MODIFICATION AND PERFORMANCE EVALUATION OF MINI OIL MILL

THESIS

Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
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(AGRICULTURAL PROCESS ENGINEERING)

By

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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the thesis entitled **"MODIFICATION AND PERFORMANCE EVALUATION OF MINI OIL MILL"** or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/publication of any University or Scientific Organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

Place: Akola. (**ABHIPSA DHANANJAY KHOBRAGADE**)

Date: / /2019 Enrollment No. LL-2452

CERTIFICATE

This is to certify that the thesis entitled **"MODIFICATION AND PERFORMANCE EVALUATION OF MINI OIL MILL"** submitted in partial fulfillment of the requirement for the degree of "**Master of Technology In Agricultural Engineering (Agricultural Process Engineering)"** of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by **Abhipsa Dhananjay Khobragade** under my guidance and supervision.

The subject of thesis has been approved by the Student's Advisory Committee.

Place: Akola
Date: / /2019

Dr. P.A. Borkar
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THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE INCLUDING EXTERNAL EXAMINER (AFTER VIVA–VOCE)

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(D) ABBREVIATIONS

AICRP	:	All India Coordinated Research Project
Anon	:	Anonymous
ANOVA	:	Analysis of Variance
Avg	:	Average
aw	:	Water activity
b*	:	Yellow/blue colour
BIS	:	Bureau of Indian Standards
cfu/g	:	Colony forming unit per gram
Cl	:	Clearence
cm	:	Centimeter
cm^3	:	Cubic centimeter
CV	:	Coefficient of variation
d	:	Diameter
db	:	Dry basis
Eqn.	:	Equation
et al.	:	*et alibi*, and others
etc.	:	et cetra
Fig.	:	Figure
g	:	Gram
GI	:	Galvanized Iron
g/cc	:	Gram per cubic centimeter
h	:	Hour
hp	:	Horse power
i.e.	:	that is
kg	:	Kilogram
kg/cm^3	:	Kilogram per cubic centimeter
kg/h	:	Kilogram per hour
kW	:	Kilowatt
L*	:	Lightness or darkness

Max	:	Maximum
Min	:	Minimum
m/s	:	Meter per second
m^3	:	Cubic meter
mg	:	Milligram
min	:	Minute
ml	:	Milliliter
mm	:	Millimeter
MS	:	Mild steel
N	:	Newton
N-m	:	Newton-meter
N-mm	:	Newton-millimeter
NS	:	Non-significant
SEM	:	Standard error mean
SS	:	Stainless steel
PDKV	:	Panjabrao Deshmukh Krishi Vidyapeeth
PGI	:	Post Graduate Institute
PHET	:	Post Harvest Engineering and Technology
TPC	:	Total Plate Count
rpm	:	Revolutions per minute
RSM	:	Response Surface Method
SD	:	Standard deviation
viz.	:	*Videlicet,* namely
wb	:	Wet basis
%	:	Per cent
^oC	:	Degree Celsius
μm	:	Micro Meter
@	:	At the rate
&	:	And

(E) THESIS ABSTRACT

a)	**Title of thesis**	:	**MODIFICATION AND PERFORMANCE EVALUATION OF MINI OIL MILL**
b)	**Name of Student**	:	**ABHIPSA DHANANJAY KHOBRAGADE**
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ABSTRACT

A mini oil mill was modified and evaluated for its performance. The major components of the mini oil mill include the boiler, main frame, feed kettle, oil extraction chamber, oil canals and cake outlet.

. The performance of the mini oil mill was evaluated for extracting oil from safflower, at three shaft speed 28 rpm, 36 rpm, 44 rpm and length of reverse worm 38.1 mm, 50.8 mm, 63.5 mm and for two worm pitches i.e. high and low respectively. The response parameters investigated were oil recovery, cake recovery, oil extraction efficiency, feed rate and deficit oil yield. Two numeric variables 3 levels and one categoric variable 2 levels, 3 level factorial, reduced cubic model of response surface methodology by using Design Expert Software was used to optimize mini oil mill parameter for better oil recovery, oil extraction efficiency, lower percent cake recovery and feed rate, deficit oil yield in range. The physical properties of safflower oil seeds i.e. size, sphericity, bulk density, true density, porosity, angle of repose and coefficient of static friction were determined. A shaft speed of 36 rpm, length of reverse worm of 50.8 mm and worm pitch P_2 was found to favour the oil extraction unit, while a oil recovery, cake recovery, oil extraction unit, feed rate and deficit oil yield was observed. The mini oil mill was therefore observed to perform the best at the optimum shaft speed 36 rpm and length of reverse worm 50.8 mm for worm pitch P_2. The physiochemical properties of the oil i.e. saponification value, iodine value, free fatty acid, peroxide value, viscosity, polyunsaturated fatty acid and mono saturated fatty acid were analyzed for both worm pitches i.e high and low. The result of the study shows that the mini oil mill can extract oil from the safflower seeds satisfactorily. Besides, the mini oil mill can be used for other oil seeds eg. groundnut, sunflower, sesame, coconut etc.

Keywords: - mini oil mill, safflower oil seeds, oil recovery, cake recovery, worm pitch, oil extraction efficiency, deficit oil yield.

CHAPTER I

INTRODUCTION

1.1 Background Information

Fats and oils are one of the five essential ingredients of human diet and the others are protein, carbohydrates, minerals and vitamins. In a balanced diet, the oils and fats requirement per person per day is 35 g for vegetarians, 39 g for non-vegetarian and 38 g for average diet. Oilseeds and animals are the main sources of fat. Though India has the largest number of animals compared to any single country of the world, but the animal fats are not preferred and our efforts to exploit fats of land and marine animals are negligible. The major responsibility of oil production in India, both for edible and industrial usages depends on vegetable oil seeds production (Shukla,1992).

Oilseed crops are the second most important determinant of agricultural economy, next only to cereals within the segment of field crops. The self-sufficiency in oilseeds attained through “Yellow Revolution” during early 1990’s, could not sustain beyond a short period. Despite being the fifth largest oilseed crop producing country in the world, India is also one of the largest importers of vegetable oils today. There is a spurt in the vegetable oil consumption in recent years in respect of both edible as well as industrial usages (Anonymous, 2019).

India is the largest producer of oilseeds in the world and oilseed sector occupies an important position in the agricultural economy of the country. Oilseeds are among the major crops that are grown in the country apart from cereals. In terms of acreage, production and economic value, these crops are second after food grains. The edible oil industry is one of the most important industries of agriculture sector in India. India is a leading player in the industry, with the world’s largest importer from Indonesia and Malaysia and third largest consumer.

Recently more than14 million tonnes of edible oil were imported in India with a total value of Rs. 6,43,965 million during 2014-15. In terms of volumes, crude edible oil contributes about 89% and refined oil contributes about 11% of the total import during 2014-15. The analysis of sources of oilseeds growth and changing pattern, area production oilseeds in different period from 1986-87 to 2014-15. Analysis demand-supply share edible oil import and solution for self-sufficiency in edible oil in future and the constraints on inputs growth are like quality seeds, irrigation in recent year and growth of minimum support prices of major oilseed.

Oilseeds have been the backbone of agricultural economy of India since long. The major oilseeds cultivated in our country are Groundnut, Rapeseed , Mustard, Castor seed, Sesamum, Nigerseed, Linseed, Safflower, Sunflower and Soybean. However, Groundnut, Rapeseed/Mustard, Soybean and Sunflower account for a major chunk of the output. The oil content ranges from 19 % to 68 % depending upon various oil seed crops. At present, more than 27 million hectares of land is under oilseeds cultivation. The area under oilseeds has been increasing over time and production has registered many fold increases but its productivity is still low as compared to other oilseed producing countries in the world. To improve the situation of oilseeds in the country, government of India has been pursuing several development programs. They are Oilseed Growers Cooperative Project, National Oilseed and Development Project, Technology Mission Oilseeds (TMO) and Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize. The efforts of these development programs/schemes register significant improvement in annual growth of yield and area under oilseed crops. However, India, still imports a significant proportion of its requirement of edible oil (Narayan *et. al*. 2011).

There are two main types of processes for obtaining oil: physical and chemical. The physical process, or expression, involves the use of mechanical power to remove oil from the seeds such as batch hydraulic pressing and continuous mechanical pressing (screw presses).Chemical processes, or extraction, are based in solvent extraction. These processes can be combined in commercial operation, i.e. continuous mechanical pressing (expelling) with continuous solvent extraction and batch hydraulic pressing followed by solvent extraction (Walkelyn& Wan, 2005; Weiss, 1983).

New technologies are emerging, related to the production of vegetable oils, such as supercritical-fluid extraction (Pradhan *et al*., 2011)."Expression" means the process of mechanically pressing liquid out of liquid-containing solids and “extraction” is the process where a liquid is separated from a liquid-solid system with the use of a solvent (Khan & Hanna, 1983).

The extraction of oil from oilseeds, either by mechanical expression or by means of solvents, is facilitated by reduction of the seed in small particles by grinding or rolling. Oil from oilseeds in India is mostly extracted with the help of traditional animal drawn ghanies (Kolhus), power ghanies, rotary oil mills, mechanical expellers and solvent extraction units. However, the solvent extraction techniques are also used for recovery of oil from soybean, rice bran and pressed oilseed cakes.Five common methods of extraction are used to extract oil are Water assisted, Ghanis, Manual pressing, Expelling, Solvent extraction.The ghani/expeller pressed cakes contain high amount of oil which goes waste if the cake is as such used for cattle feed or cakes are further solvent extracted.

Carthamustinctorius L., widely accepted as Safflower or false saffron, belongs to the *Compositae* or *Asteraceae* family. This thistle-like species typically thrives in an arid climate, namely Southern Asia, China, India, Iran, and Egypt (Shirwaikar et.al., 2010).

India occupies premier position in safflower in the world as it was cultivated over an area of 364 thousand hectares (50% of world area) and had a production of 229 thousand tons (27% of world production) during 2005-06 (Anonymous, 2007). However, after attainment of the peak area in 1988 (69% of world area) and peak production in 1994 (69% of world production), the area and production have been continuously declined. State of Maharashtra where NARI is located accounts for about 72% area and 69% of production of safflower in India. Safflower is the most important rabi oilseed crop in the Maharashtra state and occupying a pride of place in oilseeds production. In Maharashtra it is grown on 5.89 lakh hectares with production of 3.30 lakh tonnes in 2007-08. The average yield of safflower in the state is 560 kg/hectare (2007-08). The area covered under Safflower oilseeds in India during 2017-18 was 81000 ha and yield was 557 kg/ha (Anonymous, 2018).

1.2 Importance and need of study

Agriculture is a principal occupation for farmer. India has the second largest area under oilseeds, next only to USA. However, it falls behind to the fourth place in terms of production due to comparatively low yields. Ground nut, safflower, sesame, linseed, niger and sunflower are the important oilseed crops grow in Maharashtra over an area of 4207.9 ha with annual production of 4233.1tonnes (2017/18).Edible oil prices had contributed significantly to the national inflation levels during the recent years. The requirement of oil per year is 10 million tonnes. So to meet the increased demand, since last 10 years the number of oil mills increased in some states particularly in Gujrat, Karnataka, Andhra Pradesh and Maharashtra (Shrivastav, 1985).

To meet the increased demand for edible oil in India, the oil mill owners established a modern heavy machinery and modern processing technology. Out of the total 10.52 million tonnes per year edible oil production in India, Maharashtra contributes 20%. Each segment of Maharashtra’s oilseed processing industry has small capacities and low technical efficiency compared with the other states. At present the oil is being highly adulterated by mixing various low quality seed. For refining oil and for maximizing oil yield, various harmful chemicals are being used. Oil extracted at lower temperature has better health characteristics. The screw speed and temperature has a positive effect on oil recovery. Higher capacities oil extraction machines are available but rare work has been carried out on small capacity oil extraction machine. Modifications in mini oil mill will ensure efficient working resulting in production of non-adulterated oil at farm level. It will also reduce the expenses on maintenance of mini oil mill. Hence the efforts will be made to access possibility to modify mini oil mill to higher capacity, higher oil extraction efficiency and performance evaluation of mini oil mill will be carried out. Hence considering the above issues a research project on modification and performance evaluation of mini oil mill was planned to be carried out.

1.3 Objectives of study:

1. Modification of mini oil mill
2. To study the effect of rotational speed of shaft on oil recovery.
3. To study the performance evaluation of mini oil mill (5 hp).

CHAPTER II

REVIEW OF LITERATURE

A comprehensive review of concepts and past relevant literature to this study are presented in review of literature. The work of various researchers related to the present study has been reviewed and the findings reported in them are reviewed briefly as under following sections.

1. Oil seed availability and scope for utilization
2. Oil extraction technologies
3. Performance of oil extraction technologies

2.1 Oil seed availability and scope for utilization

Shukla (1992) reported that large scale cultivation of safflower, containing 35 to 45 percent oil, has started about 25 years ago in India. Traditionally known as source of dye in ancient India, the safflower has attained considerable importance as an oilseed crop. It is cultivated in many states of India and numerous races of this crop are under cultivation, varying markebly in botanical features and in oil and dye contents. It is highly branched, herbaceous, thistle like annual, the spinous variety of which is valuable particularly for oil production. Safflower is mostly cultivated as a rainfed crop in the country and is drought resistant and can even be qrown on poor sandy soils.

Bargale (1997) found that Oilseeds represent one of the most important components of modern agriculture. This is due to the fact that they provide easily highly nutritious human and animal food. Nutritionally, oils obtained from oilseeds provide the calories, vitamins and essential fatty acids in the human diet, while the de-oiled cake is a valuable source of protein for animal feeds.

Kizil (2008) reported that Safflower (*Cartamustinctorius*L) is believed to be originated in an area bounded by the eastern Mediterranean and Persian Gulf, encompassing southern parts of former USSR, Western Iran, Iraq, Syria, Southern Turkey, Jordan and Israel. Oil is rich in polyunsaturated fatty acids (linoleic acid 78%) which play an important role in reducing blood cholesterol level. Safflower in India is cultivated over an area of 2.794 lakh ha with a production of 1.777 lakh tonnes and productivity of 636 kg/ha (Average of 2007-08 to 2011-12). Important zones for cultivation in India are Maharashtra, Karnataka, Andhra Pradesh. Maharashtra and Karnataka states are the major safflower growing states and these two states contribute about 87% of India's area and production of safflower. Safflower is cultivated by more than 20 countries on an average area (2007-08 to 2011-12) of 7.30 lakh ha. This area provided a production of safflower to the tune of 6.27 lakh tonnes with productivity of 859 kg/ha.

Jha *et al*., (2012) studied that India is emerging in the late 1990s as one of the world's largest importers of edible oils. Higher incomes, low productivity in domestic oilseeds production, and more liberal policies for edible oil imports have driven expanding trade. The domestic demand for vegetable oils and fats has also been rising rapidly at an increasing rate due to increase in per capita income and increase in standard of living. Thus, annual demand is increasing at the rate of 6% while our domestic output has been increasing at just about 2%.

Narayan (2016) reported thatIndia is the largest producer of oilseeds in the world and oilseed sector occupies an important position in the agricultural economy of the country. Oilseeds are among the major crops that are grown in the country apart from cereals. In terms of acreage, production and economic value, these crops are second after food grains. The edible oil industry is one of the most important industries of agriculture sector in India. India is a leading player in the industry, with the world's largest importer from Indonesia and Malaysia and third largest consumer. India is the fourth largest oilseed-producing country in the world after Brazil 100 MT, followed by Argentina 66 MT, China 59.6 MT and India 34.6 MT during 2014-15. Being fifth largest oilseed crop producing country in the world, India is also one of the largest importers of vegetable oils today. There is a spurt in the vegetable oil consumption in recent years in respect of both edible as well as industrial usages (Anonymous, 2019).

Reddy (2017) found that India is the fourth largest producer of oilseeds accounting for about 19% of the global area, 2.7% of global production in the world. The oilseed crops have registered the significant growth in area and production in last 30 years. However, compared to cereals like paddy and wheat, the growth rate of area and production of oilseeds is insignificant and there exists wide variability in their yield in different states of the country. The study has explored the growth performance, and dynamics of major oilseeds in different states of the country. Oilseeds exhibited a dismal picture in their production performance both spatially and temporally.

4th Advance Estimates (2018), Press Information Bureau Government of it was found that in India the estimated production of major oil seed crops during 2017-18 is 31.31 million tonnes which included 10.98 million tonnes of soyabean, 9.18 million tonnesof groundnut ,8.32 million tonnes of mustard, rapeseed and 1.57 million tonnes of castor seed, respectively. It is marginally higher than the production of 31.28 million tonnes during 2016-17. However, the production of oilseeds during 2017-18 is higher by 1.76 million tonnes than the average oilseeds production.

Indian Council of Agriculture (2018) Indian oil seed market reported that the Indian vegetable economy is world's fourth largest, which accounts for 7 % of world's oilseeds output, 7% of world's oil mill production, 6% of world's oil mill exports, 6% of vegoil production, 14% of world's imports and 10% of world edible oil consumption.

2.2 Oil Extraction Technologies

Sari (2006) stated that currently, worldwide there are four basic methods for obtaining vegetable oil: chemical extraction, supercritical fluid extraction, steam distillation and mechanical extraction. The most common method of extracting edible oil from oleaginous material, which has been practiced for thousands of years, is mechanical pressing of oilseeds. Mechanical oil extraction (also known as pressing) is based on mechanical compression of oleaginous materials. Through pressing, oil is separated from the oleaginous material (solid-liquid mixture) under the action of compressive external forces that arise in special machines called presses. This method ensures extraction of a non-contaminated, protein-rich low fat cake at relatively low-cost.

Owolarafe(2007) investigated the effect of hydraulic press parameters on crude palm oil yield. An investigation was carried out on the effect of hydraulic press parameters such as press cage diameter (D) (80, 120, and 150mm)and wall pore diameter (H) (4, 6, and 10mm) and expression pressure (P) on crude palm oil yield. The oil yield was found to be increased with increase in cage diameter from 80 to 120 mm, after which it decreased as the cage diameter was increased to 150 mm. The volumetric oil flow followed the same pattern. The oil yield and volumetric flow increased with increase in pore size from 4 to 6 mm and decreased as the pore size increased to 10 mm. Increase in pressure form 0.5 to 1.5 MPa was observed to increase oil yield.

Bamgboye (2007) developed a sunflower oil expelling machine for extracting oil from decorticated sunflower seeds. The expelling unit consists of an auger with decreasing pitches and the heating of seeds is achieved by generated steam, which heats the surrounding of seeds passage. The machine was tested at auger speeds of 30, 40, 50rpm respectively and three throughputs. He found that performance efficiencies increased with auger speed and throughput. expelling efficiency of over 70% was obtained at 50 rpm with expelling capacity of 24.4 litres/hr. of oil and throughput capacity of 502.64 kg/day. The power requirement of the machine was 3hp.

Akinoso (2009) studied effects of compressive stress, feeding rate and speed of rotation on palm kernel oil yield. Compressive stress, feeding rate and rotational speed are some of the operational parameters that influence efficiency of an oil expeller. A 3*3 factorial experimental design was employed to determine the effects of these parameters on palm kernel oil expression using oil expeller. Obtained data was analysed statistically by regression and ANOVA to obtain relationship between independent variables; compressive stress, feeding rate and speed of operation of the oil expeller and dependent variable; oil yield. Maximum oil yield of 46.3% was recorded at 30 MPa compressive stress, 150 kg/h feed rate and 110 rpm of rotational speed while minimum oil yield of 16.3% was obtained at 10 MPa compressive stress, 50 kg/h feed rate and 110 rpm of rotational speed.

Deli *et al*., (2011) studied the effects of physical parameters of the screw press oil expeller on oil yield from *Nigella sativa* L seeds. The effects of physical parameters of a screw press machine on oil yield of *N. sativa* seeds were studied using a KOMET Screw Oil Expeller. Different nozzle size (6, 10, and 12 mm), extraction speed (21, 54, 65 and 98 rpm) and diameter of shaft screw (8 and 11 mm) were applied in this study. Different nozzle size, diameter of shaft screw and rotational speed do effects the percentage of oil yield and observed that optimum condition for cold press of *N. sativa* seeds oil by using 6 mm of nozzle size, 8 mm of diameter shaft screw and pressing at speed 21 rpm. The highest amount of oil yield was 22.27% on diameter shaft screw 8 mm and 19.05% on diameter shaft screw 11 mm. The highest percentage of oil yield recorded was at the combination of shaft screw with diameter of 8 mm, rotational speed at 21 rpm and nozzle size of 6 mm. The percentages of oil yield decreased with increasing of nozzle sizes, diameter screw, speed and temperatures. The effect of all combined physical parameters of screw press oil expeller was significant different ($p<0.05$) on oil yield of *N. sativa* seeds oil. There was significantly different ($p<0.05$) between oil yield with heat temperatures. The oil yield was higher at 50°C (22.68%) and lower at 100°C (15.21%).

