tooth profile and the vessel. In the third prototype, tooth profile had no rounded edges at the tooth root. In this type, the edges at the tooth roots were rounded. The reason for this was to reduce the frictional losses, arising from the high pressure at the tooth root edges. Also vessel was developed with some adjustments. The thickness of the vessel was increased with a higher factor of safety to prevent any failure. Also, this time vessel was one piece as shown in Figure 5.12. This is an advantage both in manufacturing and ease of mounting-dismounting. Also, eccentricity problem occurred during assembly of the two components of the previous vessel was overcome with a one piece vessel. Although the curvature shaped grooves used in the third prototype were successful in canalizing the compressed seeds at high pressures, cost and time of manufacturing of these grooves were high. Then inside the vessel, four triangular grooves were machined with triangular cutting tools.

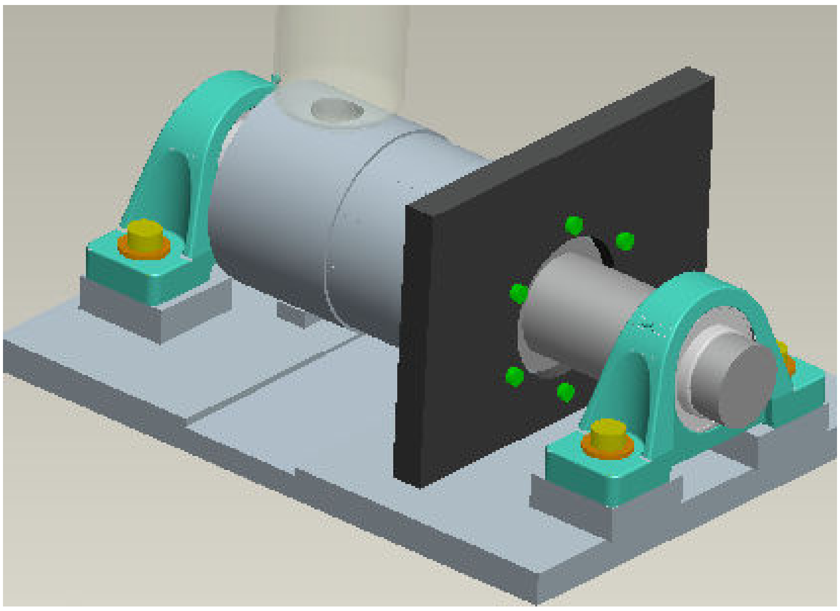


Figure 5.11: 3D model of the fourth prototype

In this type another difference was the oil drainage system. In the third prototype, oil drainage was supplied by slits that were machined longitudinally onto the vessel. In this type, holes were machined onto the vessel for oil drainage.

In this system, no heating mechanism was used. For the previous prototype, experiment durations had never exceeded 10 minutes. In this mechanism, experiment duration increased. And it was observed that the temperature of the system increased naturally after 10-15 minutes. So no heating mechanism was required. However, a cooling unit may be used in order to maintain the overall temperature of the system below the 90 ° C in order to preserve the quality of the yield oil.

In the first experiment, cake drainage gap was adjusted to 3 mm at 40 rpm. Accordingly, extruded cake thickness was 3 mm. Efficiency of the system (percentage of recovered oil according to the total oil content for a certain amount of seeds) was obtained as 25% as given in Table 5.1. This result showed that higher pressure was required for higher oil recovery rates.

Figure 5.12: View of the total system after the first experiment

In the second experiment, the cake drainage gap was reduced to 1.5 mm at 30 rpm. So, cake thickness was 1.5 mm as shown in Figure 5.13.

Figure 5.13: View of the extruded cake

After several minutes, flow of the seeds stopped and the system choked. The reason for choking depends on the insufficient number of the grooves inside the vessel. Four grooves were insufficient to canalize the compressed seeds forward at high pressures.

In the third experiment, number of grooves inside the vessel was increased to twelve. This time, the grooves were machined for 150 mm length starting from the cake drainage side of the vessel. The reason for not machining the grooves from one end to other end of the vessel is to prevent the recovered oil from passing to the feeding section. Since the grooves serve as oil channels, they should not reach to the feeding section. In this configuration, cake thickness was adjusted to 0.8 mm.

Figure 5.14: View of the oil and cake recovery after the third experiment

Initially, from the oil drainage holes, a muddy substance, composed of compressed cake and oil, came as shown in Figure 5.14. After 10 minutes, temperature of the vessel increased up which was caused by the frictional forces and high pressure inside the vessel. The higher temperature resulted in higher oil recovery rates and cooked cake flakes. However, this temperature increase should be controlled for the quality of the yield oil. The residual oil content was 15% of the total weight of the sampled cake, extruded from the cake drainage as given Table 5.1.

Table 5.1: Residual oil contents for two cake thickness samples at 40 rpm

	Ex. 3	Ex. 1
Cake Thickness	0.8 mm	3 mm
Efficiency of the Screw Press $(\frac{\text{Recovered Oil}}{\text{Total Oil}})$	62.5%	25%

In order to determine the residual oil content of the cake, certain amount of sample from the extruded cake was exposed to solvent extraction method which is explained in Appendix B.

a) Calculation of the Seed Capacity of the Fourth Prototype for 62.5% efficiency

At the beginning of the design calculations, volumetric flow rates of the recovered oil and extruded cake was calculated as if the efficiency of the system was 85%. However, 62.5% efficiency was achieved during the tests. Then volumetric flow rates of the recovered oil and the extruded cake changed as given in Table 5.2.

Table 5.2: Volumetric flow rate of the contents in the screw press with 50 kg/h seed capacity and 62.5% efficiency

	Volumetric Flow Rate (L/h)
$Q_{uncompressed\_seed}$	70
$\frac{Q_{uncompressed\_seed}}{\varsigma}$	77.8
$Q_{compressed\_seed}$	38.9
Q_{oil}	15
Q_{cake}	23.9

According to Figure 5.15, the annular area from where the compressed cake extrudes can be calculated as ($\pi 42.8^2 - \pi 42^2 = 213 mm^2$). During the experiments, it was observed that the velocity of the extruded cake was approximately 10 mm/s. So, volumetric flow rate of the compressed cake is determined as 2130 mm^3/s. According to Table 5.2, volumetric flow rate of the compressed cake is 23.9 L/h (6640 mm^3/s) for 50 kg/h seed capacity at the same conditions.

The theoretical volumetric flow rate is three times greater than the real volumetric flow rate of the compressed cake. This means, seed capacity of the developed machine is nearly 15 kg/h.

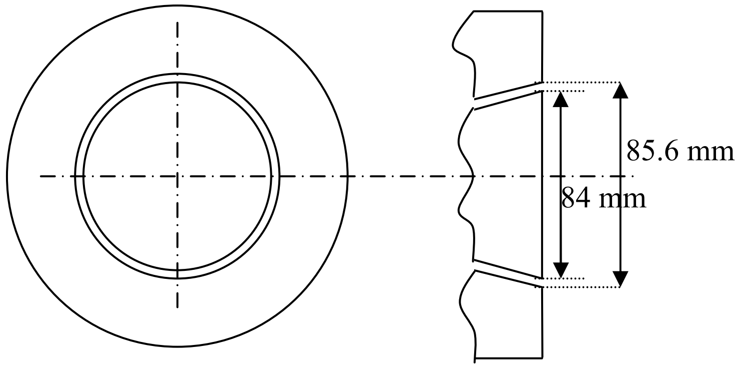


Figure 5.15: Illustration of the cake drainage section with geometrical dimensions

b) Calculation of the real motor power required for the developed screw press

In the fourth experiment, the maximum temperature change at the cake drainage and the maximum power consumption of the drive system were determined. During the experiment, the system was driven at a speed of 30 rpm for 15 minutes. After 15 minutes, the speed of the system was increased to 40 rpm. The system rotated at 40 rpm for 15 minutes. The cake drainage gap was adjusted to 0.8 mm. The results of the fourth experiment are presented in the subsections.