Grewal (2011)studied the effect of enzymatic treatment on oil recovery using mechanical expression from mustard seeds. The experiments were carried out with the objectives to determine various engineering characteristics and determining the operational parameters for better recovery of oil from two varieties of Mustard seed i.e. PBR-91 and RLC-1. The experiments were designed using response surface methodology for making various combinations of moisture content (6, 9, 12, 15 and 18%w.b.), heating time (2,4,6, 8 and 10 min), heating temperature (40,60,80,100 and 120°C) and enzyme concentration (1, 2, 3, 4 and 5%) and the experiments were conducted using single chamber oil expeller. The quality of oil was determined using acid number and peroxide value. The effect of independent variables i.e. moisture content, enzyme concentration and heating temperature on oil yield and residual oil in cake of PBR-91 and RLC-1 variety were found significant however the effect of the heating time was found non-significant in both the varieties. The highest amount of oil yield was 32.30% at 9% moisture content, 60°C heating temperature and 8 minute heating time for PBR-91 and 32.09% for RLC-1 at 9% moisture content, 60°C heating temperature and 8 minute heating time. There is 8% increase in the yield of the oil for PBR-91 extracted at optimum level of parameters whereas in RLC-1 there is 8.89% increase in the oil yield compared to untreated seeds. Flow behavior of oil was studied at different temperatures (10, 20, 30, 40 and 50°C) and different moisture level (6, 9, 12, 15 and 18%) at constant shear rate 15 S-1 showed decreasing trend of viscosity with increase in temperature. The flow behavior of the samples were predicted by the values of consistency coefficient and flow behavior index. The range for consistency of oil was found to be 1.32 to 90.12 (PBR-91) and1.13 to 65.12 (RLC-1) for Power law model where as in Casson model it was 4.14 to 24.2 (PBR-91) and 3.12 to 17.3 (RLC-1). The flow behavior index of PBR-91 ranged from -0.68 to0.94 whereas it varied from 0.18 to 0.96 for RLC-1 in Power law model. The range of yield stress was found to be 4.37 to 432 (PBR-91) and 2.1 to 400.1 (RLC-1) for Casson model.

Ugwuoke (2014) studied on design of a combined groundnut roaster and oil expeller machine. The designs consist of two distinct units: the roasting and expelling units. The components design includes the hopper, machine, casing, conveyor trays, vibrator motor, heating filament, shaft diameter, auger, belt length and velocity of electric motor. The various units were combined so as to remove the drudgery and constraints associated with having to do the roasting and expelling processes separately. This combination makes it portable and reduces space. The components design includes the hopper, machine, casing, conveyor trays, vibrator motor, heating filament, shaft diameter, auger, belt length and velocity of electric motor. The machine was designed for $6.1\times10^{-3}m^3/ha$ capacity of for a 3kg of groundnut

Gbabo(2018) studied steam heat generation system for pre-treatment of oil bearing seeds for efficient oil extraction. A steam toasting machine for pre-treatment of oil bearing seeds was designed and fabricated by Desfabeng Company Nigeria Limited Bida, Nigeria. The major component of the machine includes; hopper, heating unit, conveyor, toasting unit, electric motor of 0.25kW and a gear motor of 0.25kW. Results of testing of the system revealed maximum oil yield of 42 %, 46%, 48 % and 40 % for neem oil (8% mc), ground nut oil (6% mc), sesame oil (6%) and shea nut (10% mc), respectively. Also the result of physicochemical analysis of the oil sample showed that the values ranged from 0.3 to 2.87 for free fatty acid, 0.38 to 2.93 mg/g for peroxide value and 39.12 mg/g to 106.16 mg/g for iodine value. The capacity of the system was 4 tons per day.

Junpeng (2019) investigated steam explosion technology based for oil extraction from sesame (*Sesamum indicum L.*) seed. Steam explosion, an adiabatic expansion and conversion process of thermal energy into mechanical energy, was employed to extract oil from sesame seed. Steam explosion was performed with different pressure levels and retention time periods (2.0 MPa 10 s and 1.0 MPa 30 s). After pretreatment, petroleum ether as the solvent, oil yield was generally improved with the severity factor increased. Steam explosion resulted in micropores on the seed surface and made it rough. The kinetics of oil extraction from sesame seed showed when the severity factor raised, the oil yield increased and mass transfer coefficient decreased. In addition, GC–MS was used to analyze the change of fatty acid composition and a few changes were observed. Our study suggests that steam explosion improved the oil extraction yield of sesame seed and the quality of oil was slightly changed.

2.2.1 Traditional Oil Expelling Press

Kirschenbauer (1944) documented oil extraction dates back to 1650 B.C. when ripened olives were pressed. By 184 B.C., the Romans developed more sophisticated technology such as edge runner mills and screw and wedge presses. These technologies combined leverage and the use of animal power to aid in the milling and extraction of the oil. From Roman times until the eighteenth century, similar technology was used for oil extraction. In 1795, the hydraulic press for oil extraction were invented. Oilseeds were milled, cooked, and wrapped in filters cloths woven from horse-hair. In 1870's large hydraulic presses with up to 16 press boxes and up to 400 tons of force were being used.

Kemper (1999) stated that Hydraulic press oil mills remained in use as late as the 1950’s before the last of them were replaced with continuous screw presses and continuous solvent extraction plants, both of which required far less labor and could process at much higher rates. The mechanical screw press was a radical departure and significant technological advancement over the hydraulic presses being used at the time. The mechanical screw press used a vertical feeder and a horizontal screw with increasing body diameter to impart pressure on the oleaginous material as it proceeded along the length of the screw. The barrel surrounding the screw was slotted along its length, allowing the increasing internal pressure to first expel air and then expel the oil through the barrel. The expelled oil was collected in a trough under the screw and the de-oiled cake was discharged at the end of the screw. The primary advantage of the mechanical screw press was that it allowed continuous oil extraction and could process large quantities of oleaginous materials with minimal labor.

2.2.2 Hydraulic Expression

Owolarafe (2002) studied Comparative evaluation of the digester–screw press and a hand-operated hydraulic press for palm fruit processing. order to demonstrate the strength and possible weaknesses of the digester–screw press (DSP) system for small-scale oil palm fruit processing, a comparison was made of its performance and that of the erstwhile hand-operated hydraulic extraction system. Indices of evaluation include oil yield and quality, and operational economics. The results indicate that the throughput of the DSP system was four folds of that of the hydraulic system, whilst also operating at higher oil extraction efficiency (89.1%). There was no significant difference between the quality of the palm oil obtained from the two systems. However, the economic analysis of the systems indicates that at throughput of 0.75 t/h and above, the DSP system was more economical than the hydraulic system in terms of equipment, labour, material and floor space requirement and revenue accruing from the processing operation.

2.2.3 Mechanical Oil Expression

Nurhan (1997) concluded that the mechanical screw press consists of a vertical feeder and a horizontal screw with increasing body diameter to exert pressure on the oilseeds as it advances along the length of the press. The barrel surrounding the screw has slots along its length, allowing the increasing internal pressure to first expel air and then drain the oil through the barrel. Oil is collected in a trough under the screw and the de-oiled cake is discharged at the end of the screw. The main advantage of the screw press is that large quantities of oilseeds can be processed with minimal labor and it allows continuous oil extraction.

Anderson(1900) invented the mechanical screw press in Cleveland, Ohio. He was awarded a U.S. patent for the apparatus. The mechanical screw press was a radical departure and significant technological advancement over the hydraulic presses being used at the time. The mechanical screw press used a vertical feeder and a horizontal screw with increasing body diameter to impart pressure on the oleaginous material as it proceeded along the length of the screw. The barrel surrounding the screw was slotted along its length, allowing the increasing internal pressure to first expel air and then expel the oil through the barrel. The expelled oil was collected in a trough under the screw, and the de-oiled cake was discharged at the end of the screw. The primary advantage of the mechanical screw press was that it allowed continuous oil extraction and could process large quantities of oleaginous materials with minimal labor.

Schaufler (2013) studied Oilseed Press and found that from the funnel the seed is fed into the hopper on the expeller press. The press is a crucial part of the system, as it extracts the oil from the seed. An expeller press is composed of several components. From the hopper, the seed is fed into the barrel, in which a screw slowly turns. The screw pulls the seed forward, where it is crushed, squeezing the oil back into the barrel, where it drips from a series of small holes and is collected. The crushed seed is compacted and extruded through the press head, where it is also collected. The extruded pulp, known as meal, has a variety of uses. Meal is commonly used as feed for livestock, as it is high in protein. It can also be used as pellets in stoves, which burn the meal at high temperature for heating both homes and other buildings. The meal can also be used as organic fertilizer.

2.2.4 Solvent Extraction

Bargale (1999) stated that in solvent extraction, the seeds are first flaked and cooked. Then, the cooked seed flakes are mixed with the solvent in order to extract the oil. It results a mixture of oil and solvent, called miscella, which is heated in evaporators at 80°C. Steam is injected on the shell side to vaporize and reduce hexane to about 5% of the oil, then the oil is directly steam-stripped in a vacuum tower at temperatures rising to a final 110°C. This is the most efficient technique to recover oil from oilseed. It is expected that the residual oil in the meal to be less than 1% after commercial solvent extraction. There are, however, some limitations and disadvantages related to the solvent oil extraction: the chemical solvents are harmful to human health, the chemicals used are highly flammable and the danger of fire and explosion always exists, the initial capital and operating costs are high, the energy requirements are high and the quality of recovered oil is lower than that of pressed oil.

2.2.5 CO_2 Extraction

Nurhan (2007) studied that on taking into account the concerns about environmental and human health hazards produced by the organic solvents and residues in oil, it was necessary the replacement of the solvents for edible oil extraction. Thus, the replacement of solvents with supercritical fluids (SCF) have been studied for more than two decades. The supercritical fluid extraction (SFE) is a technique similar to conventional solvent extraction, but the solvent is not a liquid but rather a gas above its critical point. Supercritical fluid used in oil extraction is CO_2, this being the supercritical fluid most used in analytical applications because it does not extract molecular oxygen and is not a toxic fluid. In the supercritical carbon dioxide technique, the seeds are mixed with high pressure carbon dioxide in liquid form (at 31°C temperature and 7,3 MPa pressure). Then, oil dissolves in the carbon dioxide. When pressure is released from the system, the carbon dioxide returns to the gas phase and oil precipitates out from CO_2-oil mixture. The extraction efficiency depends on the temperature, pressure, contact time between the extracting fluid and the oilseed material and the solubility of the oil in the extracting fluid.

Mitra (2009) reported that Pumpkin (Cucurbita maxima) seed oil was extracted using supercritical carbon dioxide and the physicochemical properties of the oil were determined. A central composite rotatable design was usedto analyse the impact of extraction parameters (temperature, time and pressure) and a response surface methodology was used to obtain optimal extraction conditions for the maximum oil yield. All three variables studied were significant demonstrating quadratic effects. The maximum yield of the extracted oil was 30.7% and the optimum conditions were 32,140 kPa and 68.1°C for 94.6 min which was within the experimental domain. Physicochemical properties of the oil showed that the extracted oil could be used as food oil supplement

2.3 Pretreatments to Oil Seeds

Singh (2002) studied the influence of moisture content and cooking on screw pressing of crambe seed. The cooking and drying conditions for oil seeds preparatory to screw pressing are some of the most important factors that influence screw-press performance. Screw-press oil recovery, residual oil, pressing rate, and oil sediment content were measured for uncooked crambe seed and crambe seed cooked at 100°C for 10 min, pressed at six moisture contents ranging from 9.2 to 3.6 % dry basis. Oil recovery significantly increased ($P \leq 0.01$) from 69 to 80.9 % and 67.7 to 78.9 % for cooked and uncooked seeds, respectively, as moisture content decreased. Residual oil significantly decreased ($P \leq 0.01$) from 16.3 to 11.1 % and 16.9 to 11.9 %, respectively, as moisture content decreased. The reduced oil loss due to only drying the seed from 9.2 to 3.6 % was 32 % for cooked seed, whereas cooking contributed only 3.6 to 7 % reduced oil loss. Pressing rate decreased from 5.81 to 5.17 kg/h and 6.09 to 5.19 kg/h for cooked and uncooked seeds, respectively, whereas sediment content increased from 0.9 to 7.8% and 1.1 to 5.4%, respectively, as moisture content decreased.

Patil and Ali (2006) studied the effect of expeller screw press and pre-treatments on the quality and quantity of soybean oil and cake was studied using a commercial oil expeller. The pretreatments included whole soybean crushing, soy grits crushing, and crushing of soy grits extruded at 135°C. The screw speeds were 28, 35, and 45 rpm. The moisture content of soybean used in the experiment was 10% wet basis. The average capacity of the oil expeller was found to be 145 kg/h, 110 kg/h and 120 kg/h for whole, grits, and extrudate, respectively at 45 rpm. The average capacity of oil expression from whole soybean did not vary significantly from 28 to 45 rpm. In the case of soy grits, however, the capacity was higher when the expeller speed was lowest,i.e., 28 rpm. In the case of extrudate, even in a single pass, the recovery was higher, i.e.,to 71% at both 45 and 35 rpm. The color of oil from soy grits was lighter followed by extrudate,and the color of oil obtained from whole soybean was dark. The FFA in oil from allthe samples was below 1%, however the lowest percentage was for oil obtained from extrudate at 0.5%. The urease activity of the extruded cake was 0.15 pH units, and the protein and oil content were about 48% and 5%, respectively. The optimum process variables for mechanical expelling of soybean were found to be extrusion as a pretreatment and speed of expeller screw at 45 rpm, which yielded throughput capacity 103 kg/h, oil recovery of70.5%, and urease activity of the cake at 0.15.

2.4 Oil Extraction Efficiency

Wakelyn (2006) found that cooking is performed prior to extraction for the following purposes: (1) break down cell walls to allow the oil to escape; (2) reduce oil viscosity; (3) control moisture content (to about 7% for expanding operation); (4) coagulate protein; (5) inactivate enzymes and kill microorganisms; and (6) fix certain phosphatides in the cake, which helps to minimize subsequent refining losses. Cooking temperatures are around 87.8°C during 120 min. An excess in the cooking time will result in a meal with lower nutritional value and can darken both the oil and meal.

2.5 Performance of oil extraction technologies

Bandara (2014) studied performance evaluation of a screw type oil expeller for extraction of sesame oil. The popular screw type machine with 25 mm shaft pitch, 75×315 mm internal barrel and 4 kW three phase motor were used. The development was made in order to increase the oil expelling efficiency in terms of extract bar clearance, speed of the main spiral shaft and outer body closer to the exhaust out let. The optimum oil yield was 44% obtained under 0.2mm and 0.3mm barrel shaft clearance and the main spiral shaft speed of 75 rpm. The capacity and energy consumption per kilograms of refined sesame oil were 39kg/hr and 0.103kWh/kg.

Aviara (2013) a manually operated multi-application oilseed expressing machine was designed and constructed using locally available materials. Performance tests were conducted on the oilseed expressing machine using guna and groundnut seeds that were subjected to pre-pressing treatments of roasting temperature and duration in the ranges of 30-120^oC and 10- 30 min and ground in to pastes respectively. The results of performance test analysis showed that pre-pressing treatments significantly influenced the performance indices of the machine at 1% level. Extraction rate decreased with increase in roasting temperature from 30 to 120^oC and duration from 10 to 30 min, while machine extraction efficiency depended on the product being processed. The maximum extraction rate obtained was 0.00125 and 0.00133 kg/s for guna and groundnut seeds roasted at 60^oC for 10min and 30^oC for 10 min, respectively. The maximum extraction efficiency of 45 and 46.6% was obtained at pre-pressing treatments of 120^oC and 10 min and 30^oC and 30 min for guna and groundnut seeds, respectively. Guna and groundnut seeds treated at 30 and 60^oC for 10min gave the machine maximum throughput.

Moses(2014) evaluated Performance evaluation of continuous screw press for extraction soybean oil. The performance evaluation test was conducted to investigate the expelling efficiency of the machine, the effect of kneading temperature on the oil yield and the extraction losses of the machine. The literature put soybean oil content as between 18-20% of the whole soybean. The moisture content of the soybean used for the experiment was 10.7% (w.b). The mean oil yield, expelling efficiency and extraction losses ranged between 6.61 and 14.22%, 32.26±0.39% (50^oC) and 68.13±2.27% (90^oC), and 5.39% and

9.90% respectively. The optimum kneading temperature that corresponded to the highest expelling efficiency was(69.13±2.27%) at 90^{o}C.

CHAPTER III

MATERIAL AND METHODS

In this chapter the physical properties of safflower oil seeds, method of testing the machine and optimization of machine/process parameters are discussed. Various parameters which affect the machine performance were studied in order to obtain better oil extraction efficiency. The details are given in the following sections.

3.1 Raw material

The safflower oil seeds of variety AKS 207 were procured from CDF, Wani Rambhapur, Akola (Maharashtra) and were used for the purpose of experimentation.

3.2 Physical properties of safflower oilseeds

Some physical properties of safflower seeds before actual experimentation for optimizing machine process parameters and performance evaluation were studied.

a) Size

b) Sphericity

c) Bulk density

d) True density

e) Porosity

f) Angle of repose

g) Coefficient of static friction

a) Size

The size of the safflower seeds were specified by length, width and thickness.It was measured by digital vernier calliper (Mityutoyo) with least count

0.01 mm.The dimensions of randomly selected fifteen seeds were measured and average value was calculated.

b) Sphericity

The sphericity is a measure of shape character compared to asphere. Assuming that volume of solid is equal to the volume of tri-axial ellipsoid with intercepts a, b, c and that the diameter of circumscribed sphere is largest intercept of the ellipsoid. The sphericity was calculated using the following equation (Mohsenin, 1970).Average of five replications was considered as a sphericity value.

$$\text{Sphericity } (\Phi) = \frac{(a \times b \times c)^{\left(\frac{1}{3}\right)}}{a} \quad \text{.......3.1}$$

Where,

a = Longest intercept, mm

b = Longest intercept normal to a, mm

c = Longest intercept normal to a and b, mm

c) Bulk density

The bulk density of safflower seeds was determined by using the mass/volume relationship. An empty measuring jar of known volume was filled with safflower seeds separately and the mass of filled amount was weighed using an electronic balance (Mohsenin, 1970). The bulk densities of the samples were calculated using the following equation. Average of three replications was considered as a bulk density value of the safflower seed.

$$\rho_b = \frac{M}{V} \quad \text{…….3.2}$$

Where,

ρ_b= Bulk density, kg/m^3

M = Mass of fruit, kg

V = Container volume, m^3

d) True density

The ratio of mass of sample to the true volume is termed as true density of the sample. The true density of the safflower seeds was measured by using liquid displacement method. Toluene was used instead of water because it was absorbed by the sample to a lesser extent. Toluene was taken in a measuring jar of known volume. Sample of 10 gram safflower oilseeds were weighed and poured into the jar. The change in the level of toluene in the jar was recorded. The true densities of the samples were calculated using the formula (Mohsenin, 1970). Average of five replications was considered as a true density value of the safflower oil seeds.

$$\text{True volume of sample} = \begin{Bmatrix} \text{Final toluene level} \\ \text{in measuring jar} \end{Bmatrix} - \begin{Bmatrix} \text{Initial toluene level} \\ \text{in measuring jar} \end{Bmatrix}$$

.......3.3

$$\text{True density kg/m}^3 = \frac{\text{Weight of sample}}{\text{True volume of sample}}$$

…….3.4

e) Porosity

The porosity is also known as the packing factor and it was determined from bulk density and true density of sample. The porosity was calculated by using the following expression (Mohsenin, 1970).Average of five replications was considered as a porosity of safflower oil seeds.

$$\text{Porosity (\%)} = \frac{\text{True density} - \text{Bulk density}}{\text{True density}} \text{x } 100$$

…….3.5

f) Angle of repose

The angle of repose of safflower oil seeds was determined by allowing the material to fall freely to form a heap cone. The diameter of the base circle and height of the heap were measured. The angle of repose was calculated by using the following expression. Average of five replications was considered as anangle of repose of safflower oil seeds.

$$\theta = \tan^{-1}\frac{2h}{D}$$

…….3.6

Where,

θ = angle of repose, degrees

h = height of the pile, m

D = diameter of the pile, m

g) Coefficient of static friction

The coefficient of static friction on mild steel surface was measured for safflower oil seed by using inclined plane method. The material was kept on horizontally placed surface and slope was increased gradually. The angle at impending slip was recorded. The coefficient of static friction was computed by using following formula. The experiment was repeated five times and means value of θ for safflower oil seed was calculated.

Coefficient of static friction = tan θ ……3.7

Where,

θ = angle of static friction, degrees.

3.2.2 Thousand seed weight

One thousand randomly selected safflower oil seeds were collected and weighed on electronic balance (Contech) with least count 0.01 g. This magnitude was termed as the thousand seed weight. The procedure described in IS: 4333 (Part IV)-1968 was adopted. Average of five replications have been considered and reported as thousand seed weight.