In the experiments, prototypes were clamped to the turning machine (Universal Centre Lathe, SN32/1000) which was used as a drive system for the prototypes. The current of the electric motor of the turning machine (3 phase) at different operating conditions are represented in Table 5.3. Specifically, power is determined by using the "root mean squared voltage" (V_{rms}). According to Equation 5.1, apparent power, S_{total} (watt), is equal to the sum of the powers at each phase calculated by the multiplication of the potential difference (volt) and the current (ampere). Since the voltages and the phase currents are equal for three phases, then the system is symmetrical and balanced. Then, Equation 5.1 can be written as Equation 5.2. In this equation, V_{rms} is 220V and electric currents are given in Table 5.3. A power factor, cosφ, should be multiplied with the apparent power in order to determine the real power as given in Equation (5.3).

$$S_{total} = V_{rms(1)} I_{rms(1)} + V_{rms(2)} I_{rms(2)} + V_{rms(3)} I_{rms(3)} \tag{5.1}$$

$$S_{total} = 3 V_{rms} I_{ms} \tag{5.2}$$

$$P_{total} = S_{total} \cos\varphi \tag{5.3}$$

As written in the machine technical data of the turning machine, total power input (apparent power), S_{total}, is 5.2 kVA and motor input (real power), is 4 kW. The power factor, $\cos\varphi$, of the turning machine at maximum loading condition is the proportion of motor input to total power input which is 0.76 Equation 5.3.

At unloaded condition, apparent power, $S_{unloaded}$, can be written in terms of real power, $P_{unloaded}$ and reactive power, $Q_{unloaded}$ as given in Equation 5.4. By using Equation 5.2, $S_{unloaded}$ is calculated as 3 kVA. If $P_{unloaded}$ is assumed as zero by neglecting the frictional losses, then $Q_{unloaded}$ is determined as 3 kW. $Q_{unloaded}$ is assumed to be constant for all the loading conditions.

$$S_{unloaded} = \sqrt{P_{unloaded}^{\ 2} + Q_{unloaded}^{\ 2}} \tag{5.4}$$

For 4.9 Ampere loading condition, the power factor ($\cos\varphi$) is lower than 0.76, because the apparent power is not at the maximum loading condition. S_{total} is calculated as 3.2 kVA for 4.9 Ampere. Then similar to Equation 5.4, at loading condition for 4.9 Ampere, real power for the loaded condition, P_{loaded}, is calculated as 1.1 kW as shown in Table 5.3 if reactive power is taken as the same for this loading condition.

Table 5.3: The electric currents and the power consumed by the turning machine at different operating conditions

Operating Conditon	Current (Ampere)	Complex Power (kVA)	Reactive Power (kVA)	Real Power (kW)
without load	4.6	3	3	0
with load	4.9	3.2	3	1.1

Current of the electricity was measured with a clamp meter. Clamp meter is a type of ammeter which measures electrical current without any need to disconnect the wiring through which the current is flowing. Clamp is opened to put the wiring, and then closed for the measurement. The current of the turning machine at no load condition was measured as 4.6 Ampere. After connecting the prototype to the turning machine, then the current increased to 4.9 Ampere.

c) Calculation of the Temperature Change for the Developed Screw Press

As shown in Figure 5.16, the maximum temperature, at the cake drainage of the screw shaft during the experiment, was measured as 88°C (40 rpm).

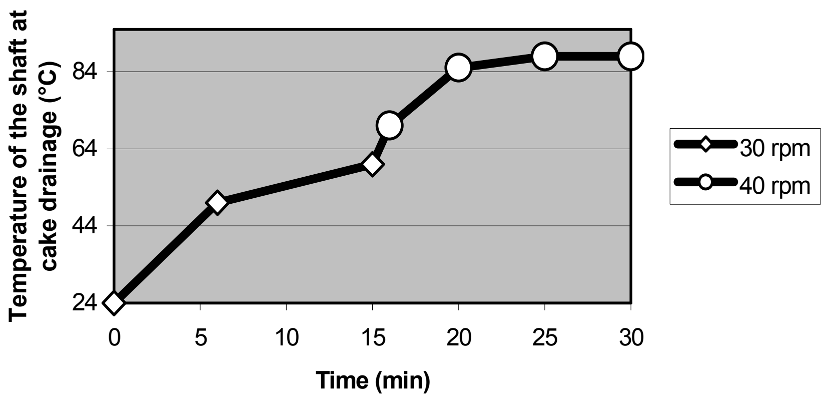


Figure 5.16: The temperature change of the screw shaft at 30 rpm for the first 15 minutes and at 40 rpm for the rest

The temperature of the screw shaft and the vessel was measured with a non-contact thermometer (Raytek ST60 XB with a temperature range between -32°C and 600°C).

The maximum temperature at the outside surface of the vessel, closed to the cake drainage zone, was measured as 86°C (40 rpm) as shown in Figure 5.17.

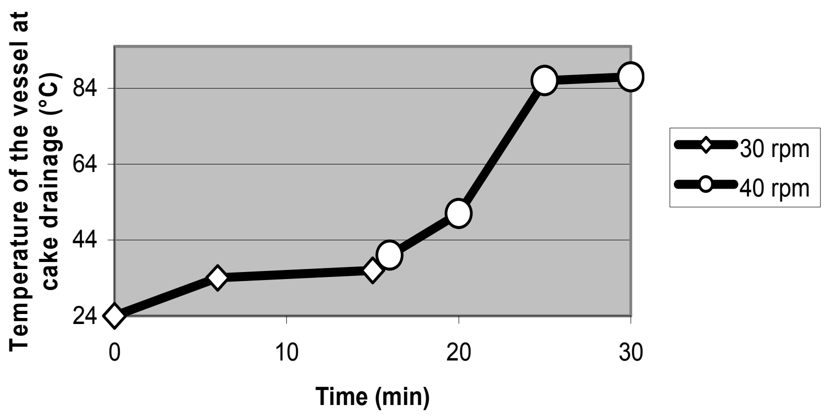


Figure 5.17: The temperature change of the vessel at 30 rpm for the first 15 minutes and at 40 rpm for the rest

CHAPTER 6

DISCUSSION AND CONCLUSION

The aim of the study is to develop an oil extraction machine for the canola seed. The main criteria of this study are the required seed capacity which is 50 kg/h and the maximum available power which is 4 kW. During the study, various alternatives were generated depending on the previous studies and available oil extraction machines in the markets. Different screw configurations, oil and cake drainage systems were developed for four different designs. According to the results of testing of the prototypes, they have been modified and gradually improved. Discussion and conclusion on the manufacturing and testing of the prototypes are represented in the following subsections.

6.1 Discussion on Manufacturing and Assembly Stage of the Prototypes

At the manufacturing and assembly stage, several problems were experienced. The most important problem during the manufacturing of the prototypes was the eccentricity between the screw shaft and the vessel. Depending on the tolerances of the manufacturing machines and manufacturing methodology, eccentricity problems may occur. In this study, concentricity was very important for the screw shaft and the vessel. Since there was small clearance between the screw shaft and the vessel, any small eccentricity resulted in locking of the system arising from the contact of the metal parts.

In the manufacturing and assembly stage of the fourth prototype (in Section 5.3), to overcome the eccentricity problem on the screw shaft, all the machining process of the screw shaft were performed between two centers of the CNC turning machine. During the assembly of the screw shaft and the vessel, it was observed that the axes of them were not coinciding. Since the vessel was mated to the flange with bolts, slope at the mating surface of the vessel and the flange or at the bottom surface of the flange might cause eccentricity. The problem was overcome by supporting the free end of the vessel with a block in order to make the axes of the vessel parallel to the platform surface. Afterwards, elevation height of the pillow block bearings was adjusted. This step was really difficult to implement since the minimum clearance between the screw shaft and the vessel was 0.05 mm. So any small difference in the heights of the bearings would cause locking of the mechanism. Very thin metal sheets with certain thickness were used to determine the exact height of the pillow block bearings.