3.3 Modification and performance evaluation of mini oil mill

The mini oil mill provided by Rajlaxmi Engineering Corporation, Nagpur was considered for modification and performance evaluation. The experimentation was carried out at All India Co-ordinated Research Project on

Post Harvest Engineering and Technology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

3.3.1 The components of the machine

Various views of the mini oil mill are shown in Plate 3.1 and the orthographic view of mini oil mill is shown in Fig 3.1 and isometric view in Fig 3.2.Various components of mini oil mill are as below:

- Boiler
- Main frame
- Feed kettle
- Oil extraction unit
- Power transmission system

Specification of various component of mini oil mill are given in Table 3.1

a) Front view

b) Back view

Plate 3.1 Mini Oil Mill

Table 3.1: Specification of components of the mini oil mill

Sr. No.	Component	Specification
1	**Complete Mini oil mill**	
	a) length	1829 mm
	b) width	1620 mm
	c) height	1527 mm
2	**Boiler**	

	a) diameter	381 mm
	b) height	1270 mm
	c) height of chimney	1250 mm
	d) diameter of chimney	38.1
3	**Main frame**	
	a) length	1320 mm
	b) width	1613 mm
	b) height	1397 mm
4	**Feed Kettle**	
	a) diameter	457 mm
	b) height	368 mm
5	**Oil extraction unit**	
i)	Casing	
	a) length	508 mm
	b) outer diameter	220 mm
ii)	Screw	
	i) length	914 mm
	ii) screw outer diameter	39 mm
6	**Power transmission**	v-belt and pulley
	Motor	5 HP
	Pulley diameter used for experimentation	88.9, 114.3,127mm
	Flywheel Diameter	762 mm

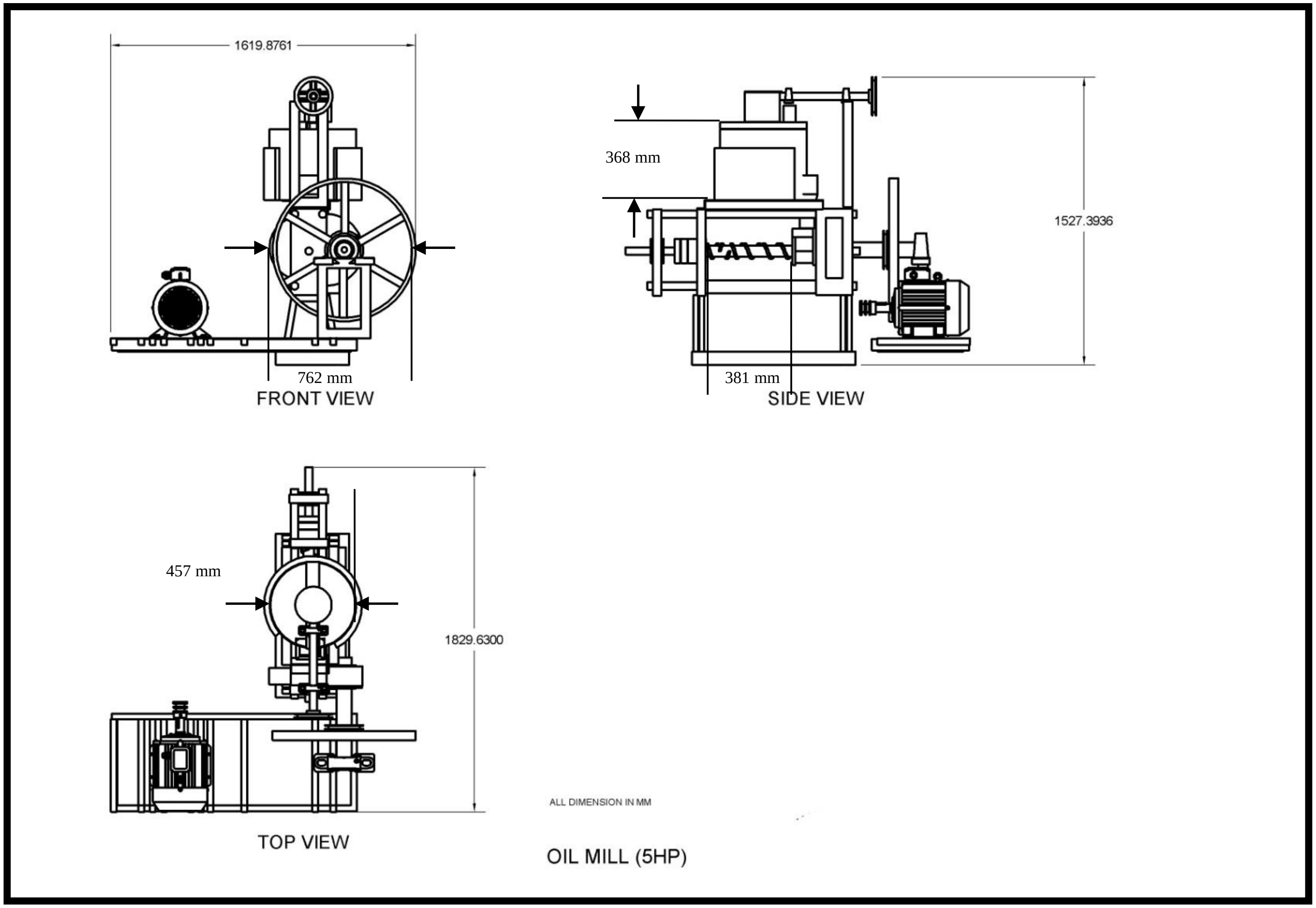


Fig 3.1 Orthographic view of Mini Oil Mill

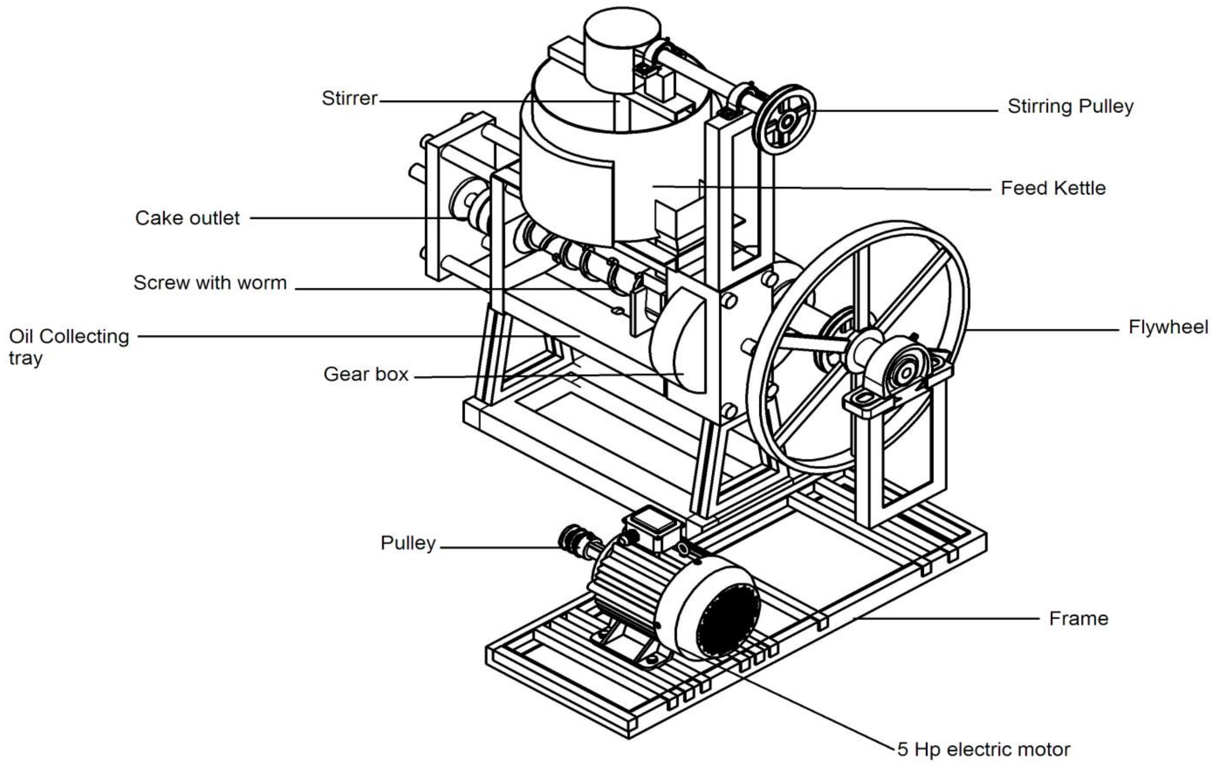


Fig 3.2 Isometric view of Mini Oil Mill

1) Boiler

The water tube type boiler of 2540 mm total height, 381 mm diameter was used for steam generation. The boiler was mounted on stand of 520.7 mm length, 508mm width and 457.2mm height. The boiler was used for experimentation purpose for the generation of steam (Plate 3.2 and Fig 3.3). The dry wood pieces were used as fuel for the boiler. The amount of wood pieces were weighed and then fed to the furnace. The water tank having capacity 500 litres was used to fill the water in the boiler. The amount of water was maintained by observing the level of water in water level indicating tube which should be around 80% of water in water level indicator tube. A tap for over flow of water was provided in boiler in order to maintain proper level of water in boiler. The wood was burnt in the furnace and it heated the water in boiler. After about one hour the valve for steam flow was opened and the steam was allowed to flow towards the steam jacket of the feed kettle of the mini oil mill through the steam inlet. The pressure of the steam generated within the boiler with all valves closed was observed as 15 psi.

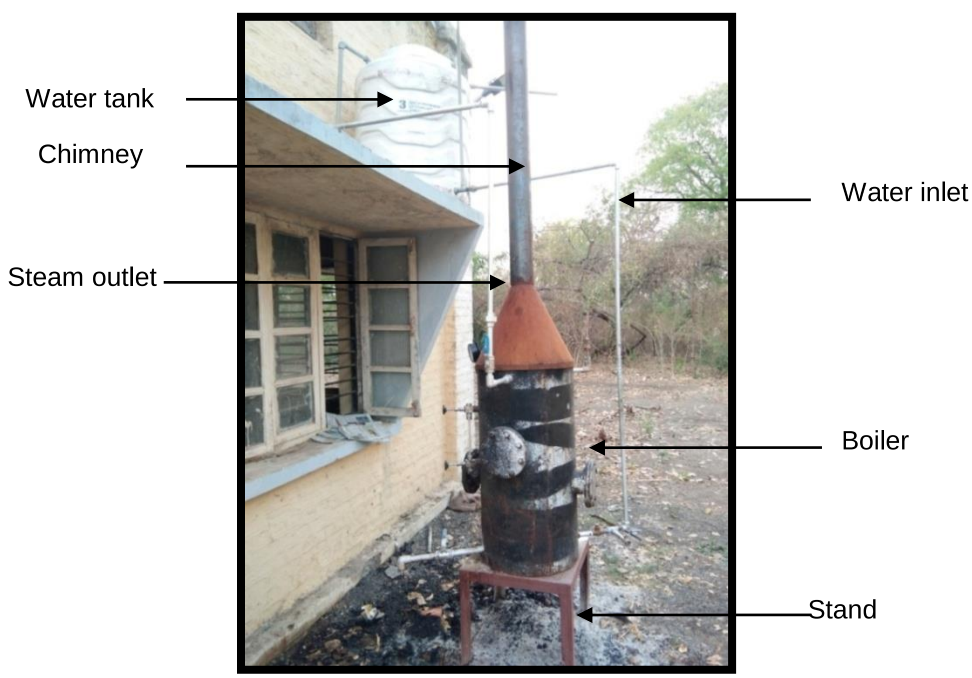


Plate 3.2 Boiler for steam generation

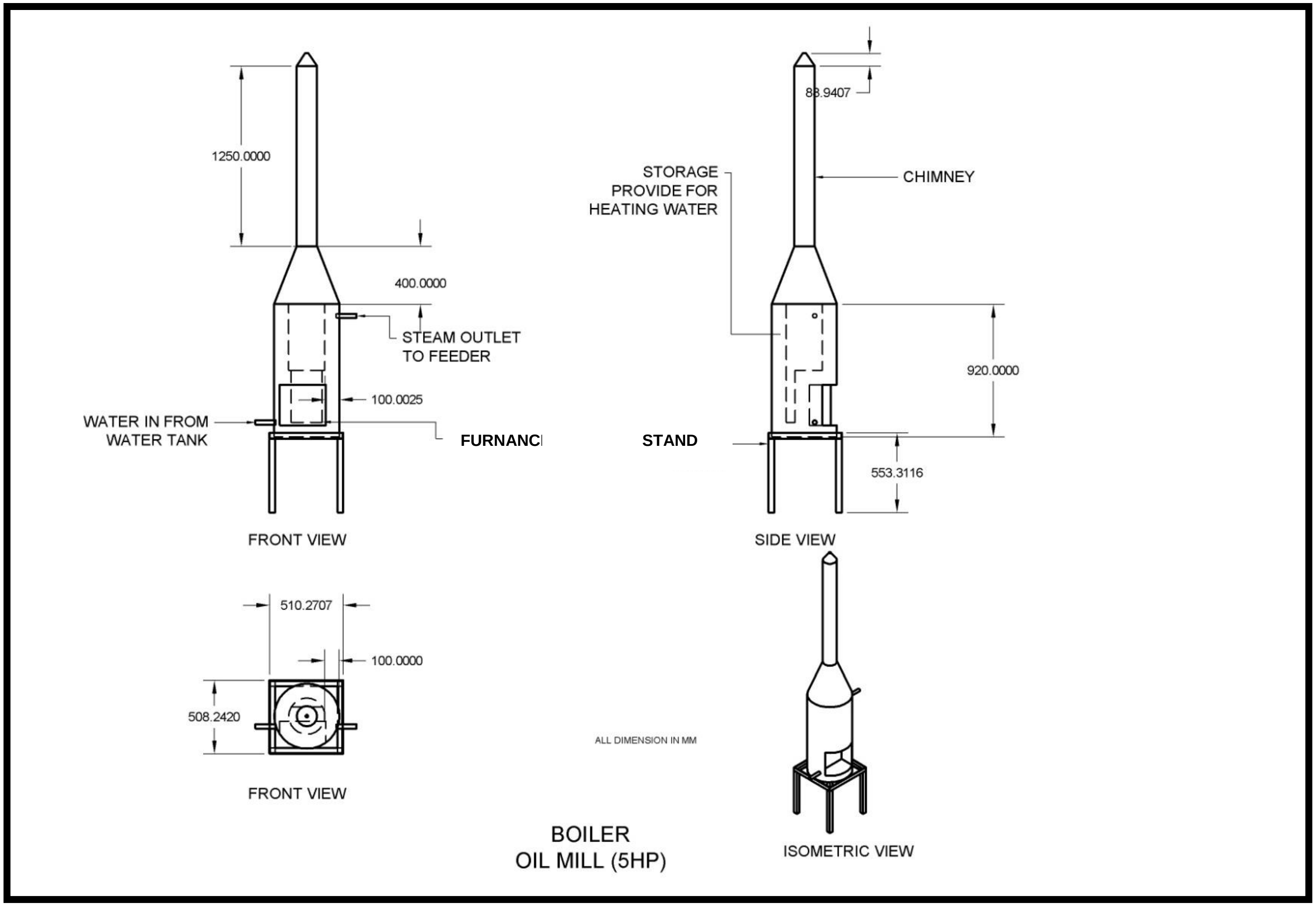


Fig 3.3 Orthographic and Isometric view of boiler

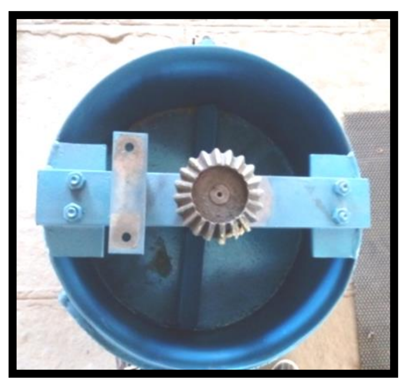
2) Main frame

The main frame of the machine was fabricated out of M.S. angle section of 0.5 mm (Fig 3.4). The frame was made up by merging various sections together. The dimensions of main frame were length 1320 mm, width 1613 mm and height- 1397 mm. The main frame was divided in two sections. At section 1, the assembly of oil extraction unit was fixed at frame, which includes feed kettle, oil extraction chamber, oil outlet, cake outlet and gear box. The electric motor was mounted on frame at section 2. The frame was well braced to mount and support other parts of the machine and also withstand the vibrations during operation.

3) Feed kettle

The feed kettle was fabricated of M.S. sheet having thickness 0.5 mm considering the bulk density of safflower oilseeds. The feed kettle was cylindrical and had the dimensions of 457 mm diameter and height 368 mm as shown in Plate 3.3. The feed kettle consisted of a hollow steam jacket of thickness 25 mm at outer periphery for heating the feed. The shape and volume was decided considering the angle of repose and bulk density of safflower seeds so as to accommodate 30-40 kg of safflower oil seeds. The steam inlet and outlet were provided for steam flow through steam jacket. The pivot blade stirrer was provided for thorough stirring, mixing the feed so as transform the heat uniformly. The temperature of the steam at the steam inlet in steam jacket of feed kettle was 105°C and at steam outlet was 50°C. The temperature of the feed was 75°C.

a) Side view



b)Top view

Plate 3.3 Feed kettle

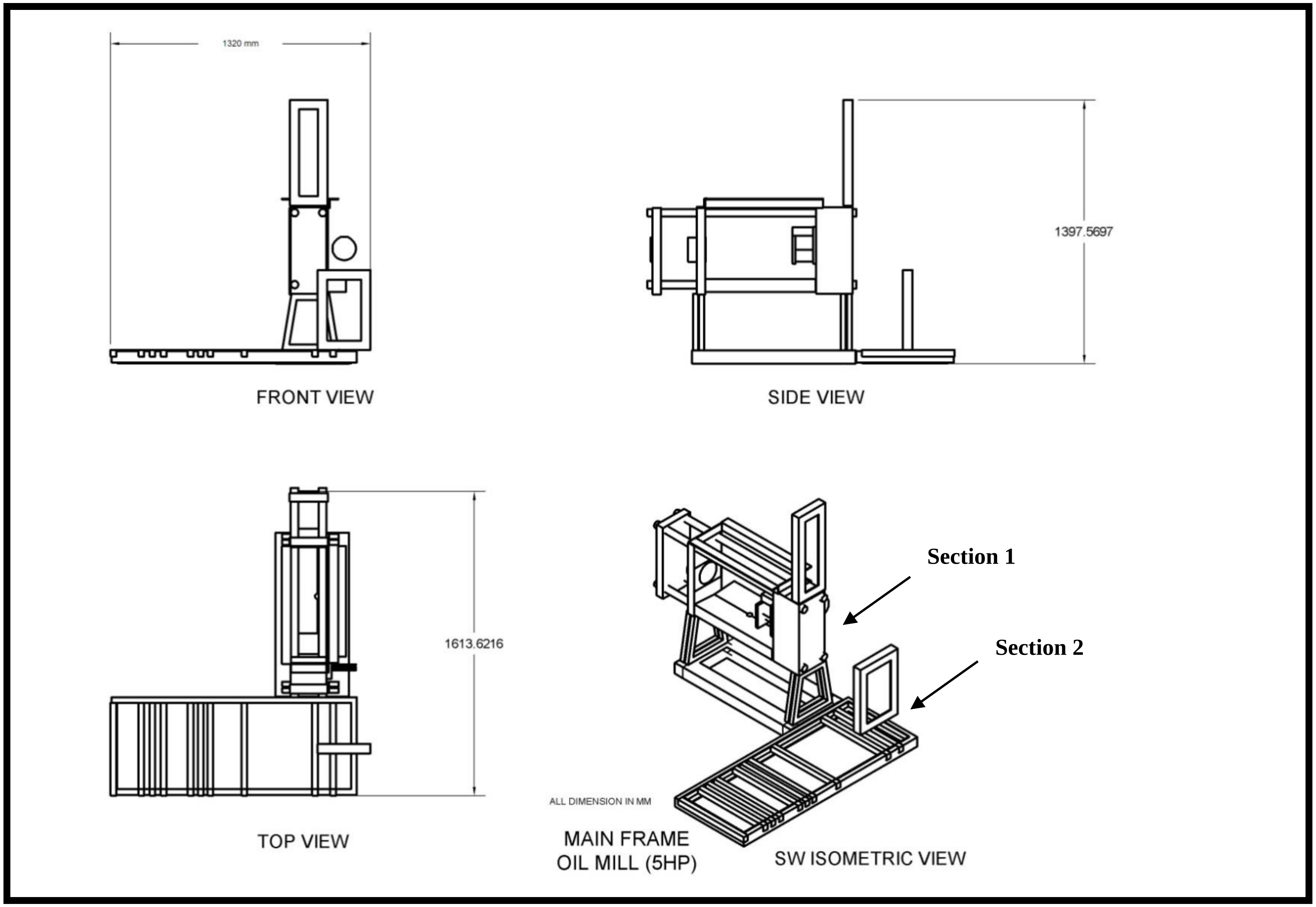


Fig 3.4 Orthographic and Isometric view of frame of mini oil mill

4) Oil extraction unit

The oil extraction unit consisted of i) casing and shaft, ii) oil canals and iii) cake outlet.

i) Casing and shaft

The casing and the shaft was fabricated out of M.S. having outer diameter of 220 mm and 914 mm length. The casing is made up of small M.S bars arranged in semicircular pattern with specific clearance of about 3 mm in between the bars. Five casing plates of M.S having thickness 20 mm, width 220 mm and height 115 mm were spaced out 105 mm inside which the M.S bars were fitted in a semicircular fashion as shown in Fig 3.5. Similar semicircular structure was fabricated and fitted below. Two semicircular structures are joined to form the casing. The shaft was placed inside the casing. The M.S worms were fixed upon the shaft. The clearance between the casing and worm on shaft was 8 mm. Two worm pitches were used for the experimentation i.e. high pitch and low pitch (Plate 3.4). The high pitch worm had a pitch of 76 mm between the threads, pushed the feed 88 mm forward in one revolution of flywheel and low pitch worm with pitch 63 mm between the threads pushed the feed 76 mm forward in one revolution of flywheel.Three various length of reverse worm were used for experimentation i.e 38.1mm, 50.8 mm and 63.5mm are shown in Plate 3.5. The sequence of worms for various lengths of reverse worm is shown in Fig 3.6 and Table 3.2. The arrangements of various lengths of reverse worms are shown in Fig 3.7. The worms upon the shaft rotate along with the shaft inside the casing. The forward worms take the feed forward and the reverse worm rotates reversely and moves the oil seeds in reverse direction. Due to this arrangement the safflower oil seeds get crushed and oil is extracted which passes through the oil canals provided on the casing. The remaining seed cake moves forward and is removed from the cake outlet.