In the third prototype, the groove profile was manufactured by using CNC WEDM located in METU-BİLTİR Center. However, this production method was both expensive and time consuming. It took 15 hours to machine the groove profile in the CNC WEDM. So, in the fourth prototype, an alternative geometry for the ease manufacturing of the groove profile was developed. In the fourth prototype, cutting tool was machined in the shape of a perpendicular triangle. Then it was driven in the longitudinal direction of the inside vessel with a small penetration (0.7 mm) to form the grooves. Also an advantage for this type of manufacturing method was that the groove can be machined to any length.

Manufacturing of the oil drainage holes was a difficult and time consuming process. Duration of the drilling for one hole took 5 minutes which means for 200 holes it takes 1000 minutes (16.7 hours). In the fourth prototype the number of the drilled holes was increased gradually. Initially, 4 holes were drilled in the longitudinal direction to analyze the effect of the distance between the hole and the cake drainage zone. Afterwards, the number holes were increased to 12 (4 holes at each 90° orientation to the axes of the vessel). At the last configuration, there were 36 holes drilled on the vessel since it was determined as sufficient. Actually, as a future work, an alternative solution for the oil drainage system should be developed.

Assembly and disassembly of the machine components was another important problem during the study. After each experiment, the screw press was left to be cooled down before the disassembly process of the machine components for cleaning. However, cooled screw press was very hard to disassemble. At high temperatures, compressed seed could easily penetrate through the clearance between the vessel and the screw shaft by the expansion of the material at high temperatures. After cooling down, the dry seeds caused high friction force between the vessel and the screw shaft. In order to overcome this problem, after each operation of the screw press, the cake drainage cone can be moved forward before cooling down. As a second alternative solution to prevent locking of the mechanism, the vessel can be composed of two parts which are separated in the axial direction after each operation. Furthermore, by this configuration, the disassembly can be performed by only separating the vessel easily.

6.2 Discussion on the Testing of the Prototypes

During the experiments, it was observed that four main features affected the compression efficiency. These were the groove profile inside the vessel, the taper angle of the screw shaft, the operating temperature and the rotational speed.

Grooves were very effective in canalizing the compressed seeds and prevented jamming of the system. In order to obtain an effective canalizing of the compressed seeds, the direction of short edge of the groove should be in the radial direction. So, the maximum available tangential force can be applied to stop the rotating compressed seeds. Furthermore, the depth and the length of grooves were also important in canalizing. As an experience, the length of the grooves should not be machined from one end to the other. Since the grooves serves as oil channels, oil may go back to the feeding section and may choke the feeding tube. Two types of grooves were tested in the prototypes. In the third prototype, the curvature shaped groove profile (Figure 4.15) of the vessel was very successful in canalizing the compressed seeds at high pressures. Curvature shape of the long edge of the groove was highly capable of stopping and canalizing the rotating compressed seeds. In the fourth prototype, the groove profiles (Figure 4.16) were not as effective as the grooves in the third prototype.

Since the geometry of the grooves was in a triangular shape, their influence area was small to stop the compressed seeds. Also, in the third prototype, although the cake drainage gap distance was reduced to 0.2 mm, no jamming occurred. The reason was the high canalizing capability of the curvature shaped groove. However, in the fourth prototype, at high pressures, canalizing effect of the triangular shaped grooves decreased and at a cake drainage gap of 0.5 mm, the system jammed. Cheaper and more time-efficient manufacturing technique for machining the curvature shaped grooves may be investigated to implement the curvature shaped groove profile to the developed screw press.

In the first prototype, screw with alternating pitch configuration was implemented. And in the second prototype, straight screw shafts with uniform pitch were used. However, tapered screw shaft (Section 5.3) which was used in the third and the fourth prototypes was more effective in compressing the seeds than the previous prototypes. The reason depends on the compression of the seeds in two directions in the tapered screw shaft. First one occurs between the adjacent two turns of the screw by the compression of the newly added seeds. Other way of compression takes place between the inner surface of the vessel and the inner surface of the screw shaft.

Temperature is essential for increasing the oil recovery rate. During the experiments, temperature increased the fluidity of the oil. So oil could be able to move faster and easily penetrated into the gaps of the cake easily. It also cooked the cake which resulted in cake flakes. In the third prototype, a heating mechanism was used to increase the temperature at the cake drainage. It resulted in higher oil recovery rates and very thin cake flakes. However, in the fourth prototype it was observed that, there was no need for a heating mechanism since the temperature of the whole system increased naturally because of the friction between the compressed seeds and the machine components.

Rotational speed is another important factor which affects the flow of the seeds. If the rotational speed is higher than the required, then the system can be jammed. Or if the rotational speed is lower than the required, and then seeds can not be pushed forward effectively. In the experiments, it was observed that 40 rpm was convenient for the developed screw press. During the experiments, jamming problem was overcome by increasing the rotational speed to an upper value.

6.3 Conclusion

The technical data for the developed screw press is given in Table 6.1.

Table 6.1: Technical data for the developed screw press

Seed capacity of the screw press	15 kg/h
Cake thickness	0.8 mm
Extraction efficiency of the screw press $\left(\frac{\text{Recovered Oil}}{\text{Total Oil Content}}\right)$	62.5%
Motor Power	1.1 kW
Rotational Speed	40 rpm

Seed capacity rate was assumed as 50 kg/h at the beginning of the design calculations. However the present system has a seed capacity of 15 kg/h. Theoretically, assumed seed capacity is three times greater than the real seed capacity of the developed screw press. This means, the feeding efficiency which was assumed as 0.9 in Section 4.2.2.1, is not correct for the developed screw press. It should have been taken as 0.3 to obtain 50 kg/h seed capacity. However, if the feeding efficiency is taken as 0.3, then the machine size enlarges too much.

Another alternative to increase the seed capacity of the present screw press is increasing the canalizing capability of the grooves inside the vessel. This can be achieved by adjusting the groove profile, depth and length.

According to Table 6.1, the power consumed by the turning machine clamped to the prototype is 1.1 kW. However, the assumed available power for the developed oil extraction system was taken as 4 kW at the beginning of the detail design calculations. One of the reasons for the difference in the theoretical and the real value of the motor power is the efficiency of the system. The efficiency of the system was assumed as 85%; however the efficiency of the developed machine is 62.5%. Since lower oil recovery rate was obtained, the maximum pressure inside the vessel has never reached to 60 MPa, which was an assumed value for an oil recovery rate of 85%. Accordingly, lower pressure resulted in lower torque and, lower torque lead to lower required motor power. The difference between the theoretical and the real value of the motor power also depends on the assumption of pressure distribution which was a third order polynomial. During the tests, it was observed that only the last two turns were filled with compressed seed, the other turns were filled with non-deformed seeds. This means that the function of the pressure distribution should have been assumed as higher order polynomials. Another assumption, which would have lead to a higher theoretical motor power, was the kinetic friction coefficient between the seeds and the machine components. Although the friction coefficient was taken as constant through the shaft, it was different for compressed and uncompressed seed.

During stress analysis of the screw shaft, factor of safety was calculated slightly higher than 1 at the most critical cross-section of the shaft according to Maximum Shear Stress Theory (Section 4.2.3.1). However, real torque obtained during the tests was determined as 260 Nm which is equal to 1/5 of the calculated torque. Then, factor of safety becomes 5 which means the design is safer.

The maximum temperature obtained during the fourth experiment in Section 5.4 was 88°C at the cake drainage zone of the screw shaft. The temperature of the recovered oil should be preserved under 90°C for the quality of the oil. The obtained maximum temperature (88°C) is under the limit. However, it should be lower than 88°C since it is very close to 90°C.

As a design criterion it was aimed to produce a screw press that can easily be assembled for cleaning purposes. However, in the prototype it was hard to reassemble due to the need to readjust the concentricity of the shaft and vessel after every disassembly. It also necessitates some expertise and time to put everything back in place, which can also be considered to be a drawback for a possible future marketable machine.