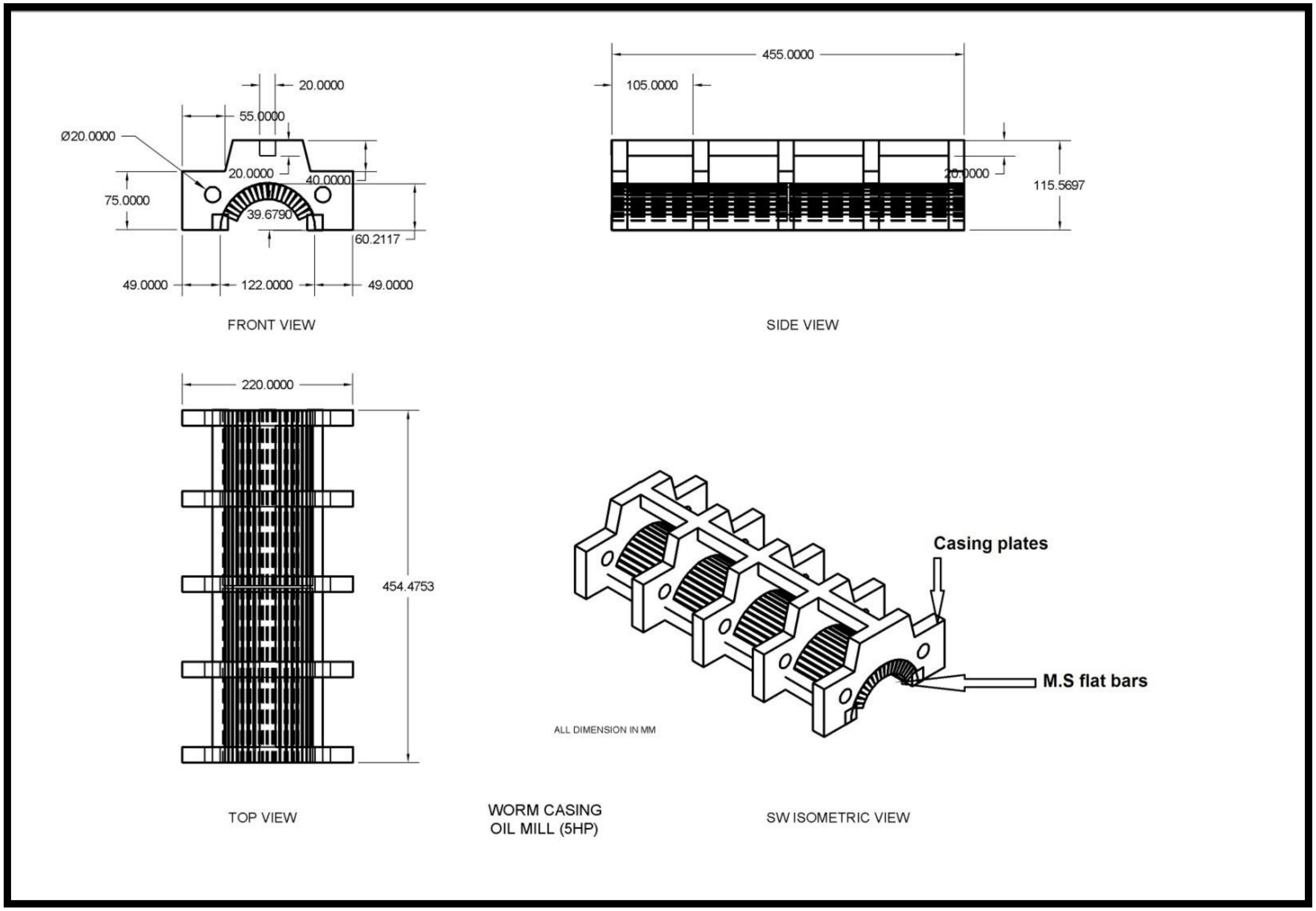
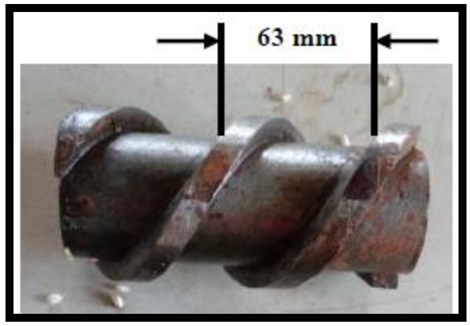
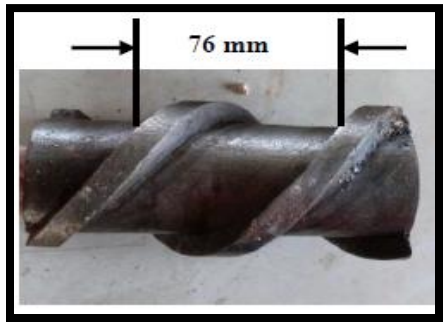


Fig 3.5 Orthographic and Isometric view of casing



a) Low worm pitch 63 mm



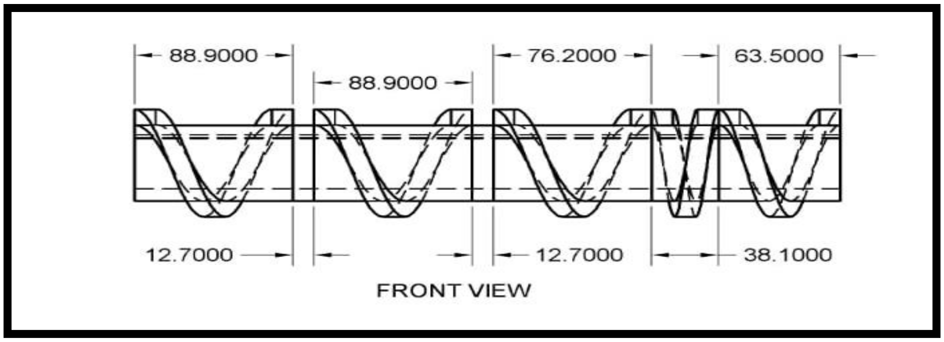
b) High worm pitch 76 mm

Plate 3.4 Worms with varying pitches

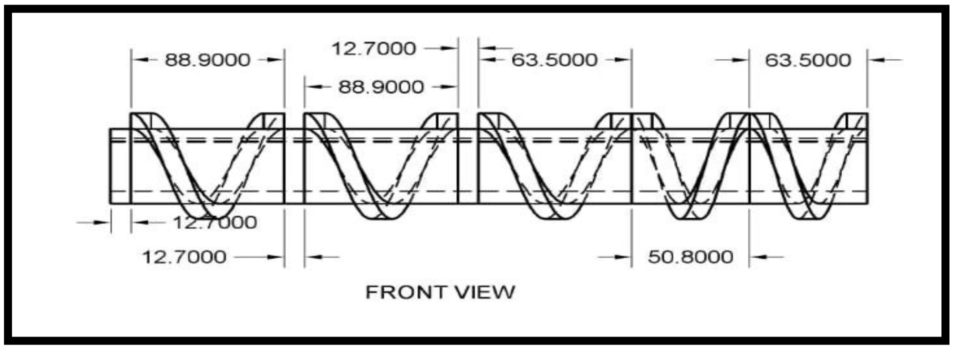
Table 3.2: Sequence of forward and reverse worms on the shaft for various length of reverse worm

Worm Position	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**Total length, mm**
Length of reverse worm								
38.1 mm	88.9*	12.7***	88.9*	12.7***	76.2*	38.1**	63.5*	381
50.8 mm	88.9*	12.7***	88.9*	12.7***	63.5*	50.8**	63.5*	381
63.5 mm	88.9*	12.7***	88.9*	63.5*	63.5**	63.5*		381

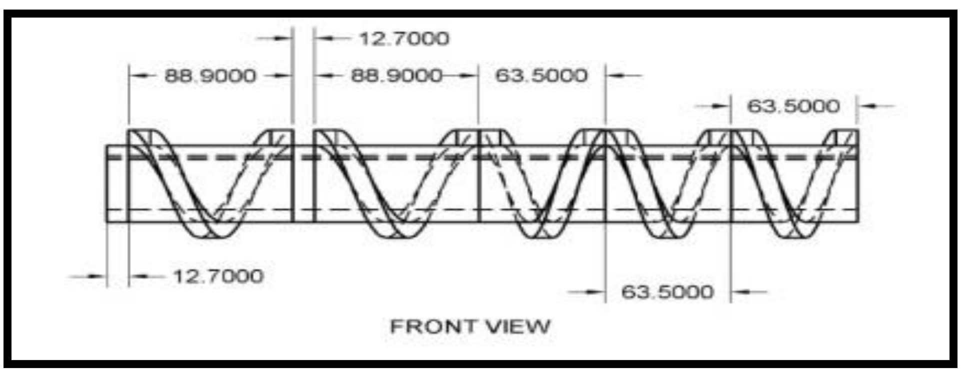
Where * indicates forward worm,** indicates reverse worm and*** indicates collar



a) 38.1 mm reverse worm



b) 50.8 mm reverse worm



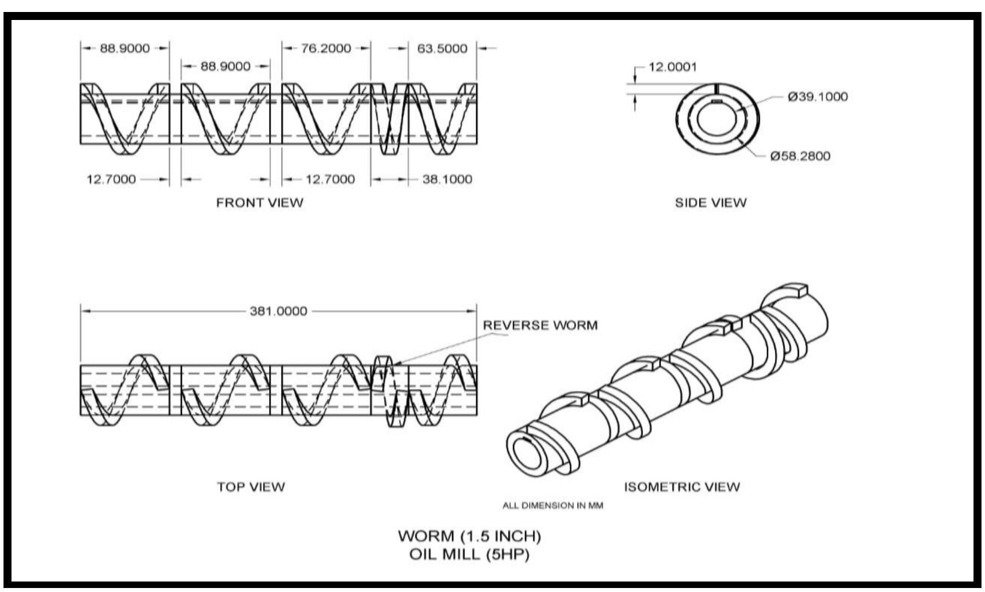
c) 63.5 mm reverse worm

Fig 3.6 Sequence of arrangement of reverse worm on shaft for various lengths of reverse worm

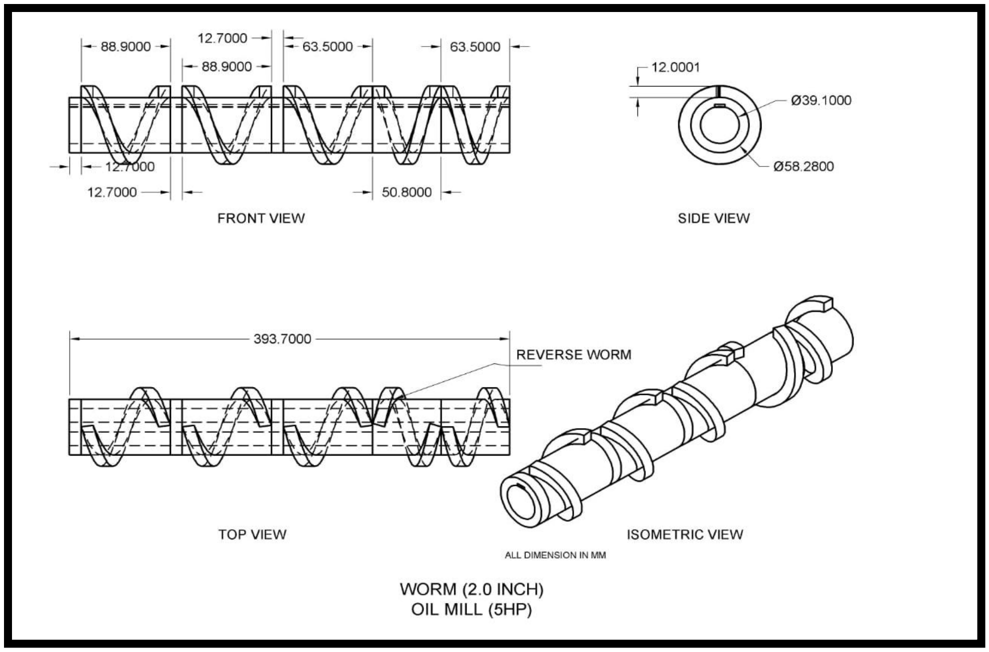
a) 38.1 mm reverse worm b) 50.8 mm reverse worm

c) 63.5 mm reverse worm

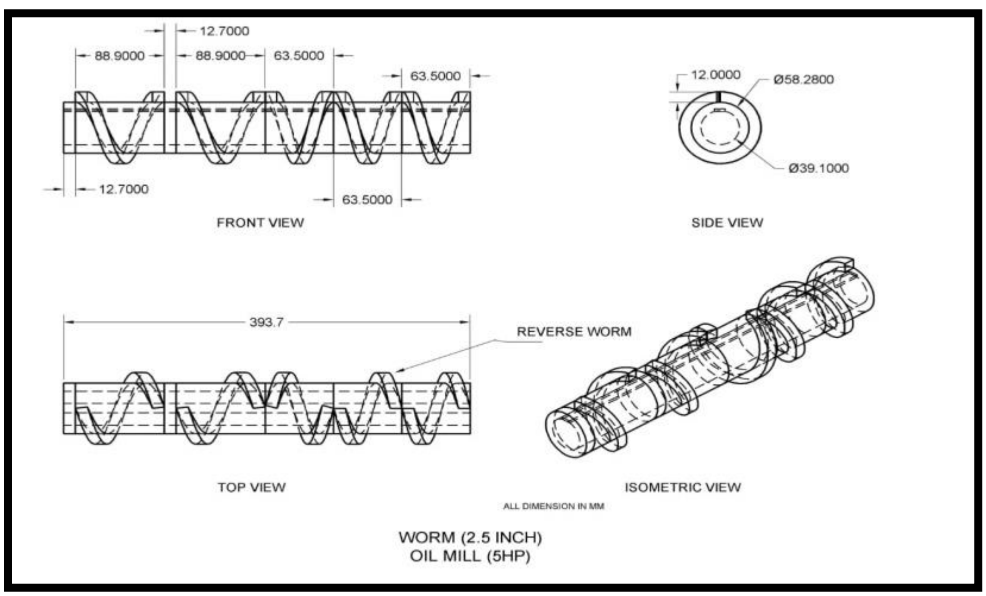
Plate 3.5 Reverse worm



a) 38.1 mm reverse worm



b) 50.8 mm reverse worm



c) 63.5 mm reverse worm

Fig 3.7 Arrangement of reverse worm in screw for various length of reverse worm

ii) Oil canals

The oil canals through which the oil was removed are the spaces in between the bars of the casing. The casing consists of M.S bars which are arranged in a semicircular pattern. The spaces in between the casing bars acts as oil canal i.e. the oil flows through these small spaces and gets collected in the tray below. The tray of length 584 mm, width 279 mm and height 76 mm collects the oil and the residue shown in Fig 3.2. The tray has a hole in the centre through which the oil is removed and collected.

iii) Cake outlet

The cake outlet includes the rotating screw and a narrow opening of 10 mm as shown in Plate (3.6). The placement of cone type cap can be changed so as to vary the clearance between the casing and cone type cap, thereby obtaining cake of different thickness. The opening is adjusted at 10 mm thickness so that the cake is removed easily without creating load on the mini oil mill.

a) Top view

b) Side view

c) Front view

Plate 3.6 Cake Outlet

4) Power transmission system

The mini oil mill was provided with three phase, five-horse power induction motorhaving 995 rpm. The mini oil mill was provided with a vertical gear box. The teeth ratio of 1:5 was used so as to reduce the speed in same proportion. Gear box was developed and coupled to electric motor of 5 hp.

3.4 Optimization of parameters for mini oil mill

3.4.1 Oil extraction of safflower seeds in mini oil mill

The steam from the boiler was used to heat the feed. All the trials were conducted with 15 kg sample size and data for oil recovery, cake recovery, oil extraction efficiency, feed rate, deficit oil yield, extraction losses was reported. The boiler was fed with wood of measured quantity as fuel Plate (3.7).The steam generated from the boiler was conveyed to the steam inlet of steam jacket through the pipe. The safflower seeds of sample size 15 kg were fed to the hopper as shown in Plate 3.8. The stirrer in the feed kettle was used for thorough stirring and mixing of the feed so as to transform the heat uniformly (Plate 3.9). The heating of the feed results in more oil recovery since the oil in the seeds flows towards the outer periphery of the seeds and the fat globules get free and move towards the seed coat which eases oil extraction. Heating before pressing increases oil yield due to the breakdown of oil cells, coagulation of protein, adjustment of moisture content to the optimal value for pressing, and decreased oil viscosity, which allows the oil to flow more quickly (Gunstone, 2005).After uniform heating of the feed, the feed outlet was opened and the safflower seeds were allowed to pass through the oil extraction chamber. Traditionally 44 rpm of shaft speed, 63.5 mm of length of reverse worm and low pitch shafts were used. The oil extraction chamber consisted of worms rotating on the shaft. The speed of the shaft was changed for the experimentation by changing the pulley on the electric motor with different diameter so as to obtain the desired levels of shaft speed(rpm) required for experimentation (Plate 3.10). Two different worm pitches i.e. high worm pitch and low worm pitch were used as per the levels of the experimentation (Plate 3.4). The pitch of the worm pushed the feed forward at varying speed i.e. high pitch worm with pitch 76 mm between the threads, pushed the feed 88 mm forward in one revolution of flywheel and low pitch worm with pitch 63 mm between the threads pushed the feed 76 mm forward in one revolution of flywheel. The worms were arranged in various sequences and forward and reverse worm were used for oil extraction as shown in Table 3.2 and Fig 3.6. Three different length of reverse worm were used as per the levels of the experimentation. The worms on the shaft were covered by the casing as given in. The forward worms carried the feed forward. The reverse worm rotated the feed in reverse action. The simultaneous forward and reverse direction crushed the seeds and oil was extracted. The mini oil mill in operation is shown in (Plate 3.11). The oil escaped through the oil canals on casing, collected from the oil collecting tray below the casing, collected in a can (Plate 3.12). One forward worm was attached next to the reverse worm, which conveyed the cake forward. The cake was collected from the cake outlet (Plate 3.13). The clearance of the cake outlet was adjusted to 10 mm, so as to obtain cake of 5 mm thickness. The thickness of the cake can be varied by adjusting the placement of the cone type cap at the cake outlet. After each experiment the oil from oil extraction chamber and cake from cake outlet were collected for further analysis of sample.