As a future work,

- Alternative ways for easier assembly and disassembly of the machine components should be investigated (e.g. the vessel can be produced as separable in order not to disorder the concentricity of the bearings).
- The effect of the location and the size of the oil drainage holes should be analyzed to improve its oil recovery efficiency. A fluid flow analysis of the oil can be performed.
- Temperature effects on the cake and the oil can be studied.
- Groove shape optimization can be studied in order to create less torque and increase the canalizing ability.
- Pretreatments like heating and moisture effect on the seed can be investigated.
- Feasibility analysis for usage of a tractor`s PTO shaft as drive system for a screw press.

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APPENDIX A

Screw Thread Thickness Calculations

In Equation A.1, axial force distribution on the total thread length is given. According to Figure A.1, maximum unit force applied on the threads occurs at 2150 mm of the total thread length (2832 mm) which is determined as 70 N/mm.

$$F_a(\xi) = P(\xi).H(\xi) \tag{A.1}$$

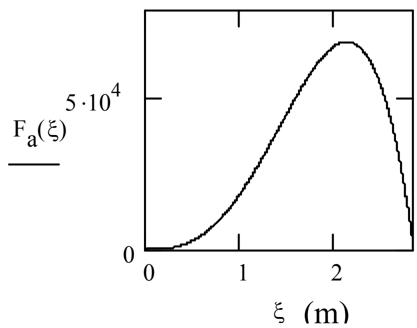

Figure A.1: Axial force distribution applied on the threads along the thread length

According to maximum shear stress theory, the maximum shear stress can be calculated by using Equation A.2. If tooth thickness, t, is taken as 7 mm, then maximum shear stress, τ_{max}, is determined as 10 MPa.

$$\tau_{max} = \frac{F_a(2150mm)}{t} \tag{A.2}$$

In Equation A.3 [55], maximum yield strength, S_y, of the material should be greater than 20 MPa. According to stress analysis calculations in Section 4.2.3.1, the material of the screw shaft is selected as AISI 1045 which has yield strength of 505 MPa. Then it is safe for a tooth thickness of 7mm.

$$S_y = 2.\tau_{max} \tag{A.3}$$

APPENDIX B

Solvent Extraction Experiment for Calculation of the Residual Oil Content in the Cake

Residual oil content in the cake flakes, which were sampled from the developed screw press at 40 rpm and with 0.8 mm cake thickness, was calculated to determine the efficiency of the system. As a first step, the flakes of the sampled cake flakes were resized by a grinder as shown in Figure B.1. By resizing, the contact area of the sample was increased that solvent could easily penetrate into the sample. So, the measurement result became more reliable.

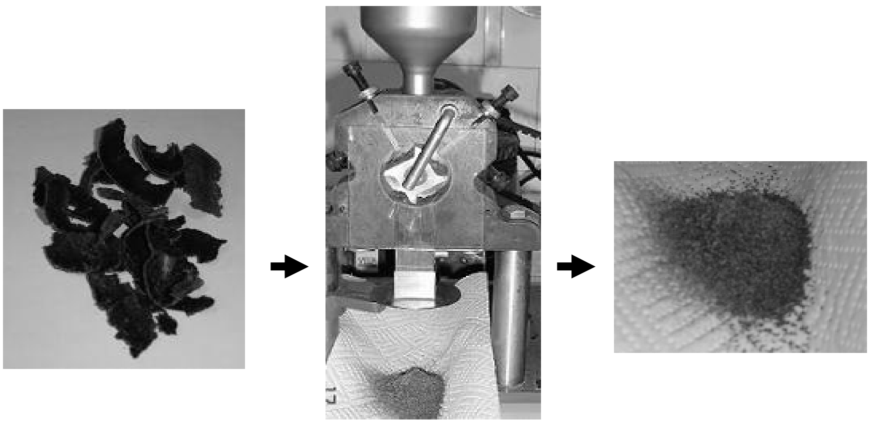

Figure B.1: Flow chart of the grinding process of the cake flakes

Solvent extraction method is proposed by AOAC [58] and is a reliable way of determining residual oil content in the cake.

During the experiments, soxhlet extraction apparatus was used (Figure B.2). Sample was placed into the thimble which was made up of a permeable substance. As a solvent, hexan was poured into the boiling flask and heated up to 70 °C which is the boiling temperature of hexan. Evaporated hexan was condensed by the condenser and dripped the sample. After five to ten minutes, solvent completely surrounded the sample, and then siphoned back to the boiling flask through the siphon arm. Oil dissolved in the hexan and accumulated in the boiling flask with each siphon. This process was repeated for 2.5 hours. Afterwards, hexan and oil mixture in the boiling flask were placed onto an oven and heated up until all the hexan evaporated. The left oil was the residual oil content in the cake.

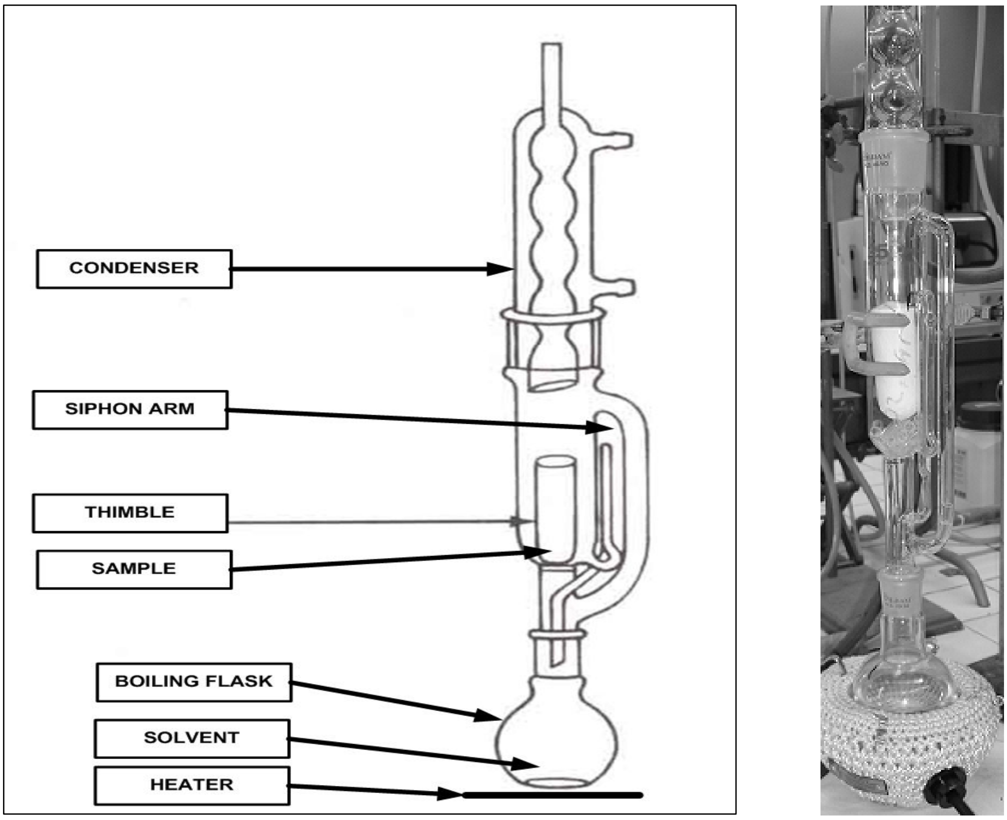

Figure B.2: Soxhlet extraction apparatus

The results of the solvent extraction process are shown in Table 5.1.