Plate 3.7 Feeding of wood as fuel to the boiler

Plate 3.8 Feeding safflower seeds to feed kettle

Plate 3.9 Stirrer in the feed kettle

Plate 3.10 Pulley of varying diameter installed on electric motor

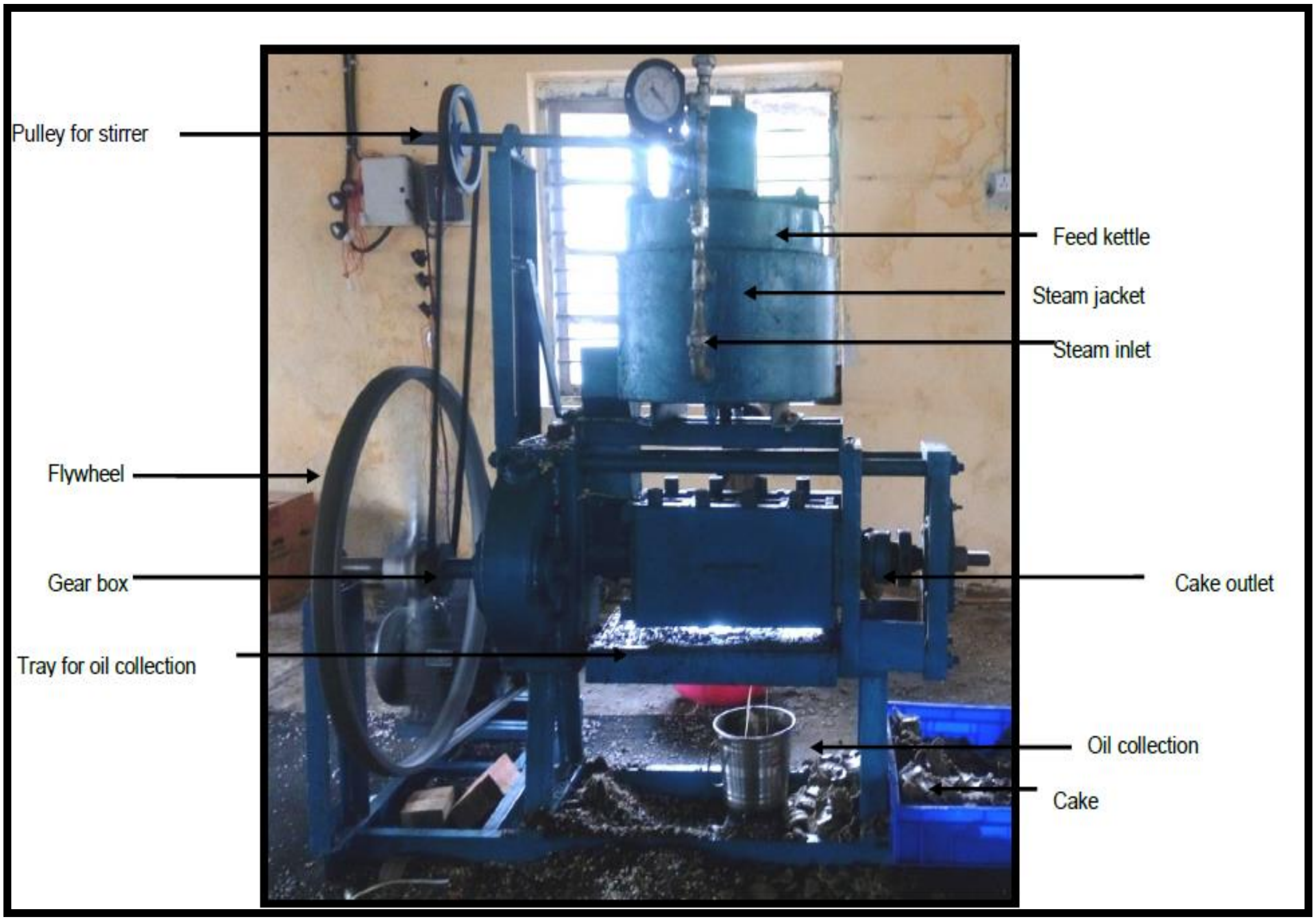


Plate 3.11 Mini oil mill in operation

Plate 3.12 Oil collected in 5 litre can

Plate 3.13 Safflower cake

3.5 Optimization of machine/process parameters

3.5.1 Independent parameters

Two numeric parameters:

1) Shaft speed, rpm – 3 levels

2) Length of reverse screw, mm – 3 levels

One categoric parameter

3) Worm Pitch – 2 levels

The coded and decoded level of independent parameter for oil extraction of safflower seeds are shown in Table 3.3.

3.5.2 Dependent parameters

1. Oil recovery, %
2. Cake recovery, %
3. Oil extraction efficiency, %
4. Feed rate, kg/h
5. Deficit oil yield ,%

3.5.3 Design of experiments

Response-surface methodology comprises of methods used for exploring the optimum operating conditions through experimental methods.The standard techniques were applied. As per 2 numeric variable 3 levels and one categoric variable worm pitch with two levels i.e. low pitch and high pitch Randomized Design, 3 level factorial, reduced cubic model, 26 trials were performed as enumerated in Table 3.3 and Table 3.4 for obtaining the oil extraction efficiency, oil recovery, cake recovery, feed rate and deficit oil yield . All these trials were conducted with 15kg sample size and data for oil extraction efficiency, percent oil recovery, cake recovery were reported. To avoid bias, 26 runs were performed in a random order. The decision for the range and centre points of the variables was taken through preliminary trials and discussion with mini oil mill manufacturer.

Table 3.3 Levels of independent variables for mini oil mill

Independent Variables	**Symbols**		**Levels**	
	Coded	**Decoded**	**Coded**	**Un-coded**
Shaft speed, rpm	x_1	S	-1	28
			0	36
			1	44
Length of reverse worm, mm	x_2	R	-1	38.1
			0	50.8
			1	63.5
Worm Pitch, mm	x_1	P	-1	Low Pitch
			1	High Pitch

Table 3.4 Experimental layout for 2 numeric variables 3 levels and one categoric variable 2 levels response surface analysis for mini oil mill

Sr. No.	**Shaft speed, rpm**	**Length of reverse worm, Mm**	**Worm pitch, mm**	**Shaft speed, rpm**	**Length of reverse worm, mm**	**Worm pitch, Mm**
	X_1	X_2	X_3	S	R	P
1	0	1	1	36	63.5	High pitch
2	1	-1	1	44	38.1	High pitch
3	-1	0	1	28	50.8	High pitch
4	0	-1	-1	36	38.1	Low pitch
5	-1	1	1	28	63.5	High pitch
6	0	0	1	36	50.8	High pitch
7	-1	-1	-1	28	38.1	Low pitch
8	-1	0	-1	28	50.8	Low pitch
9	0	0	-1	36	50.8	Low pitch
10	0	0	-1	36	50.8	Low pitch
11	0	0	-1	36	50.8	Low pitch
12	-1	-1	1	28	38.1	High pitch
13	1	1	-1	44	63.5	Low pitch
14	0	-1	1	36	38.1	High pitch
15	0	0	-1	36	50.8	Low pitch
16	0	0	1	36	50.8	High pitch
17	1	-1	-1	44	38.1	Low pitch
18	1	1	-1	44	63.5	High pitch
19	0	0	-1	36	50.8	High pitch
20	0	0	-1	36	50.8	High pitch

21	0	1	1	36	63.5	Low pitch
22	-1	1	-1	28	63.5	Low pitch
23	0	0	-1	36	50.8	Low pitch
24	1	0	-1	44	50.8	Low pitch
25	1	0	1	44	50.8	High pitch
26	0	0	1	36	50.8	High pitch

Optimization

Optimization of input parameters was carried out for machine testing under shaft speed, reverse worm length and worm pitch taken for study.

3.5.4 Numerical optimization

Numerical optimization of the Design-Expert software was used for simultaneous optimization of multiple responses. The desired goals for each factor and response were chosen. The goals may apply to either factors or responses. The possible goals are maximum, minimum, target, within range, none (for responses only). The independent factors viz. shaft speed, length of reverse worm and worm pitch were kept within range while the responses viz. oil extraction efficiency and oil recovery was kept maximized, cake recovery and extraction losses was kept minimized and feed rate and deficit oil yield was kept in range.

3.5.5 Graphical optimization

Graphical optimization was also carried out for the operation parameters of safflower seeds for maximum oil extraction efficiency. For graphical optimization, super imposition of contour plots for all responses was done using design expert software. The super imposed contours of responses for shaft speed, length of reverse worm and worm pitch and their intersection zone for maximum oil extraction efficiency, oil recovery and minimum cake recovery and feed rate, deficit oil yield in range indicated ranges of variable which could be considered as optimum range for best oil extraction efficiency in term of responses.

3.5.6 Verification of optimum responses

The optimum responses were verified by conducting experiments on mini oil mill on optimum operational parameters. The responses such as oil extraction efficiency and oil recovery, cake recovery, oil extraction efficiency, feed rate and deficit oil yield at optimum machine parameters were compared to the values predicted by the regression model.

3.5.7 Estimation of dependent parameters

3.5.7.1 Oil recovery

Oil recovery indicates the quantity of oil obtained after extraction. It is expressed by following expression:

$$\text{Oil recovery, \%} = \frac{\text{Quantity of oil recoverd(kg)}}{\text{Quantity of sample feed(kg)}} \times 100$$

……. 3.8

3.5.7.2 Cake recovery

Cake recovery can be calculated as:

$$\text{Cake recovery, \%} = \frac{\text{Quantity of cake recoverd(kg)}}{\text{Quantity of sample feed(kg)}} \times 100$$

…....3.9

3.5.7.3 Oil Extraction Efficiency

Oil Extraction Efficiency E is given by (Olaniyan, 2010):

$$\mathrm{E} = \frac{\mathrm{Y}}{\mathrm{C_o}} \times 100$$

……3.10

Where,

Y = Oil recovery in percentage

C_o= Oil Content of oilseed

3.5.7.4 Deficit Oil yield

Deficit oil yield of the cake was measured by using Soxlet apparatus. The deficit oil yield can be calculated as:

$$\text{Oil, \%} = \frac{W_2 - W_1}{W} \times 100$$

…....3.11

Where,

W_1 = Weight of empty dry beaker

W_2 = Weight of beaker along with oil

W = Weight of sample

3.6 Equipment and Instruments

3.6.1 Determination of moisture content

The moisture content of the safflower seeds was determined by using hot air oven method. A known weight of safflower seed samples was taken and kept in an oven at 130°C for 3 hours (Plate 3.14). After constant weight, sample was removed from the oven and cooled. After cooling, final weight of the sample was taken and the moisture content on wet basis was determined by using the following formula and expressed in percentage (Sahay and Singh, 1994).

$$\text{Moisture content (w.b), \%} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \text{x } 100$$

…….3.12

Plate 3.14 Hot air oven

3.6.2 Digital electronic weighing balance

Digital electronic weighing balance (Manufactured by PHOENIX, Model No: CT-300. SERIAL NO.-1200078 (Plate 3.15) with maximum 150 kg and minimum 200 g weighing capacity was used for weighing safflower seeds.

Plate 3.15 Digital electronic weighing balance

3.6.3 Digital Vernier Calliper

Length, width and thickness of safflower seeds were measured by using a digital vernier calliper (Mityutoyo) with least count 0.01 mm (Plate 3.16).

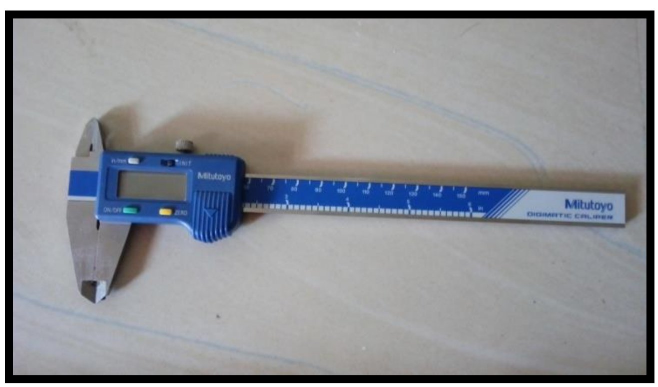


Plate 3.16 Digital Vernier calliper

3.6.4 Digital Tachometer

The speed of the shaft was measured by contact type digital tachometer (LINE SEIKI MADE IN JAPAN). Operating range of digital tachometer was 6-99,999.9 rpm (Plate 3.17).

Plate 3.17 Digital Tachometer

3.6.5 Soxlet Apparatus

The soxlet apparatus SOCS PLUS was used to measure the deficit oil yield of the cake. It consists of assembly of 6 beakers, thimble in each beaker to hold the sample. It operates at varying temperature depending upon boiling point of the solvent used (Plate 3.18).

a) Setup for Soxlet apparatus

b) Beaker with thimble and oil

Plate 3.18 Soxlet Apparatus

3.7 Physicochemical properties of safflower oil extracted from mini oil mill

The oil samples of oil extracted from mini oil mil were analyzed from the Mantri lab for physicochemical properties. Various physicochemical properties were analyzed:

1. Saponification value
2. Iodine value
3. Free fatty acid
4. Peroxide value
5. Viscosity
6. Polyunsaturated fatty acid
7. Monounsaturated fatty acid

CHAPTER IV

RESULTS AND DISCUSSION

The physical properties of safflower are presented and discussed in this chapter. Experimental data on the oil recovery, cake recovery, oil extraction efficiency, feed rate, deficit oil yield corresponding to various machine parameters was studied for oil extraction from safflower. The best fit of the experimental data has been worked out by statistical method. The optimization of machine/ process parameters for maximum oil extraction efficiency, oil recovery and minimum cake recovery and deficit oil yield, feed rate in range was carried out.

4.1 Physical Properties

Some physical properties of safflower were measured. Coefficient of friction, angle of repose, colour, geometric mean diameter, sphericity, moisture content, true density, bulk density, porosity of safflower oil seeds of variety AKS 207 were measured. The observations were replicated thrice and average was calculated which are given in Table 4.1 (Appendix 1).

The average length, width, thickness and geometric mean diameter of the safflower seeds observed to be 7.47±1.34mm, 3.5±0.51mm, 2.8±0.33 mm and 4.21±0.63 mm respectively. The sphericity of safflower seeds was 47.14±0.003.

Bulk density, true density and porosity of the safflower seeds were determined. The observations were thrice replicated and average was calculated which are given in Table 4.1.

The bulk density of safflower seeds was 0.46±0.02 g/cc. The true density of safflower seeds was 0.89±0.11 g/cc. The porosity of safflower seeds was 47.52±6.41 %.

The angle of repose of safflower seeds was measured. The observations were thrice replicated and average was calculated which are given in Table 4.1.

The average value for angle of repose of safflower seeds was 30.84±1.96 °.

The moisture content of the safflower seeds was measured. The observations were replicated thrice and average was calculated which are given in Table 4.1.

The average value for moisture content of safflower seeds was found to be 4.63± 0.66% on wet basis.

Table 4.1: Physical properties of safflower seeds

Safflower seeds

Particular	**Range**	**Average**
Length, mm	7.13-7.79	7.47±1.34
Width, mm	3.0-3.9	3.49±0.51
Thickness, mm	2.1-3.5	2.8±0.33
Geometric mean diameter, mm	3.55-4.97	4.21±0.63
Sphericity, %	41.11-56.09	47.14±0.003
Bulk density, g/cc	0.44-0.49	0.46±0.02
True density, g/cc	0.76-1	0.89±0.11
Porosity, %	41.96-54.54	47.52±6.41
Angle of repose, degree	28-33	30.84±1.96
Thousand seed weight, g	52.6-54.1	53.6±0.04
Moisture content, %(w.b)	3.9-5.3	4.634±0.66

4.2 Performance Evaluation of Mini Oil Mill

The safflower seeds were fed into the mini oil mill through the feeding kettle. The mini oil mill was tested for safflower by using three levels of length of reverse worm(38.1 mm, 50.8 mm, 63.5 mm) for three levels of shaft speed(28 rpm, 36 rpm and 44 rpm) and for two levels of worm pitch P_1 and P_2i.e. high and low pitch. These levels of input parameters were decided based on some filler trials and discussion with manufacturer of mini oil mill. The clearance between the casing and worms on shaft made the oil seeds crush and oil to discharge. The moisture content of safflower seeds was found to be 4.63 %(w.b.) during oil extraction. The oil content of safflower seeds was 27%. The effect of shaft speed, length of reverse worm and worm pitch on various parameters like oil recovery, cake recovery, deficit oil yield, feed rate, oil extraction efficiency and extraction losses was determined.

Capacity of the machine

The capacity of the machine was determined by feed rate of safflower seeds into the machine and weighing the oil recovered, irrespective of the losses. Before feeding the total weight of safflower seeds was taken and the total time required for oil extraction was noted. The capacity of the machine was expressed as kg of safflower seeds processed per unit time i.e. kg/h.

4.2.1 Optimization of machine/ process parameters for safflower oil extraction

Optimization of machine/ process parameters such as shaft speed, length of reverse worm and worm pitch is necessary so that maximum oil recovery, and oil extraction efficiency and minimum cake recovery, extraction losses could be achieved.

4.2.1.1 Response 1: Oil recovery, (%)

The experiments were conducted with various treatment combinations as given in Table 4.2 and show the effect of various levels of input parameters on oil recovery. The oil recovery was observed between 17.27 to 23.38 %. The maximum oil recovery of 23.38 % was observed at 36 rpm shaft speed, 50.8 mm length of reverse worm and at high worm pitch P_2. The minimum oil recovery of 17.27 % was observed at 44 rpm shaft speed and 38.1 mm length of reverse worm and at low worm pitch P_1.

Table 4.2 Effect of various levels of input parameters on oil recovery of safflower seeds

Sr. No.	Run	Shaft speed, rpm	Length of reverse worm, Mm	Worm pitch	Oil recovery, %
		S	R	P	
1	20	28	63.5	High pitch	20.11

2	16	44	38.1	High pitch	17.99
3	13	36	50.8	Low pitch	21.53
4	18	36	50.8	High pitch	22.79
5	24	36	50.8	High pitch	23.18
6	11	36	50.8	Low pitch	22.39
7	21	36	63.5	High pitch	21.41
8	9	44	63.5	Low pitch	17.28
9	7	28	63.5	Low pitch	19.89
10	25	36	50.8	High pitch	**23.38**
11	15	36	38.1	High pitch	20.79
12	22	44	63.5	High pitch	18.79
13	14	28	38.1	High pitch	19.03
14	4	28	50.8	Low pitch	19.16
15	23	36	50.8	High pitch	22.51
16	19	44	50.8	High pitch	18.48
17	26	36	50.8	High pitch	22.91
18	12	36	50.8	Low pitch	22.79
19	6	44	50.8	Low pitch	17.99
20	10	36	50.8	Low pitch	21.67
21	17	28	50.8	High pitch	19.59
22	5	36	50.8	Low pitch	22.01
23	8	36	63.5	Low pitch	21.13
24	3	44	38.1	Low pitch	**17.27**
25	1	28	38.1	Low pitch	18.81
26	2	36	38.1	Low pitch	20.51

The analysis of variance (ANOVA) was carried out for the experimental data and the significance of shaft speed, length of reverse worm and worm pitch was analyzed.

The response surface (3 level factorial) quadratic model was fitted to the experimental data and statistical significance of linear, interaction and quadratic terms were analyzed for oil recovery (Table 4.3). It revealed that the model was highly significant at 1 % level of significance and lack of fit was non-significant indicating that the model was quite adequate for predicting response.

Table 4.3 ANOVA for effect of machine/ process parameters on oil recovery for safflower seeds

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	89.12	8	11.14	38.51	< 0.0001	significant
A-Shaft Speed	6.45	1	6.45	22.31	0.0002	
B-Length of reverse worm	1.47	1	1.47	5.08	0.0377	
C-Worm Pitch	2.81	1	2.81	9.70	0.0063	
AB	0.2312	1	0.2312	0.7993	0.3838	
AC	0.2883	1	0.2883	0.9967	0.3321	
BC	0.0533	1	0.0533	0.1844	0.6730	
A^2	50.95	1	50.95	176.14	< 0.0001	
B^2	4.30	1	4.30	14.86	0.0013	
Residual	4.92	17	0.2893			
Lack of Fit	3.38	9	0.3759	1.96	0.1780	not significant
Pure Error	1.53	8	0.1918			
Cor Total	94.03	25				

Std. Dev.	0.5378	**R^2**	0.9477
Mean	20.51	**Adjusted R^2**	0.9231
C.V. %	2.62	**Predicted R^2**	0.8688
		Adeq Precision	17.6272

The results showed that among linear effects shaft speed had a significant effect on oil recovery ($P<0.01$) at 1 % level of significance followed by worm pitch and length of reverse worm. The existence of quadratic terms indicates the curvilinear nature of the response. It indicates that increasing the value of variable initially increases the response up to certain level and then further increasing the value of variable decrease the response for two types of pitches.

The quadratic response surface model data indicated the result as significant. The lack of fit was found to be non-significant. The determination coefficient R^2 was 0.9477 for oil recovery which indicated that the model could fit the data for oil recovery very well for all the three variables i.e. shaft speed, length of reverse worm, and worm pitch.