APPENDIX C

Exploded Views and Dimension Views of the Prototypes

PROTOTYPE 1		
No	Part Name	Material
1	First Screw Shaft	Cast Polyamid
2	Second Screw Shaft	Cast Polyamid
3	Feeding Tubes	Cast Polyamid
4	Connecting Rod	AISI 1045
5	Side Barrel Plate	Al 3003
6	Internal Barrel Plates	Al 3003
7	Middle Barrel Plate	Al 3003
8	Cake Nozzle	Al 3003
9	Bolts for Pillow Blocks of Bearings and Platform Connection	M10x1.5x60 (4 pieces)
10	Bolts for Platform and Barrel Plates Connection	M6x1x30 (4 pieces)
11	Bolts for Barrel Plates Connection	M10x1.5x120 (4 pieces)
12	Nuts	M10 (4 pieces)
13	Platform	Al 3003
14	Hopper	Polyamid

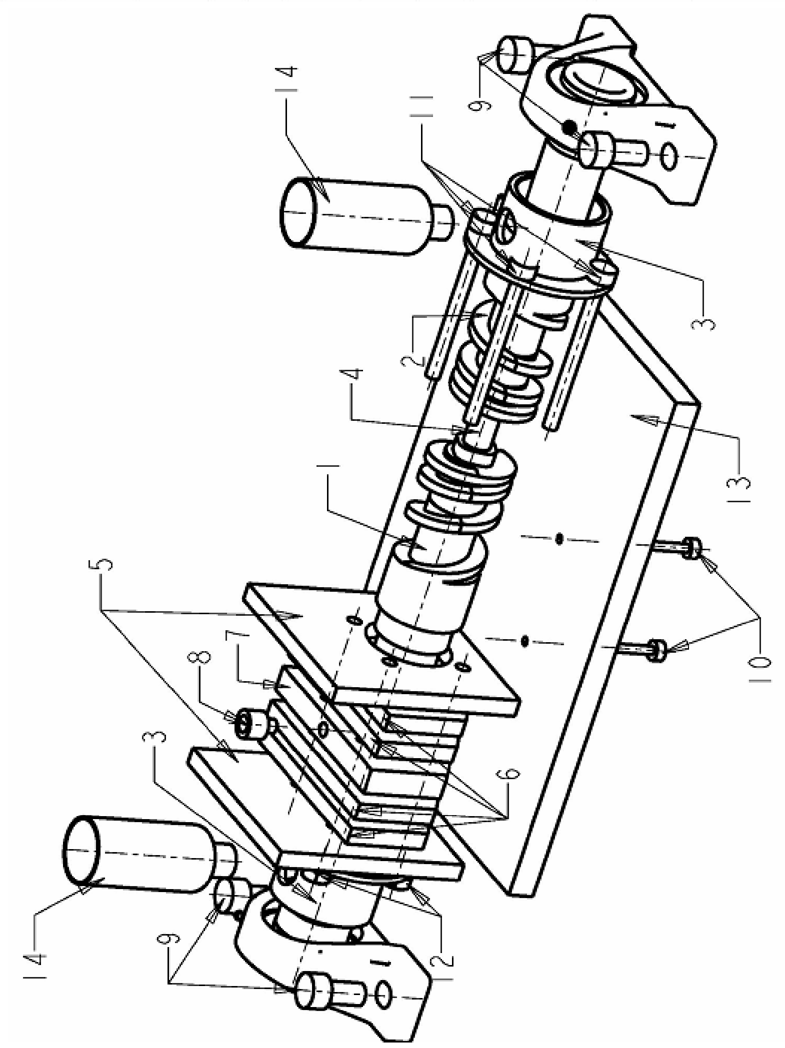

Figure C.1: Exploded view of the first prototype

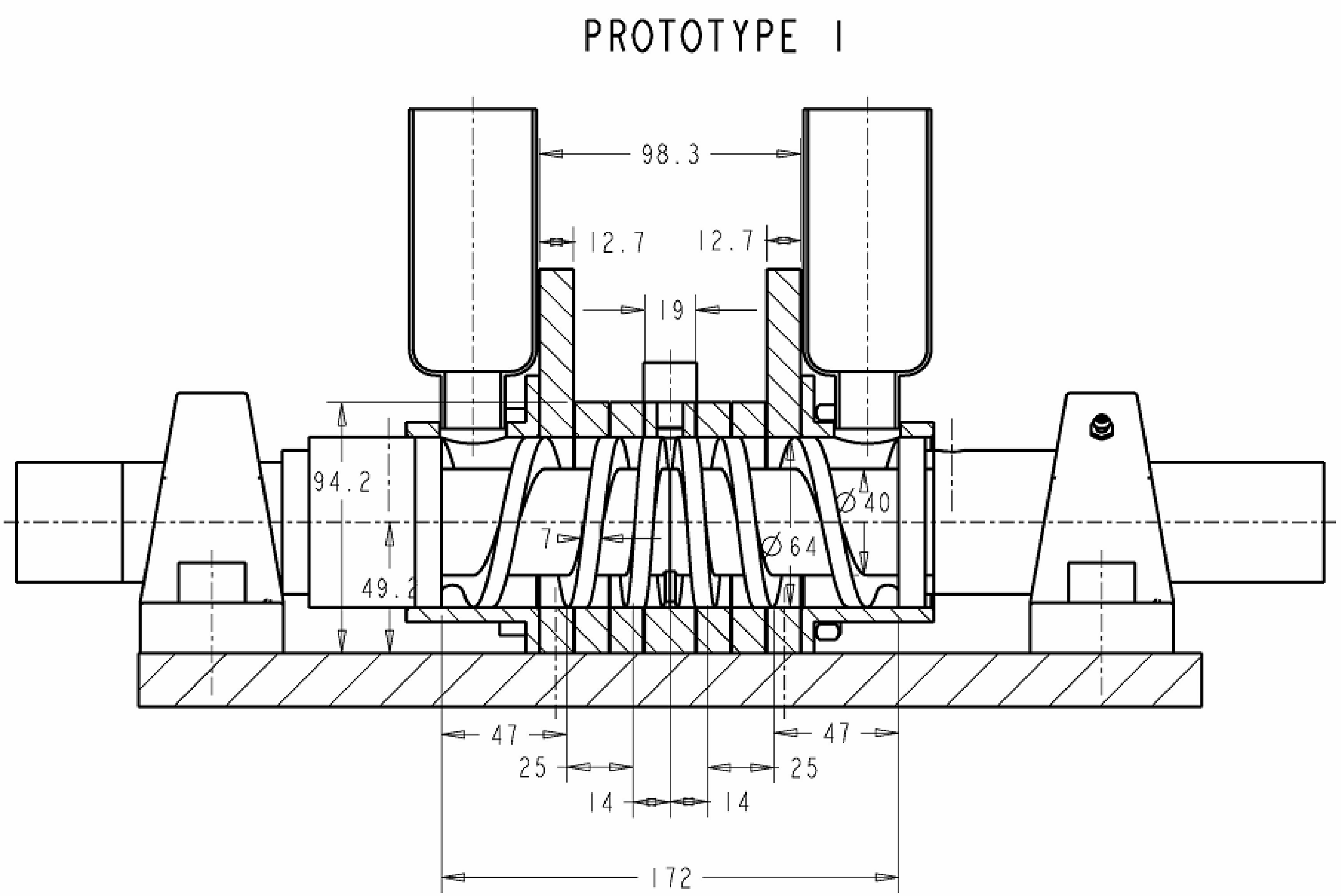