The response surface equation was obtained for the model of second degree in terms of coded factors as under:

Final equation in terms of coded factors

$$\text{Oil recovery, (\%)} = +22.32 - 0.7333 X_1 + 0.3500 X_2 + 0.3285 X_3 - 0.1700 X_1 X_2 + 0.1550 X_1 X_3 - 0.0667 X_2 X_3 - 3.04 X_1^2 - 0.8821 X_2^2 \quad \text{.........4.1}$$

Where coded factors are:

X_1= Shaft speed, rpm
X_2 = Length of reverse worm, mm
X_3 = Worm pitch, (P_1 low and P_2 high)

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. The response surface equation was obtained for the model of second degree in terms of actual factors as under,

For Worm pitch P_1,

$$\text{Oil recovery, (\%)} = -53.81460 + 3.9066S + 0.638180R - 0.001673SR - 0.047454 S^2 - 0.005469 R^2 \quad \text{..........4.2}$$

For Worm pitch P_2,

Oil recovery, (%) = -55.08601+ 3.42941S+ 0.648679R- 0.001673SR- 0.047454 S^2 – 0.005469 R^2 ……….4.3

Where actual factors

S= Shaft speed, rpm

R = Length of reverse worm, mm

P= Pitch, (P_1low and P_2high)

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

4.2.1.1.1 Effect of shaft speed, length of reverse worm and worm pitch on oil recovery of safflower seeds

The linear positive terms and negative quadratic terms S and R indicated the oil recovery increased initially with increase in shaft speed and length of reverse worm and thereafter decreased as shown in Fig 4.1 and 4.2 for both the types of pitch. The oil recovery was found to be increasing with increase in shaft speed. Oil recovery was found low at low shaft speed. This may be due to the fact that low shaft speed was insufficient to crush and extract oil from oil seed. As the shaft speed increased the oil recovery was increased to some extent and was maximum at medium shaft speed, which was suitable for maximum crushing and oil extraction. Further the oil recovery was found to be decreased with increase in shaft speed because of less exposure time for crushing and oil extraction from oil seed.

There was very less effect of length of reverse worm on oil. The oil recovery was found to be less at low length of reverse worm, as the crushing and extraction of the oil from oil seed was less because for low length of reverse worm reverse action was less. As the length of reverse worm increased the oil recovery was found to be increased slightly and further increase in length of reverse worm was not having much effect on oil recovery. At maximum length of reverse worm, the oil recovery decreased. This may be due to the fact that even though at maximum length of reverse worm the reverse action is more but friction developed is more, and residence time is more, which may lead to reabsorption of oil in the cake.

Further it was observed that at maximum length of reverse worm and minimum shaft speed, it created load on the machine, the cake was found to be hardened and even the machine vibrated heavily (Plate 4.1). Thus, the combination of maximum length of reverse worm and minimum shaft speed under study was not found suitable in case of both worm pitches P_1 and P_2. In this case friction and heat was generated which is not desirable.

It was also observed that the high worm pitch P_2 was most efficient worm pitch followed by low worm pitch P_1 pertaining to oil recovery with respect to various input parameters viz. shaft speed (S), length of reverse worm (R) because the low pitch worm P_2 with pitch 63mm between the threads pushed the feed 76 mm forward in one revolution of flywheel and The high pitch worm P_1 had a pitch of 76 mm between the threads, pushed the feed 88 mm forward in one revolution of flywheel which was more as compared to low pitch worm.

Plate 4.1 Hardened cake at minimum length of reverse worm and low shaft speed

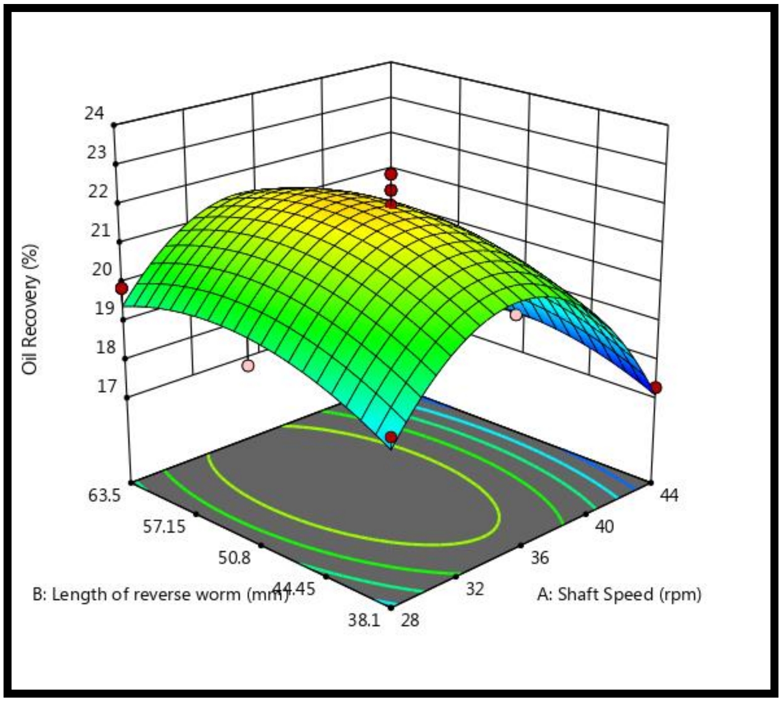


Fig 4.1 Effect of shaft speed (S) and length of reverse worm (R) on oil recovery of safflower seeds on mini oil mill for low worm pitch (P_1)

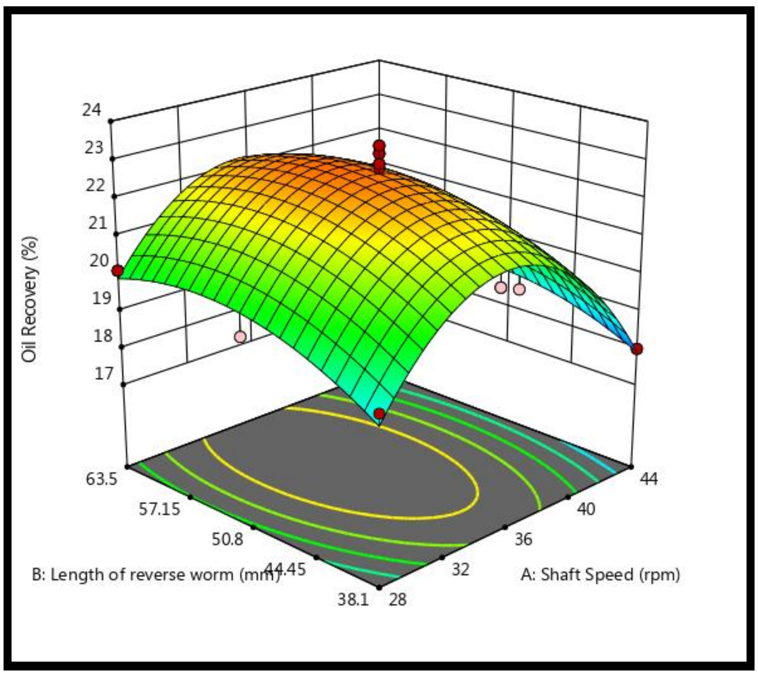


Fig 4.2 Effect of shaft speed (S) and length of reverse worm (R) on oil recovery of safflower seeds on mini oil mill for high worm pitch (P_2)

4.2.1.2 Response 2: Cake recovery, (%)

The experiments were conducted with various treatment combinations as given in Table 4.4 and show the effect of various levels of input parameters on cake recovery. The cake recovery was observed to be ranging between 74.56 to 81.99 %. The maximum cake recovery of 81.99 % was observed at 44 rpm shaft speed, 38.1 mm length of reverse worm and at worm pitch P_1. The minimum cake recovery of 81.99 % was observed at 36 rpm shaft speed and 50.8 mm length of reverse worm and at worm pitch P_2.

Table 4.4 Effect of various levels of input parameters on cake recovery of safflower seeds

Sr. No.	Run	Shaft speed, rpm	Length of reverse worm, Mm	Worm pitch	Cake recovery, %
		S	R	P	
1	20	28	63.5	High pitch	78.89
2	16	44	38.1	High pitch	81.01
3	13	36	50.8	Low pitch	77.47
4	18	36	50.8	High pitch	75.89
5	24	36	50.8	High pitch	75.82
6	11	36	50.8	Low pitch	76.91
7	21	36	63.5	High pitch	77.59
8	9	44	63.5	Low pitch	80.73
9	7	28	63.5	Low pitch	78.11
10	25	36	50.8	High pitch	**74.56**
11	15	36	38.1	High pitch	78.11
12	22	44	63.5	High pitch	80.21
13	14	28	38.1	High pitch	79.95
14	4	28	50.8	Low pitch	79.74
15	23	36	50.8	High pitch	76.91

16	19	44	50.8	High pitch	80.52
17	26	36	50.8	High pitch	76.05
18	12	36	50.8	Low pitch	75.97
19	6	44	50.8	Low pitch	81.21
20	10	36	50.8	Low pitch	77.67
21	17	28	50.8	High pitch	79.41
22	5	36	50.8	Low pitch	76.91
23	8	36	63.5	Low pitch	77.98
24	3	44	38.1	Low pitch	**81.99**
25	1	28	38.1	Low pitch	80.19
26	2	36	38.1	Low pitch	78

The analysis of variance (ANOVA) was carried out for the experimental data and the significance of shaft speed, length of reverse worm and worm pitch was analyzed. The response surface (3 level factorial) quadratic model was fitted to the experimental data and statistical significance of linear, interaction and quadratic terms were analyzed for cake recovery (Table 4.5). It revealed that the model was highly significant at 1 % level of significance and lack of fit was non-significant indicating that the model was quite adequate for predicting response.

Table 4.5 ANOVA for effect of machine/ process parameters on cake recovery for safflower seeds

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	87.34	8	10.92	17.76	< 0.0001	significant
A-Shaft Speed	7.33	1	7.33	11.92	0.0030	
B-Length of reverse worm	2.75	1	2.75	4.47	0.0497	
C-Worm Pitch	2.44	1	2.44	3.96	0.0628	
AB	0.1458	1	0.1458	0.2371	0.6325	

AC	0.4800	1	0.4800	0.7806	0.3893	
BC	0.0800	1	0.0800	0.1302	0.7227	
A^2	50.94	1	50.94	82.85	< 0.0001	
B^2	3.00	1	3.00	4.88	0.0412	
Residual	10.45	17	0.6149			
Lack of Fit	5.88	9	0.6530	1.14	0.4313	not significant
Pure Error	4.58	8	0.5720			
Cor Total	97.79	25				

Std. Dev.	0.7841	**R^2**	0.8931
Mean	78.38	**Adjusted R^2**	0.8428
C.V. %	1.3	**Predicted R^2**	0.7527
		Adeq Precision	12.5561

The analysis of variance (ANOVA) in Table 4.5 revealed that the model was highly significant at 1 % level of significance. The results showed that among linear effects, shaft speed had a significant effect on cake recovery (P<0.01) at 1 % level of significance followed by length of reverse worm and worm pitch. The existence of quadratic terms indicates the curvilinear nature of the response.

The quadratic response surface model data indicated the result as significant. The lack of fit was found to be non-significant and hence the model can be considered as quite adequate for predicting response. The coefficient of determination (R^2) was 0.8931 for cake recovery which indicated that the model could fit the data for cake recovery very well for all the three variables i.e. shaft speed, length of reverse worm, and pitch.

The response surface equation was obtained for the model of second degree in terms of coded factors as under:

Final equation in terms of coded factors

$$\text{Cake recovery, \%} = +76.64 + 0.7817\,X_1 - 0.4783\,X_2 - 0.3062\,X_3 + 1350\,X_1 X_2 - 0.2000\,X_1 X_3 - 0.0817\,X_2 X_3 + 3.04\,X_1^2 + 0.7369\,X_2^2 \qquad \text{……….4.4}$$

Where coded factors are:

X_1= Shaft speed, rpm
X_2 = Length of reverse worm, mm
X_3 = Worm Pitch, (P_1 low and P_2 high)

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.The response surface equation was obtained for the model of second degree in terms of actual factors as under,

For low worm pitch P_1,

$$\text{Cake recovery, \%} = +150.48133 - 3.36130S - 0.556116R - 0.001329SR + 0.047452S^2 + 0.004569\,R^2 \quad \text{……….4.5}$$

For high worm pitch P_2,

$$\text{Cake recovery, \%} = +151.01569 - 3.41130S - 0.543255R - 0.001329SR + 0.047452S^2 + 0.0045469\,R^2 \quad \text{……….4.6}$$

Where actual factors

S= Shaft speed, rpm

R = Length of reverse worm, mm

P = Pitch, (P_1low and P_2high)

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

4.2.1.2.1 Effect of shaft speed, length of reverse worm and worm pitch on cake recovery of safflower seeds

The linear positive terms and negative quadratic terms S and R indicated the cake recovery decreased initially with increase in shaft speed and length of reverse worm and thereafter increased as shown in Fig 4.3 and 4.4 for both the types of worm pitches. The cake recovery was found to be decreasing with increase in shaft speed.

The oil recovery was found low at low shaft speed, since the low shaft speed was insufficient to crush and extract oil from oil seed, resulting in high cake recovery. At low shaft speed the oil recovery dropped down whichmay be due even to the fact that longer residence time may allow re-absorption of the oil in thecake resulting in high cake recovery. As the shaft speed increased the cake recovery was decreased to some extent and it was minimum at medium shaft speed because at medium shaft speed, the oil recovery was more, because medium shaft speed was suitable for maximum crushing and oil extraction. Further with the increase in shaft speed, the cake recovery was found to be increased because of less exposure time for crushing and oil extraction of oil seeds, which decreases the oil recovery and thereby increases the cake recovery.

There was very less effect of length of reverse worm on cake recovery. The cake recovery was found to be more at low length of reverse worm because at low length of reverse worm, the reverse action performed by reverse worm is less, which results in less crushing and pressing of oil seeds that reduces oil recovery and thereby increases cake recovery. As the length of reverse worm increased the cake recovery was found to be decreased slightly and further increase of length of reverse worm was not having much effect on cake recovery. At medium length of reverse worm, the cake recovery was observed minimum. At maximum length of reverse worm, the cake recovery increased. This may be due to the fact that at maximum length of reverse worm, the reverse action is more, and time taken to move the feed forward was more, which resulted in higher residence time, and at higher residence time, the cake gets heated due to maximum friction and thereby re-absorption of oil in cake takes place, therefore cake recovery is more.

Further it was observed that at maximum length of reverse worm and minimum shaft speed, it created load on the machine, the cake was found to be hardened and even the machine vibrated heavily. Thus, the combination of maximum length of reverse worm and minimum shaft speed under study was not found suitable in case of both worm pitches P_1 and P_2. In this case for friction and heat was generated which is not desirable.

It was also observed that the high worm pitch $P_2$was most efficient worm pitch followed by low worm pitch P_1 pertaining to cake recovery with respect to various input parameters viz. shaft speed (S), length of reverse worm (R) because the high worm pitch moved the material 88 mm forward and low worm pitch moved the material 76 mm forward, which was less as compared to high more pitch and the low worm pitch also creates load on the machine due to less forward action as the feed takes longer time to pass and even gets stuck in low worm pitch.

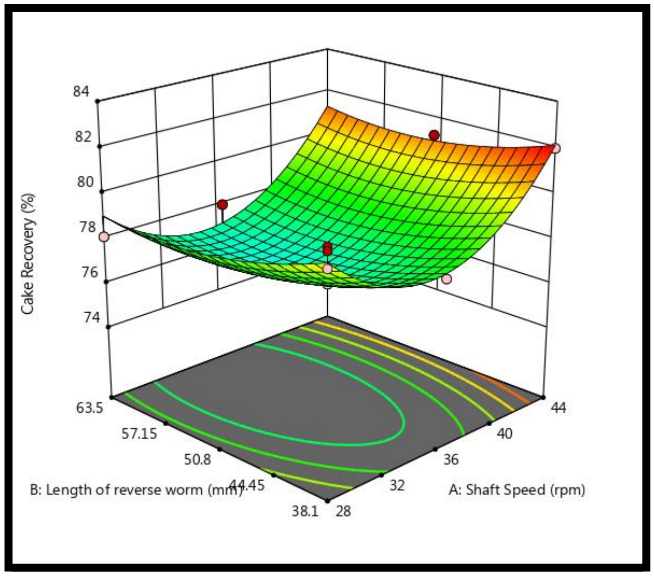


Fig 4.3 Effect of shaft speed (S) and length of reverse worm (R) on cake recovery of safflower seeds on mini oil mill for low worm pitch (P_1)

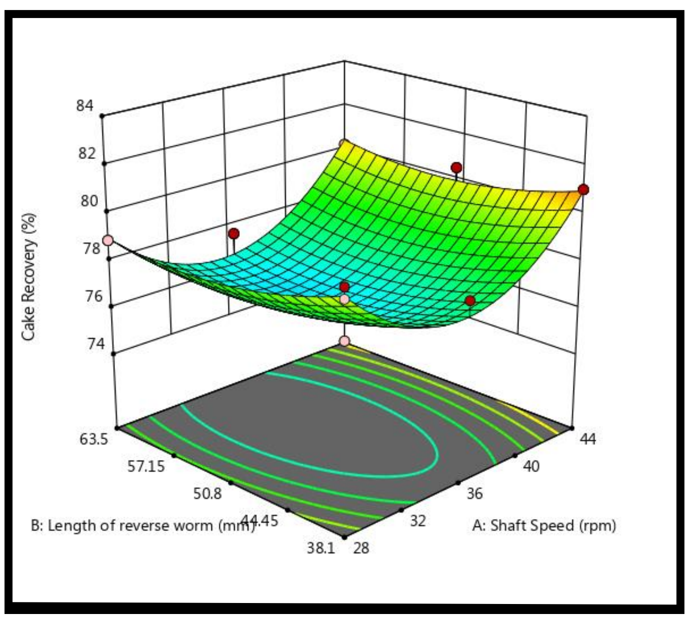


Fig 4.4 Effect of shaft speed (S) and length of reverse worm (R) on cake recovery of safflower seeds on mini oil mill for high worm pitch (P_2)

4.2.1.3 Response 3: Oil extraction efficiency, (%)

The experiments were conducted with various treatment combinations as given in Table 4.6 and show the effect of various levels of input parameters on oil extraction efficiency. The oil extraction efficiency was observed to be ranging between 63.96 to 86.59 %. The maximum oil extraction efficiency of 86.59 % was observed at 36 rpm shaft speed, 50.8 mm length of reverse worm and at high worm pitch P_2. The minimum oil extraction efficiency of 63.96 % was observed at 44 rpm shaft speed and 38.1 mm length of reverse worm and at low worm pitch P_1.

Table 4.6 Effect of various levels of input parameters on oil extraction efficiency, % of safflower seeds

Sr. No.	Run	Shaft speed, rpm	Length of reverse worm, Mm	Worm pitch	Oil extraction efficiency, %
		S	R	P	
1	20	28	63.5	High pitch	74.48
2	16	44	38.1	High pitch	66.62
3	13	36	50.8	Low pitch	79.74
4	18	36	50.8	High pitch	84.40
5	24	36	50.8	High pitch	85.85
6	11	36	50.8	Low pitch	82.92
7	21	36	63.5	High pitch	79.29
8	9	44	63.5	Low pitch	63.97
9	7	28	63.5	Low pitch	73.66
10	25	36	50.8	High pitch	**86.59**
11	15	36	38.1	High pitch	77
12	22	44	63.5	High pitch	69.59
13	14	28	38.1	High pitch	70.48
14	4	28	50.8	Low pitch	70.96
15	23	36	50.8	High pitch	83.37

16	19	44	50.8	High pitch	68.44
17	26	36	50.8	High pitch	84.85
18	12	36	50.8	Low pitch	84.40
19	6	44	50.8	Low pitch	66.62
20	10	36	50.8	Low pitch	80.25
21	17	28	50.8	High pitch	72.55
22	5	36	50.8	Low pitch	81.51
23	8	36	63.5	Low pitch	78.25
24	3	44	38.1	Low pitch	**63.96**
25	1	28	38.1	Low pitch	69.66
26	2	36	38.1	Low pitch	74.48

The analysis of variance (ANOVA) was carried out for the experimental data and the significance of shaft speed, length of reverse worm and worm pitch was analyzed. The response surface (3 level factorial) quadratic model was fitted to the experimental data and statistical significance of linear, interaction and quadratic terms were analyzed for oil extraction efficiency (Table 4.7). It revealed that the model was highly significant at 1 % level of significance and lack of fit was non-significant indicating that the model was quite adequate for predicting response.

Table 4.7 ANOVA for effect of machine/ process parameters on oil extraction efficiency for safflower seeds

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	1222.45	8	152.81	38.51	< 0.0001	significant
A-Shaft Speed	88.52	1	88.52	22.31	0.0002	
B-Length of reverse worm	20.16	1	20.16	5.08	0.0377	
C-Worm Pitch	38.48	1	38.48	9.70	0.0063	
AB	3.17	1	3.17	0.7993	0.3838	

AC	3.95	1	3.95	0.9967	0.3321	
BC	0.7316	1	0.7316	0.1844	0.6730	
A^2	698.91	1	698.91	176.14	< 0.0001	
B^2	58.95	1	58.95	14.86	0.0013	
Residual	67.45	17	3.97			
Lack of Fit	46.41	9	5.16	1.96	0.1780	not significant
Pure Error	21.05	8	2.63			
Cor Total	1289.91	25				

Std. Dev.	1.99	**R^2**	0.9477
Mean	75.98	**Adjusted R^2**	0.9231
C.V. %	2.62	**Predicted R^2**	0.8688
		Adeq Precision	17.6272

The analysis of variance (ANOVA) in Table 4.7 revealed that the model was highly significant at 1 % level of significance. The results showed that among linear effects, shaft speed was more effective on oil extraction efficiency followed by worm pitch and length of reverse worm. The existence of quadratic terms indicates the curvilinear nature of the response.

The quadratic response surface model data indicated the result as significant. The lack of fit was found to be non-significant and hence the model can be considered as quite adequate for predicting response. The coefficient of determination (R^2) was 0.9477 for oil extraction efficiency which indicated that the model could fit the data for oil extraction efficiency very well for all the three variables i.e. shaft speed, length of reverse worm, and pitch. The response surface equation was obtained for the model of second degree in terms of coded factors as under:

Final equation in terms of coded factors

Oil extraction efficiency, (%)= $+82.68- 2.72+ 1.30X_2+ 1.22\ X_3- 0.6296\ X_1\ X_2+ 0.5741\ X_1\ X_3 + 0.2469\ X_2\ X_3- 11.25\ X_1^2-3.27\ X_2^2$ ……….4.7

Where coded factors are:

X_1= Shaft speed, rpm

X_2 = Length of reverse worm, mm

X_3 = Pitch, (P_1 low and P_2 high)

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. The response surface equation was obtained for the model of second degree in terms of actual factors as under,

For Worm pitch P_1,

Oil extraction efficiency, (%) = $-199.31332 + 12.5580S + 2.36363R - 0.0006197SR - 0.175756S^2 - 20.16089\, R^2$ ……….4.8

For Worm pitch P_2,

Oil extraction efficiency,(%) = $-204.02225 + 12.70152S + 2.40251R - 0.006197SR - 0.175756S^2 - 0.020255\, R^2$ ……….4.9

Where actual factors

S= Shaft speed, rpm

R = Length of reverse worm, mm

P = Pitch, (P_1low and P_2 high)

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

4.2.1.3.1 Effect of shaft speed, length of reverse worm and worm pitch on oil extraction efficiency of safflower seeds

The linear positive terms and negative quadratic terms S and R indicated the oil extraction efficiency increased initially with increase in shaft speed and length of reverse worm and thereafter decreased as shown in Fig 4.5 and 4.6 for both the types of worm pitches. The oil extraction efficiency was found to be increased with increase in shaft speed. At minimum shaft speed, the oil extraction efficiency was less because the low shaft speed was less effective in crushing and oil extraction, which resulted in low oil recovery and thereby resulting in low oil extraction efficiency. Oil extraction efficiency further increased upto certain limit and was maximum at medium shaft speed. This may be due to the fact that medium shaft speed was effective in crushing and pressing oil seeds to extract oil, therefore oil recovery was more and thus oil extraction efficiency was also more. The oil extraction efficiency was found to be decreased with further increase in shaft speed, because at higher shaft speed, the seeds get less time to pass through the oil extraction chamber, resulting in less and non-uniform crushing and pressing, therefore the oil recovery was found to be low, thereby resulting in low oil extraction efficiency.

There was very less effect of length of reverse worm on oil extraction efficiency. The oil extraction efficiency was found to be less at low length of reverse worm, because at low length of reverse worm, the reverse action was less, therefore the crushing and pressing of oil seeds was less, and even the oil recovery was less thereby resulting in less oil extraction efficiency. As the length of reverse worm increased, oil extraction efficiency increased upto certain limit and was maximum at medium length of reverse worm because this length of reverse worm had an effective reverse action on the oil seeds and crushed the oil seeds to extract oil, thus the oil recovery increased, and thereby resulted in maximum oil extraction efficiency. As the length of reverse worm increased above medium length, the oil extraction efficiency decreased. At maximum length of reverse worm, the oil extraction efficiency decreased. This may be due to the fact that at maximum length of reverse worm, even though the reverse action is more, the friction is generated and residence time is more so reabsorption of oil in cake occurs thereby reducing oil recovery and thus reduced oil extraction efficiency.

Further it was observed that at maximum length of reverse worm and minimum shaft speed, it created load on the machine, the cake was found to be hardened and even the machine vibrated heavily. Thus, the combination of maximum length of reverse worm and minimum shaft speed under study was not found suitable in case of both worm pitches P_1 and P_2. In this case for friction and heat was generated which is not desirable.

It was also observed that the high worm pitch P_2 was most efficient worm pitch followed by low worm pitch P_1 pertaining to oil extraction with respect to shaft speed (S) and length of reverse worm (R) because the high pitch worm moved the feed 88 mm forward and low pitch worm moved the feed 76 mm forward. The high pitch worm moved the feed forward efficiently as compared to low pitch worm.

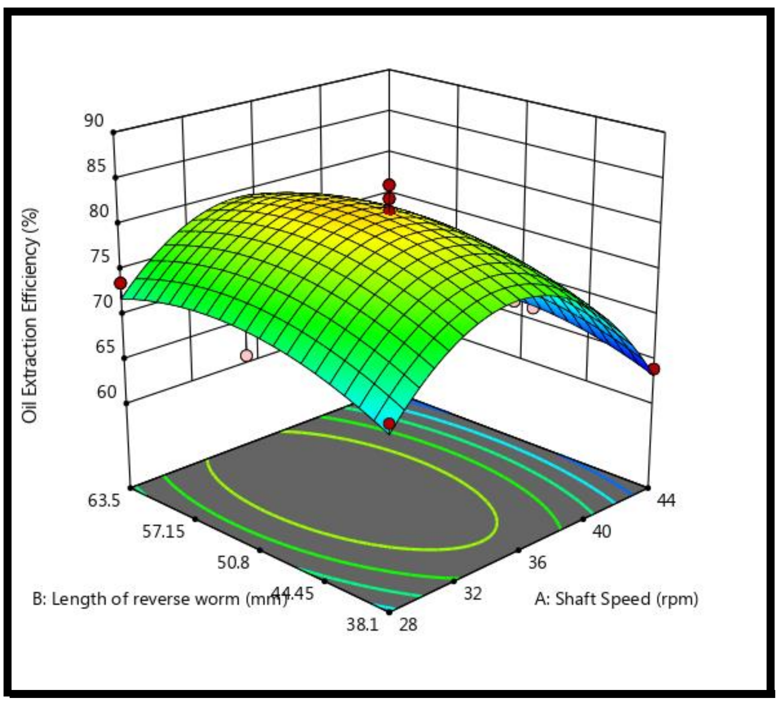


Fig 4.5 Effect of shaft speed (S) and length of reverse worm (R) on Oil extraction efficiency (%) of safflower seeds on mini oil mill for low worm pitch (P_1)

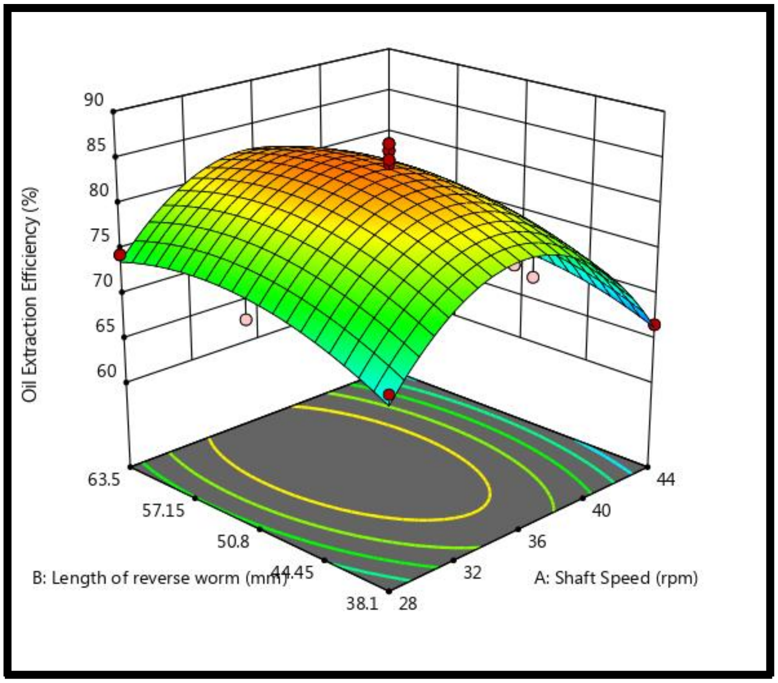


Fig 4.6 Effect of shaft speed (S) and length of reverse worm (R) on Oil extraction efficiency (%) of safflower seeds on mini oil mill for high worm pitch (P_2)

4.2.1.4 Response 4: Feed rate, kg/h

The experiments were conducted with various treatment combinations as given in Table 4.8 shows the effect of various levels of input parameters on feed rate. The feed rate was observed ranging between 42.85 to 128.57 kg/h. The maximum feed rate of 128.57 kg/h was observed at 44 rpm shaft speed, 38.1 mm length of reverse worm and at worm pitch P_2. The minimum feed rate of 42.85 kg/h was observed at 28 rpm shaft speed and 63.5 mm length of reverse worm and at worm pitch P_1.

Table 4.8 Effect of various levels of input parameters on feed rate (kg/h), of safflower seeds

Sr. No.	Run	Shaft speed, rpm	Length of reverse worm, mm	Worm pitch	Feed rate, kg/h
		S	R	P	
1	20	28	63.5	High pitch	50
2	16	44	38.1	High pitch	**128.57**

3	13	36	50.8	Low pitch	60.81
4	18	36	50.8	High pitch	71.42
5	24	36	50.8	High pitch	72.58
6	11	36	50.8	Low pitch	60
7	21	36	63.5	High pitch	69.23
8	9	44	63.5	Low pitch	75
9	7	28	63.5	Low pitch	**42.85**
10	25	36	50.8	High pitch	73.77
11	15	36	38.1	High pitch	90
12	22	44	63.5	High pitch	100
13	14	28	38.1	High pitch	64.28
14	4	28	50.8	Low pitch	47.36
15	23	36	50.8	High pitch	75.63
16	19	44	50.8	High pitch	112.5
17	26	36	50.8	High pitch	74.93
18	12	36	50.8	Low pitch	63.82
19	6	44	50.8	Low pitch	90
20	10	36	50.8	Low pitch	62.5
21	17	28	50.8	High pitch	56.25
22	5	36	50.8	Low pitch	62.93
23	8	36	63.5	Low pitch	56.25
24	3	44	38.1	Low pitch	100
25	1	28	38.1	Low pitch	52.94
26	2	36	38.1	Low pitch	69.23

The analysis of variance (ANOVA) was carried out for the experimental data and the significance of shaft speed, worm pitch and length of reverse worm was analyzed. The response surface (3 level factorial) quadratic model was fitted to the experimental data and statistical significance of interaction and quadratic terms were analyzed for feed rate (Table 4.9). It revealed that the model was highly significant at 1 % level of significance and lack of fit was non-significant indicating that the model was quite adequate for predicting response.

Table 4.9 ANOVA for effect of machine/ process parameters on feed rate kg/h for safflower seeds

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	10373.25	8	1296.66	229.80	< 0.0001	significant
A-Shaft Speed	7123.30	1	7123.30	1262.42	< 0.0001	
B-Length of reverse worm	1039.58	1	1039.58	184.24	< 0.0001	
C-Worm Pitch	1469.41	1	1469.41	260.41	< 0.0001	
AB	106.59	1	106.59	18.89	0.0004	
AC	197.66	1	197.66	35.03	< 0.0001	
BC	20.18	1	20.18	3.58	0.0758	
A^2	283.38	1	283.38	50.22	< 0.0001	
B^2	18.11	1	18.11	3.21	0.0910	
Residual	95.92	17	5.64			
Lack of Fit	74.36	9	8.26	3.07	0.0647	not significant
Pure Error	21.56	8	2.69			
Cor Total	10469.17	25				

Std. Dev.	2.38	**R^2**	0.9908
Mean	72.42	**Adjusted R^2**	0.9865
C.V. %	3.28	**Predicted R^2**	0.9745
		Adeq Precision	58.9443

The analysis of variance (ANOVA) in Table 4.9 revealed that the model was highly significant at 1 % level of significance. The results showed that among linear effects, shaft speed, length of reverse worm and worm pitch had a significant effect on feed rate ($P<0.01$) at 1 % level of significance. The existence of quadratic terms indicates the linear nature of the response.

The quadratic response surface model data indicated the result as significant. The lack of fit was found to be non-significant and hence the model can be considered as quite adequate for predicting response. The coefficient of determination (R^2) was 0.9908 for feed rate which indicated that the model could fit the data for feed rate very well for all the three variables i.e. shaft speed, length of reverse worm, and pitch.

The response surface equation was obtained for the model of second degree in terms of coded factors as under:

Final equation in terms of coded factors

$$\text{Feed rate, (kg/h)} = +68.28 + 24.36\,X_1 - 9.31X_2 + 7.52\,X_3 - 3.65\,X_1\,X_2 + 4.06\,X_1\,X_3 - 1.30\,X_2\,X_3 + 7.16\,X_1^2 + 1.81\,X_2^2 \quad \text{..........4.10}$$

Where coded factors are:

X_1= Shaft speed, rpm

X_2 = Length of reverse worm, mm

X_3 = Pitch, (P_1 low and P_2 high)

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. The response surface equation was obtained for the model of second degree in terms of actual factors as under,

For low worm pitch P_1,

$$\text{Feed rate, kg/h} = +109.73859 - 3.69453S - 12.14245R - 0.912553SR + 0.111914S^2 + 7.24319\,R^2 \quad \text{..........4.11}$$

For high worm pitch P_2,

$$\text{Feed rate, kg/h} = +98.62514 - 2.67990S - 17.32964R - 0.912553SR + 0.111914S^2 + 7.24319\,R^2 \quad \text{..........4.12}$$

Where actual factors

S= Shaft speed, rpm

R = Length of reverse worm, mm

P = Pitch, (P_1low and P_2 high)

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

4.2.1.4.1 Effect of shaft speed, length of reverse worm and worm pitch on feed rate kg/h of safflower seeds

The effect of shaft speed, length of reverse worm and worm pitch on feed rate was determined as shown in fig 4.7 and fig 4.8. Three dimensional responses for feed rate of samples were generated. From these surfaces, it could be evident that feed rate increased with increasing the shaft speed. It may be due to the reason that at minimum shaft speed, the material moves at a slow speed inside the casing, and thus less material is passed in more time, hence feed rate was less. At maximum shaft speed, the material moves at a fast speed inside the casing, and thus more material is passed in less time, hence feed rate was more.

Considering length of reverse worm, the feed rate decreased with the increase in length of reverse worm. This may be due to the fact that at minimum length of reverse worm, the material gets less time to crush and press, and hence more material is passed in less time, hence in this case the feed rate was more. At maximum length of reverse worm, the material gets more time to crush and press, and hence less material is passed in more time, hence in this case the feed rate was less.

It was also observed that the high worm pitch $P_2$was most efficient worm pitch followed by low worm pitch $P_1$of worm pitch pertaining to feed rate. The feed rate was maximum for worm pitch $P_2$and minimum for worm pitch P_1, since the low worm pitch P_1 pushed the material 76 mm forward in one revolution and the high worm pitch P_2 pushed the material 88 mm forward in one revolution.

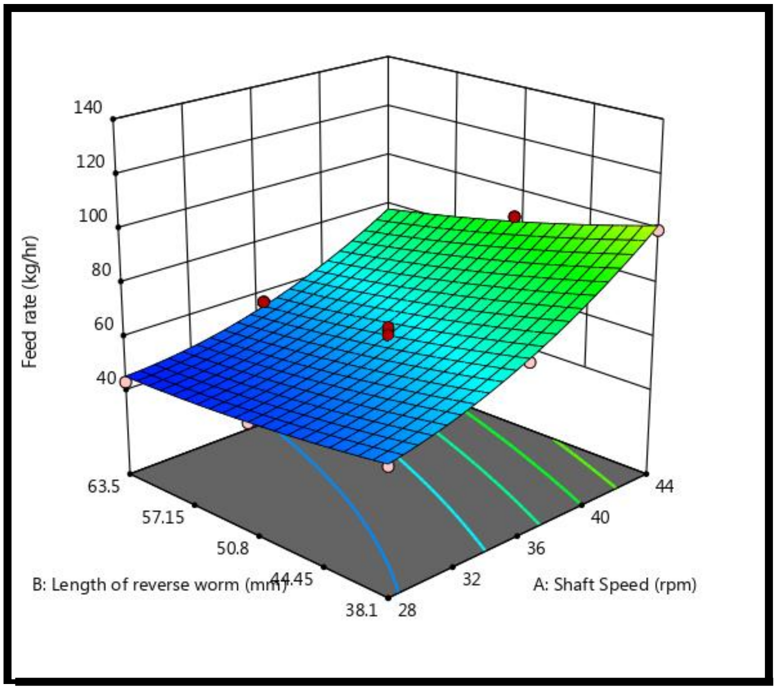


Fig 4.7 Effect of shaft speed (S) and length of reverse worm (R) on Feed rate, kg/h of safflower seeds on mini oil mill for low worm pitch (P_1)

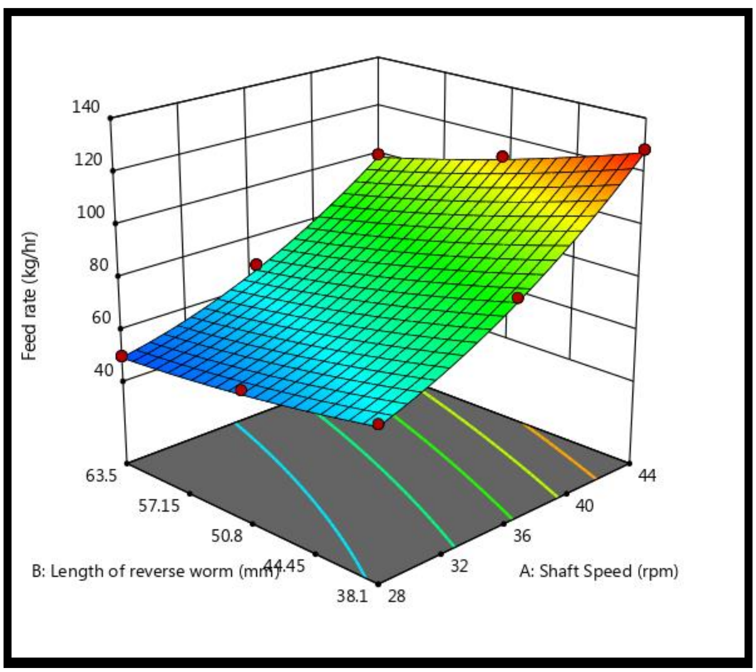


Fig 4.8 Effect of shaft speed (S) and length of reverse worm (R) on Feed rate, kg/h of safflower seeds on mini oil mill for high worm pitch (P_2)

4.2.1.5 Response 5 : Deficit oil yield, %

The experiments were conducted with various treatment combinations as given in Table 4.8 and show the effect of various levels of input parameters on deficit oil yield. The deficit oil yield was observed to be ranging between 3.62 to 9.74%. The maximum deficit oil yield of 9.74% was observed at 44 rpm shaft speed, 38.1 mm length of reverse worm and at worm pitch P_1. The minimum deficit oil yield of 3.62 % was observed at 36 rpm shaft speed and 50.8 mm length of reverse worm and at worm pitch P_2.

Table 4.10 Effect of various levels of input parameters on deficit oil yield (%)

Sr. No.	**Run**	**Shaft speed, rpm**	**Length of reverse worm, mm**	**Worm pitch**	**Deficit oil yield, %**
		S	**R**	**P**	
1	20	28	63.5	High pitch	6.89
2	16	44	38.1	High pitch	9.01
3	13	36	50.8	Low pitch	5.47
4	18	36	50.8	High pitch	4.21
5	24	36	50.8	High pitch	3.82
6	11	36	50.8	Low pitch	4.61
7	21	36	63.5	High pitch	5.59
8	9	44	63.5	Low pitch	9.73
9	7	28	63.5	Low pitch	7.11
10	25	36	50.8	High pitch	**3.62**
11	15	36	38.1	High pitch	6.21
12	22	44	63.5	High pitch	8.21
13	14	28	38.1	High pitch	7.97
14	4	28	50.8	Low pitch	7.84
15	23	36	50.8	High pitch	4.49
16	19	44	50.8	High pitch	8.52

17	26	36	50.8	High pitch	4.09
18	12	36	50.8	Low pitch	4.21
19	6	44	50.8	Low pitch	9.01
20	10	36	50.8	Low pitch	5.33
21	17	28	50.8	High pitch	7.41
22	5	36	50.8	Low pitch	4.99
23	8	36	63.5	Low pitch	5.87
24	3	44	38.1	Low pitch	**9.74**
25	1	28	38.1	Low pitch	8.19
26	2	36	38.1	Low pitch	6.49

The analysis of variance (ANOVA) was carried out for the experimental data and the significance of shaft speed, length of reverse worm and worm pitch was analyzed. The response surface (3 level factorial) quadratic model was fitted to the experimental data and statistical significance of linear, interaction and quadratic terms were analyzed for deficit oil yield (Table 4.11). It revealed that the model was highly significant at 1 % level of significance and lack of fit was non-significant indicating that the model was quite adequate for predicting response.