Figure C.2: Some important dimensions of the first prototype

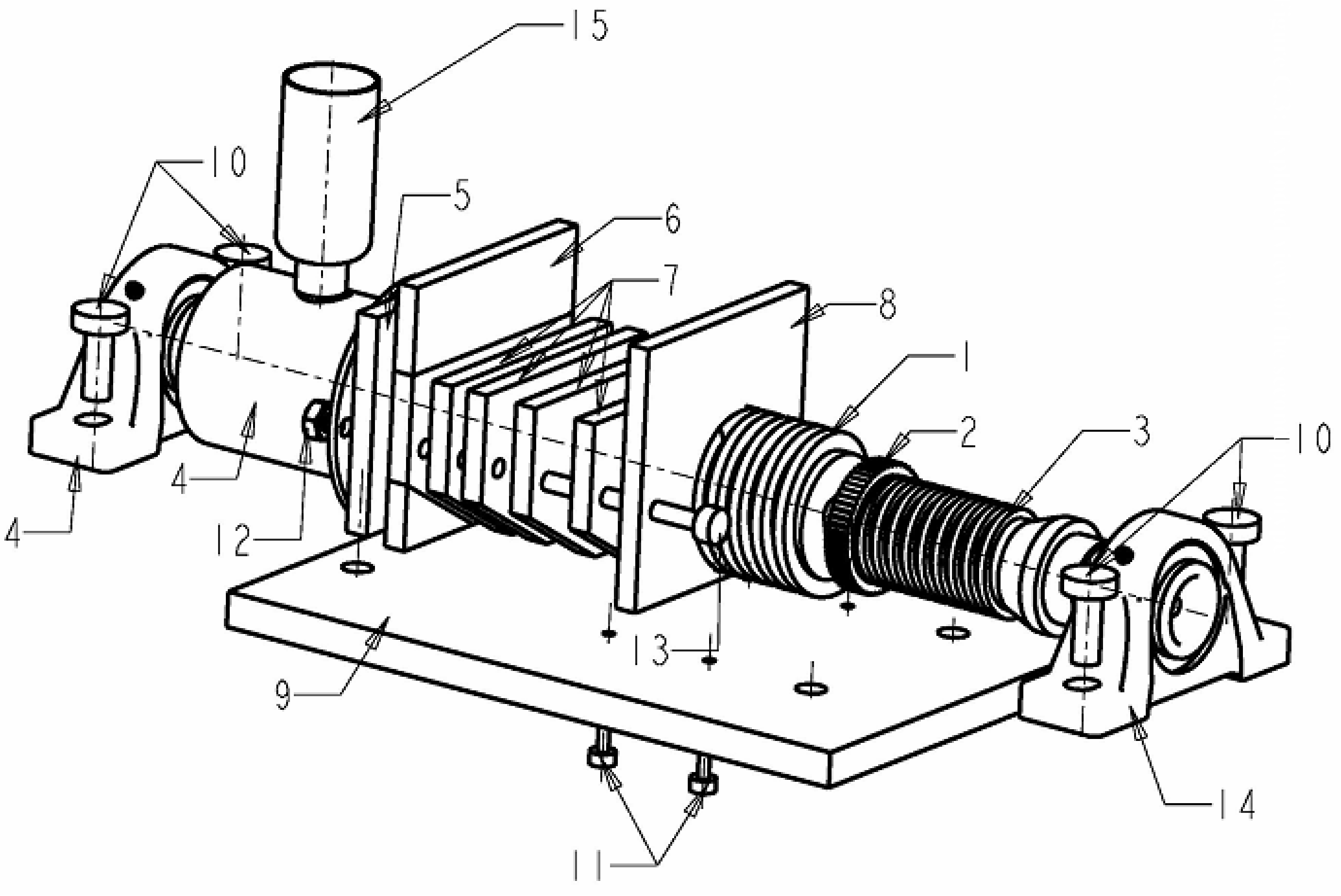

Figure C.3: Exploded view of the second prototype

PROTOTYPE 2		
No	Part Name	Material
1	Big Screw Shaft	Polyamid
2	Grinder_in	Al 3003
3	Small Screw Shaft	Polyamid
4	Feeding Tube	Polyamid
5	Grinder_out	Al 3003
6	Side Barrel Plate	Al 3003
7	Middle Barrel Plates	Al 3003
8	Cake Drainage Barrel Plate	Al 3003
9	Platform	Al 3003
10	Bolts for Pillow Blocks of Bearongs and Platform Connection	M10x1.5x50 (4 pieces)
11	Bolts for Barrel Plates and Platform Connection	M6x1x40 (4 pieces)
12	Nuts	M10 (2 pieces)
13	Bolts for Barrel Plates, Grinder_out and Feeding Tube Connection	M10x1.5x120 (2 pieces)
14	Bearing	UCP 209 (2 pieces)
15	Hopper	Polyamid

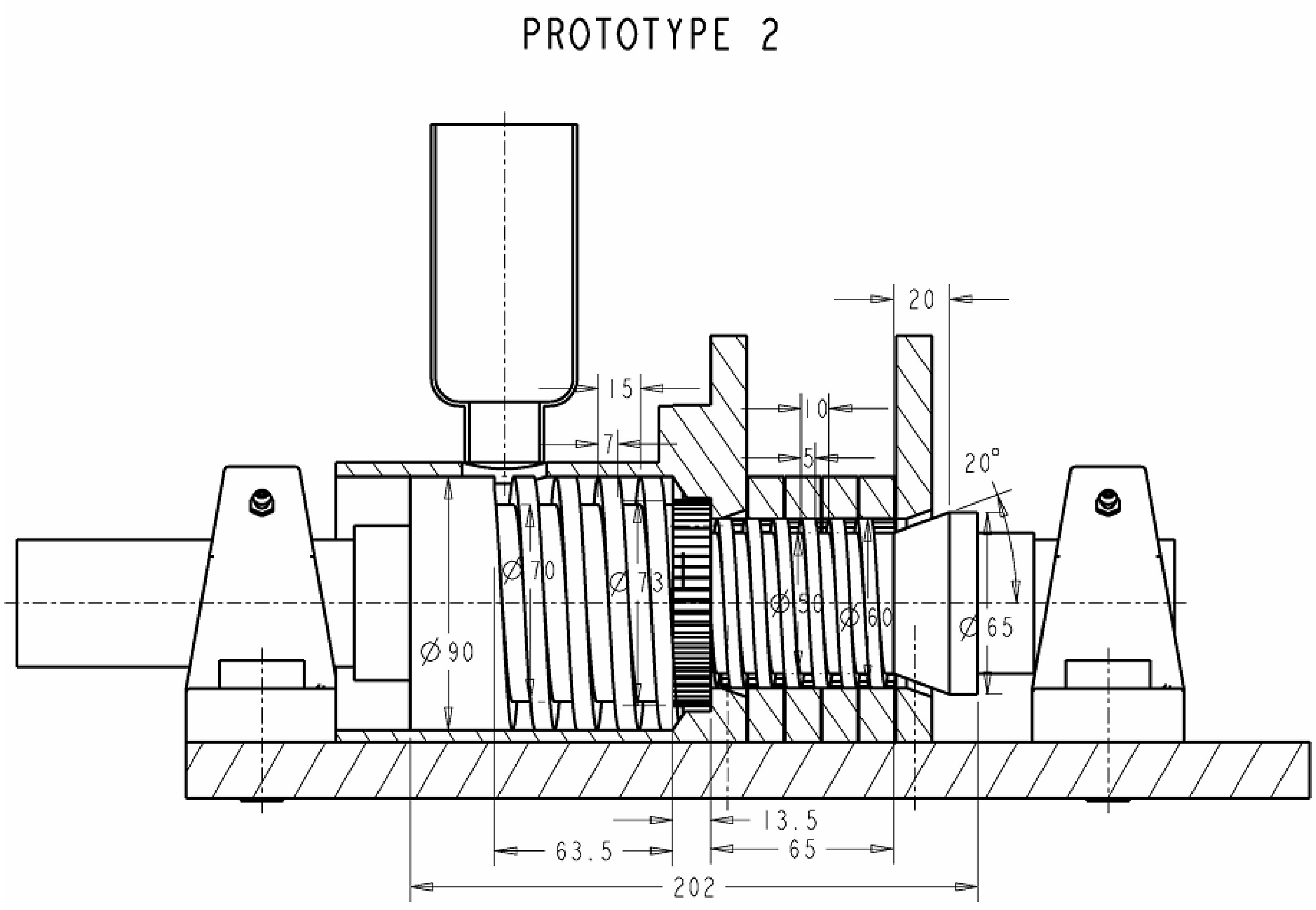

Figure C.4: Some important dimensions of the second prototype

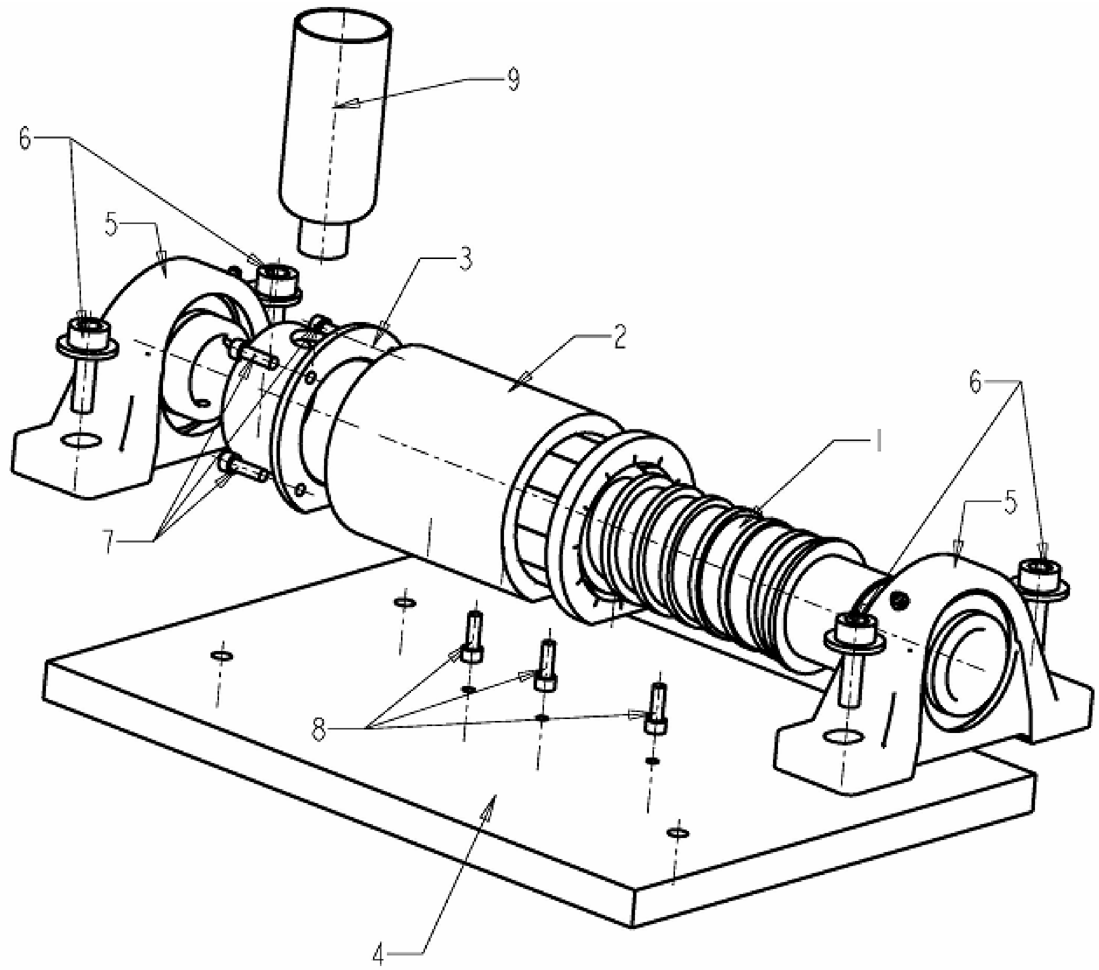

Figure C.5: Exploded view of the third prototype

PROTOTYPE 3		
No	Part Name	Material
1	Screw Shaft	Al 6063
2	Vessel	Al 3003
3	Feeding Tube	Cast Polyamid
4	Platform	Al 3003
5	Bearing	UCP 209 (2 pieces)
6	Bolts for Pillow Blocks of Bearings and Platform Connection	M10x1.5x35 (4 pieces)
7	Bolts for Feeding Tube and Vessel Connection	M6x1x20 (4 pieces)
8	Bolts for Platform and Vessel Connection	M6x1x18 (3 pieces)
9	Hopper	Polyamid

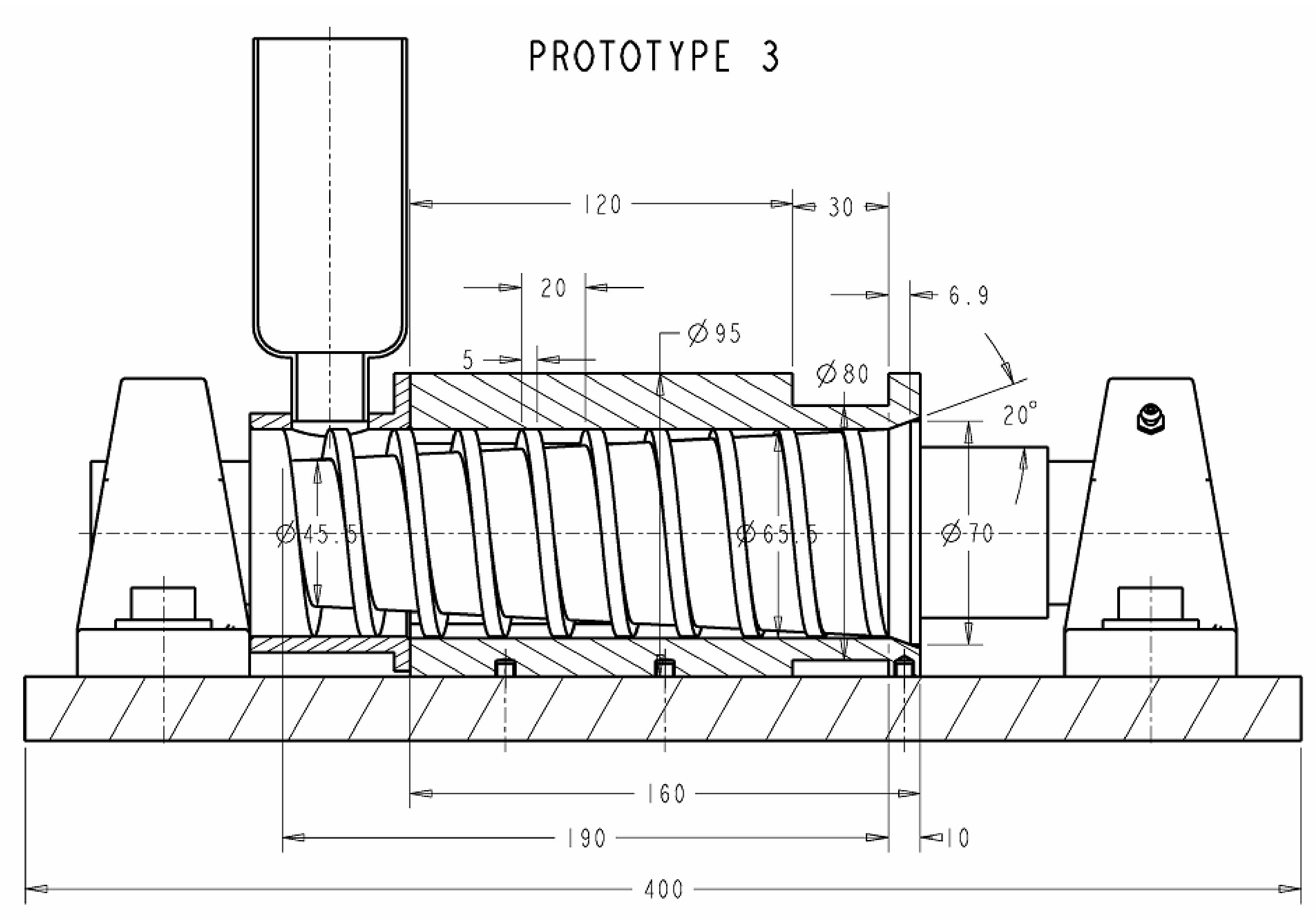

Figure C.6: Some important dimensions of the third prototype

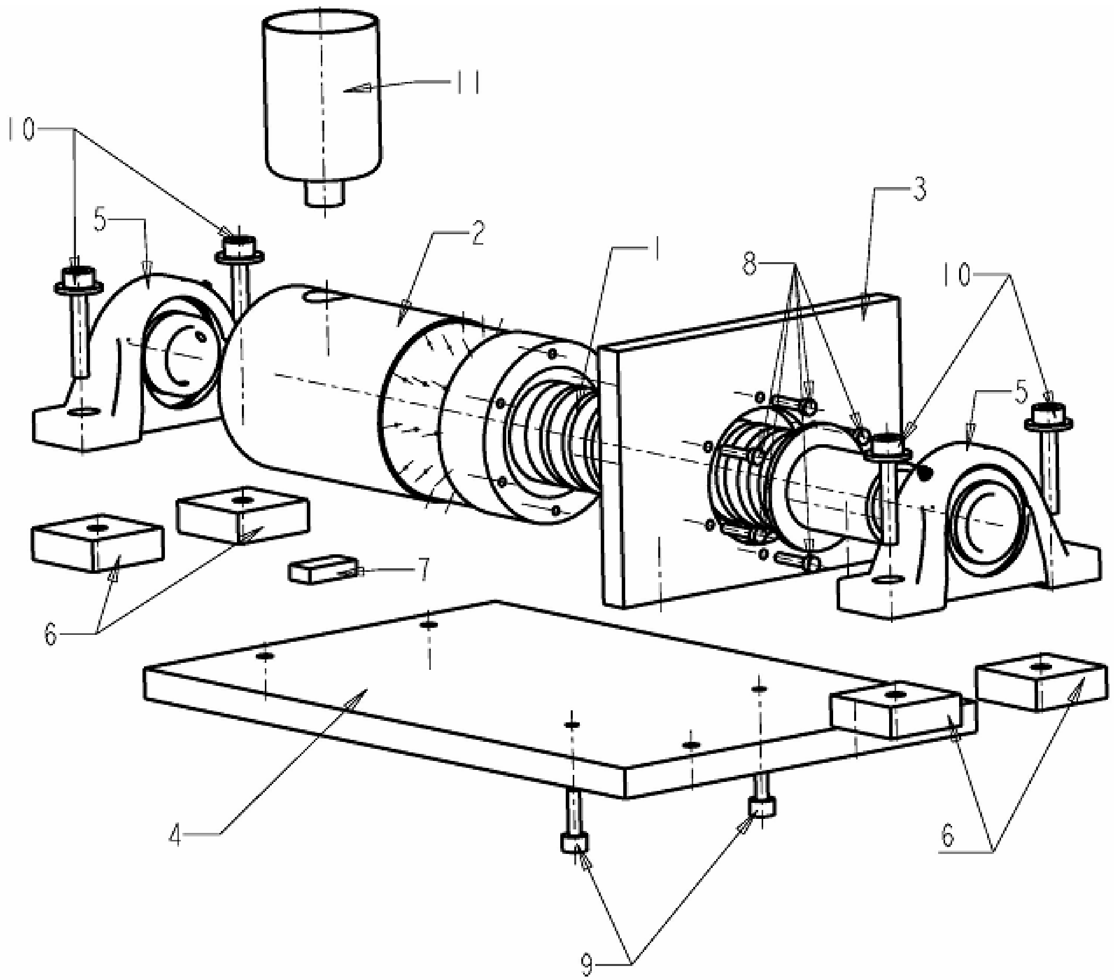

Figure C.7: Exploded view of the fourth prototype

PROTOTYPE 4		
No	Part Name	Material
1	Screw Shaft	AISI 1045
2	Vessel	Al 7075
3	Flange	AISI 1045
4	Platform	Al 3003
5	Bearing	UCP 209 (2 pieces)
6	Elevator1	Al 3003 (4 pieces)
7	Elevator2	Al 3003
8	Bolts for Flange and Vessel Connection	M6x1x30 (6 pieces)
9	Bolts for Platform and Flange Connection	M8x1.25x30 (2 pieces)
10	Bolts for Pillow Blocks of Bearings and Platform Connection	M10x1.5x80 (4 pieces)
11	Hopper	Polyamid

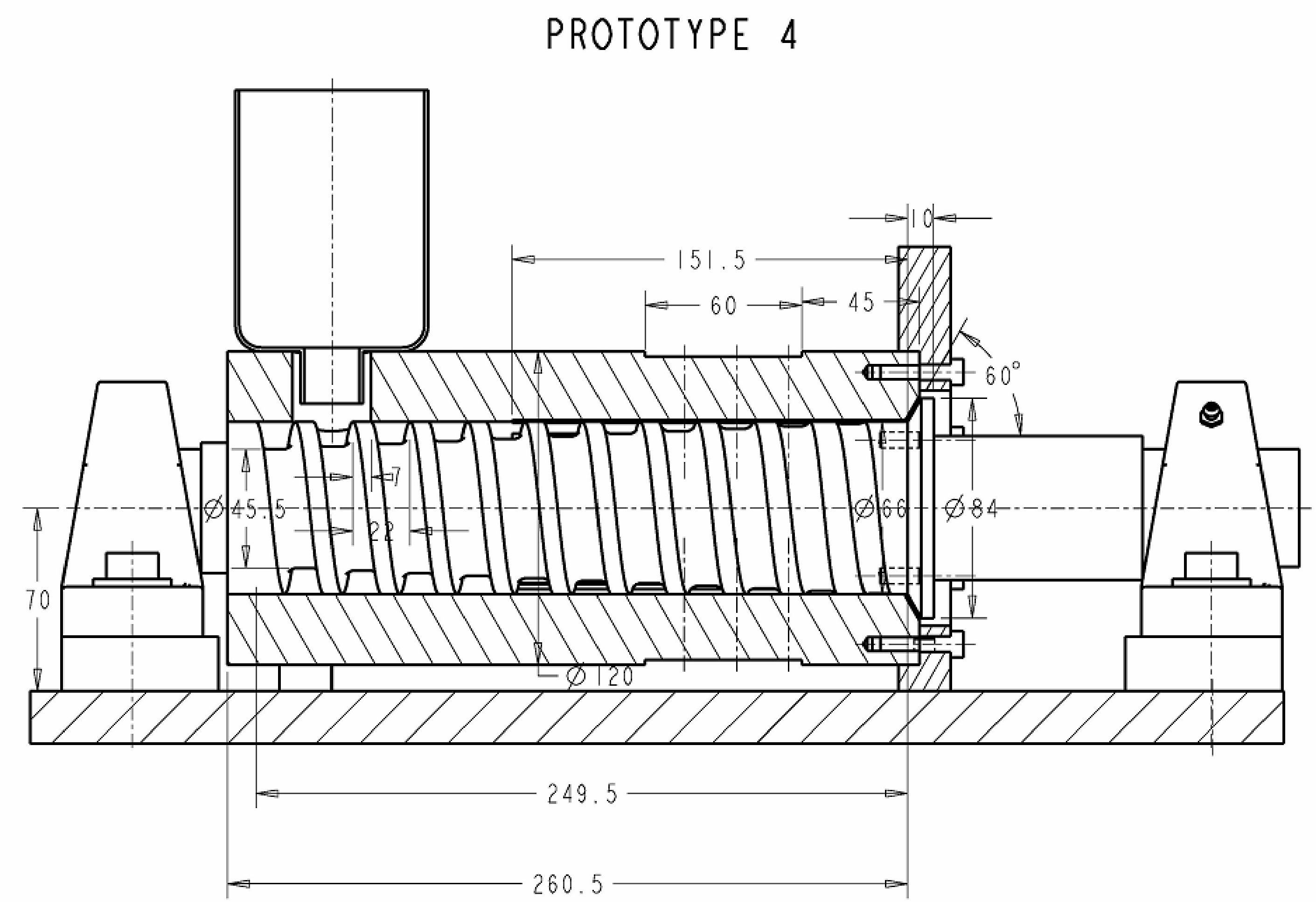

Figure C.8: Some important dimensions of the fourth prototype