Table 4.11 ANOVA for effect of machine/ process parameters on percent deficit oil yieldfor safflower seeds

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	89.12	8	11.14	38.51	< 0.0001	significant
A-Shaft Speed	6.45	1	6.45	22.31	0.0002	
B-Length of reverse worm	1.47	1	1.47	5.08	0.0377	
C-Worm Pitch	2.81	1	2.81	9.70	0.0063	
AB	0.2312	1	0.2312	0.7993	0.3838	
AC	0.2883	1	0.2883	0.9967	0.3321	

BC	0.0533	1	0.0533	0.1844	0.6730	
A^2	50.95	1	50.95	176.14	< 0.0001	
B^2	4.30	1	4.30	14.86	0.0013	
Residual	4.92	17	0.2893			
Lack of Fit	3.38	9	0.3759	1.96	0.1780	not significant
Pure Error	1.53	8	0.1918			
Cor Total	94.03	25				

Std. Dev.	0.5378	**R^2**	0.9477
Mean	6.49	**Adjusted R^2**	0.9231
C.V. %	8.29	**Predicted R^2**	0.8688
		Adeq Precision	17.6272

The analysis of variance (ANOVA) in Table 4.11 revealed that the model was highly significant at 1 % level of significance. The results showed that among linear effects, shaft speed, length of reverse worm had a significant effect on percent deficit oil yield($P<0.01$) at 1 % level of significance followed by worm pitch. The existence of quadratic terms indicates the linear nature of the response.

The quadratic response surface model data indicated the result as significant. The lack of fit was found to be non-significant and hence the model can be considered as quite adequate for predicting response. The coefficient of determination (R^2) was 0.9477 for percent deficit oil yield which indicated that the model could fit the data for percent deficit oil yield very well for all the three variables i.e. shaft speed, length of reverse worm, and pitch. The percent deficit oil yield was found to be maximum for level 2 of pitch i.e. for high worm pitch P_2.

The response surface equation was obtained for the model of second degree in terms of coded factors as under:

Final equation in terms of coded factors

$$\text{Deficit oil yield, \%} = +4.68 + 0.7333\,X_1 - 0.3500X_2 - 0.3285\,X_3 + 0.1700\,X_1X_2 - 0.1550\,X_1X_3 - 0.0667\,X_2X_3 + 3.04\,X_1^2 + 0.8821X_2^2 \qquad \ldots\ldots\ldots 4.13$$

Where coded factors are:

X_1= Shaft speed, rpm

X_2 = Length of reverse worm, mm

X_3 = Pitch, (P_1 low and P_2 high)

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.The response surface equation was obtained for the model of second degree in terms of actual factors as under,

For Worm pitch P_1,

$$\text{Deficit oil yield, \%} = +80.81460 - 3.39066S - 0.638180R + 0.001673SR + 0.047454S^2 - 0.005469R^2 \quad \text{……….4.14}$$

For Worm pitch P_2,

$$\text{Deficit oil yield, \%} = +82.08601 - 3.42941S - 0.648679R + 0.001673SR + 0.047454S^2 - 0.005469R^2 \quad \text{……….4.15}$$

Where actual factors

S= Shaft speed, rpm

R = Length of reverse worm, mm

P = Pitch, (P_1low and P_2high)

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

4.2.1.5.1 Effect of shaft speed, length of reverse worm and worm pitch on deficit oil yield of safflower seeds

The linear positive terms and negative quadratic terms S and R indicated the deficit oil yield decreased initially with increase in shaft speed and thereafter increased as shown in Fig 4.9 and 4.10 for both the types of pitch. The deficit oil yield was found to be decreasing with increase in shaft speed. At low shaft speed the deficit oil yield was high. This may be due to the fact that low shaft was insufficient to crush and extract oil from oil seed, thus more oil is retained in resulting in more deficit oil yield. As the shaft speed increased, the deficit oil yield was decreased to some extent and was minimum at medium shaft speed. This may be due to the fact that medium shaft speed was suitable for maximum crushing and oil extraction, thus the oil extraction was more, resulting in less oil in cake, thus low deficit oil yield. The deficit oil yield was found to be increased with increase in shaft speed. This may be because at high shaft speed, the material gets less time to crush and press and extract oil from seed thus less oil is extracted, and more oil is retained in cake, resulting in high deficit oil yield.

There was very less effect of length of reverse worm on deficit oil yield. The deficit oil yield was more at minimum length of reverse worm. This may be due to the fact that at minimum length of reverse worm, the seeds get less reverse action, and thus the oil extracted is less, and more oil is retained in cake resulting in more deficit oil yield. The deficit oil yield was minimum at medium length of reverse worm, since at medium length of reverse worm, the reverse action was sufficient enough to extract oil, resulting in high oil recovery and less oil in cake, thus low deficit oil yield. The deficit oil yield increased with further increase in shaft speed. At maximum length of reverse worm, the deficit oil yield was more. This may be due to the fact that at maximum length of reverse worm, the material gets more reverse action, resulting in friction and re-absorption of oil in cake due to more residence time, thus resulting in high deficit oil yield.

Further it was observed that at maximum length of reverse worm and minimum shaft speed, it created load on the machine, the cake was found to be hardened and even the machine vibrated heavily. Thus, the combination of maximum length of reverse worm and minimum shaft speed under study was not found suitable in case of both worm pitches P_1 and P_2. In this case because of friction heat was generated which is not desirable.

It was also observed that the worm pitch $P_2$was most efficient worm pitch followed by worm pitch P_1pertaining to deficit oil yield with respect to various input parameters viz. shaft speed (S), length of reverse worm (R) since the low worm pitch P_1 pushed the material 76 mm forward in one revolution and the high worm pitch P_2 pushed the material 88 mm forward in one revolution.

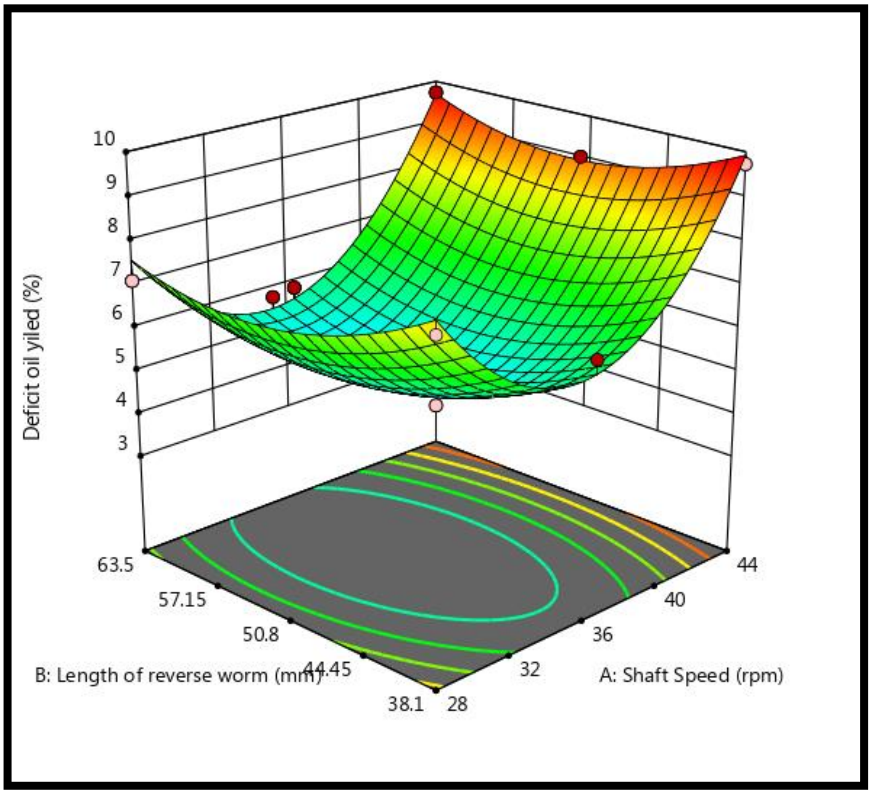


Fig 4.9 Effect of shaft speed (S) and length of reverse worm (R) on deficit oil yield of safflower seeds on mini oil mill for low worm pitch (P_1)

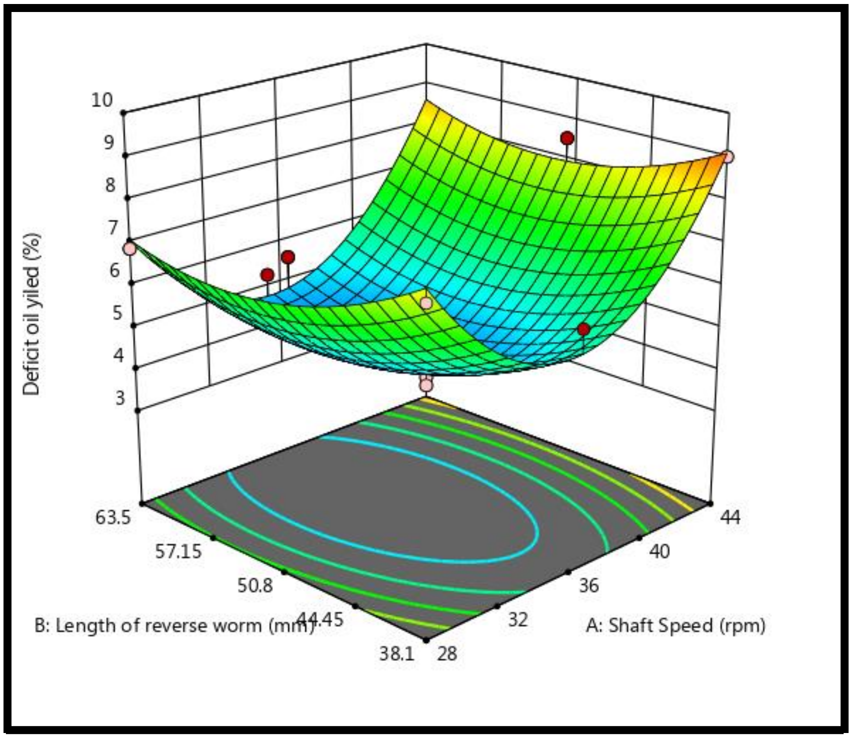


Fig 4.10 Effect of shaft speed (S) and length of reverse worm (R) on deficit oil yield of safflower seeds on mini oil mill for high worm pitch (P_2)

4.2.2 Numerical optimization

In order to optimize the input parameters for oil extraction of safflower seeds by numerical optimization which finds a point that maximizes the desirability function equal importance of 3 was given to all 3 input parameters and 5 responses. The main criteria for optimization was maximum oil recovery, oil extraction efficiency and minimum cake recovery, and feed rate, deficit oil yield in range, and all the input parameters in range. The optimization criteria for different input parameters and responses constraints are as shown in Table 4.12

Table 4.12 Optimization criteria for different input parameters and response constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Shaft Speed	is in range	28	44	1	1	3

B:Length of reverse worm	is in range	38.1	63.5	1	1	3
C:Worm Pitch	is in range	Low pitch	High pitch	1	1	3
Oil Recovery	maximize	17.27	23.38	1	1	3
Cake Recovery	minimize	74.56	81.99	1	1	3
Oil Extraction Efficiency	maximize	63.96	86.59	1	1	3
Feed rate	is in range	42.85	128.57	1	1	3
Deficit oil yield	is in range	4.91	4.26	1	1	3

Software generated optimum condition of independent variables with the predicted values of responses are as below (Table 4.13). Software Design Expert version 10.0.6 was used for optimization of the responses. A stationary point at which the slope of response surface was zero in all the direction was calculated by partially differentiating the model with respect to each variable, equating these derivatives to zero and simultaneously solving the resulting equations. The optimum value for different variables and their predicted responses thus obtained are given in Table 4.13.

Table 4.13 Optimized variables and their predicted responses for oil extraction from safflower seeds for high worm pitch P_2

Variable	**Optimized Value**	**Responses**	**Predicted Value**
Shaft Speed, rpm	35.182	Oil recovery,%	22.733
Length of reverse worm, mm	54.006	Cake recovery, %	76.245
Worm pitch	Level 2 (P_2)	Oil extraction efficiency, %	84.195

		Feed rate, kg/h	70.498
		Deficit oil yield, %	4.267

The optimum values of different variables for oil extraction were found to be in the range considered in the study.

4.2.3 Graphical optimization

The graphical multi response optimization technique was adapted to determine the workable optimum machine parameters for the mini oil mill. The contour plots for all the responses were superimposed and regions that best satisfied all the constraints were selected as optimum condition. The criteria for optimization are already given in Table 4.12. These constraints resulted in feasible zones of the optimum solutions (yellow coloured area in the superimposed plots). Superimposed contour plots having common superimposed area for all the responses for mini oil mill are shown in Fig. 4.11. The superimpose contours for responses and their intersection for maximum oil extraction efficiency Fig. 4.11 indicated that the range of optimum values of process variables.

The superimposed contours of all the responses for shaft speed (rpm) and length of reverse worm (mm) along with their intersection zones for maximum oil recovery, oil extraction efficiency, minimum cake recovery and feed rate, deficit oil yield in range indicated the range of optimum values of process variables.

The optimum values obtained from superimpose contours in the range are given below:

1. Shaft Speed, rpm : 32.91- 37.60
2. Length of reverse worm, mm :46.54 - 61.29
3. Worm pitch : P_2(High)

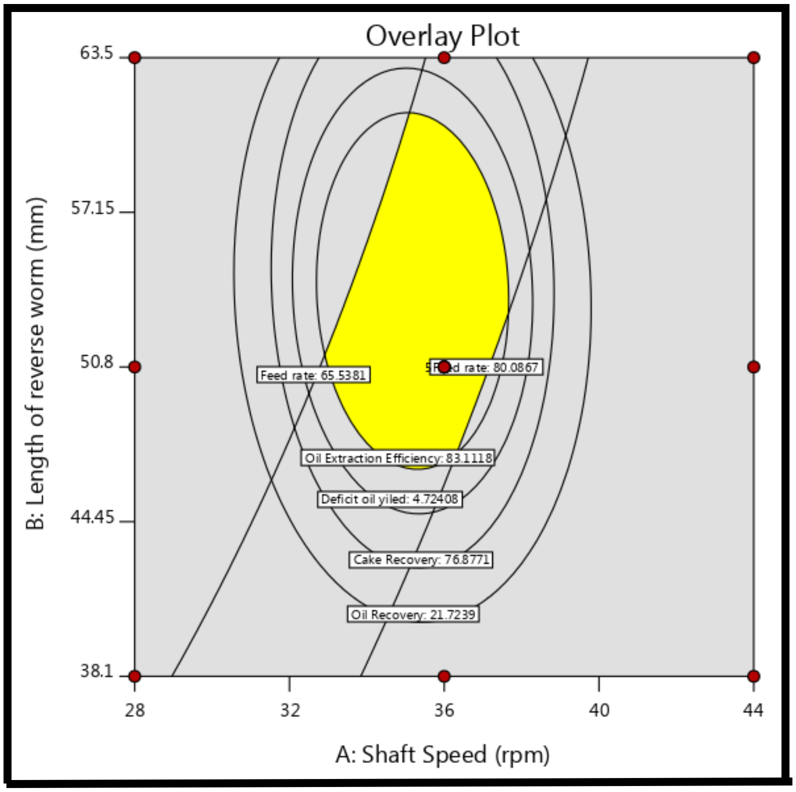


Fig.4.11 Superimposed Contours for oil recovery, cake recovery, oil extraction efficiency, feed rate and deficit oil yield

4.2.4 Verification of the model for oil extraction

The performance of the model was also verified by conducting the experiments for validation. The optimize value of different variable viz. shaft speed 35.182 rpm, length of reverse worm 54.006 mm for high worm pitch $P_2$are practically difficult to achieve. So we considered practically available variables as shaft speed 36 rpm, length of reverse worm 50.8 mm and conducted oil extraction efficiency experiment repeated thrice. The average values of three experiments are given in Table 4.15.It could be revealed that the experimental values were very close to the predicated values which confirm that the model was quite adequate to predict response. Hence the optimized combinations of input parameter can be considered.

Table 4.14 Predicted and Experimental values of Responses at optimum level of input variables

Sr. No.	Responses	Predicted values	Experimental values ($\pm$ SD)
1	Oil recovery, %	22.733	21.88±0.437
2	Cake recovery, %	76.245	77.20±0.46
3	Oil extraction efficiency, %	84.195	82.83±0.29
4	Feed rate, kg/h	70.498	69.95±0.14
5	Deficit oil yield, %	4.267	4.34±0.07

The parameters were modified with a view for higher oil recovery, oil extraction efficiency and lower cake recovery and the input parameters were optimized to shaft speed 36 rpm, length of reverse worm 50.8 mm and high worm pitch P_2 and the response parameters were observed. At traditionally used shaft speed 44 rpm, length of reverse worm 63.5 mm and low worm pitch P_1. The responses corresponding to traditionally and modified used input parameters are given in Table 4.15.:

Table 4.15 Responses corresponding to traditionally and modified used input parameters

	Input parameters			**Responses**				
	Shaft speed, rpm	**Length of reverse worm, mm**	**Worm pitch**	**Oil recovery, %**	**Cake recovery, %**	**Oil extraction efficiency, %**	**Feed rate, kg/h**	**Deficit oil yield, %**
Traditionally used	44	63.5	Low	17.27	80.73	63.97	75	9.73
Modified (optimized)	36	50.8	High	22.73	76.25	84.20	70.50	4.27

4.3 Physicochemical properties of safflower oil

The samples of oil extracted from mini oil mill were analyzed from the Mantri lab for physicochemical properties. Two samples of oil extracted at optimum shaft speed and length of reverse worm were analyzed for both the worm pitches i.e. P_1(low) and P_2(high). The results of physicochemical properties of safflower oil obtained for both the worm pitches are as follows (Table 4.16):

Table 4.16 Physicochemical properties of safflower oil

Sr.no.	Physicochemical properties	For Worm Pitch P_1(low)	For Worm Pitch P_2 (high)	Values (FSSAI mannual, 2011)
1.	Saponification value	190	188	186-196
2.	Iodine value	124	120	100-135
3.	Free fatty acid,%	0.44	0.33	Not more than 6.0
4.	Peroxide value, meq/kg	4.74	5.40	Upto 15 meq/kg
5.	Viscosity @ 40°C, cSt	22.6	23.7	
6.	Polyunsaturated fatty acid,%	89.5	88.9	-
7.	Monounsaturated fatty acid,%	0.7	1.1	-

CHAPTER V

SUMMARY AND CONCLUSION

Safflower is a multiple purpose crop generally grown for oil production. The safflower oil is considered to be a better oil since it contains higher amount of oleic and linoleic acids than other oil seed crops. Safflower oil has numerous applications in food, cosmetics, pharmaceutical and feed industry. An added advantage of safflower oil is lower cost of production thus can become an alternate option for those who cannot afford to buy olive and other functional oils(Khalid, *et al.*,2017).

At present the oil is being highly adulterated by mixing various low quality seed oils. For refining oil and for maximizing oil yield various harmful chemicals are being used. Oil extracted at lower temperature has better health characteristics. The shaft speed, length of reverse worm and pitch of worm has a positive effect on oil recovery. Higher capacities oil extraction machines are available but rare work has been carried out on small capacity oil extraction machine. Modifications in mini oil mill will ensure efficient working resulting in production of non-adulterated oil at farm level. Hence the efforts were made to explore possibilities of increasing oil extraction efficiency and oil recovery and thereby modifying mini oil mill.Hence considering the above issues a research project on modification and performance evaluation of mini oil mill has been carried out.

The study was extended to examine the effect of parameters such as shaft speed, length of reverse worm and worm pitch on the quantity oil extracted. A mini oil mill was powered by a 5 hp three phase electric AC motor and was evaluated for its performance with regards of oil recovery, cake recovery, oil extraction efficiency, feed rate and deficit oil yield.

The oil recovery was found to be significantly different for various shaft speed, length of reverse worm as well as worm pitch. The performance of the machine was evaluated at 3 shaft speeds 28 rpm, 36 rpm, 44 rpm and at 3 length of reverse worm 38.1 mm, 50.8 mm and 63.5 mm for 2 worm pitch i.e. P_1(low pitch) and P_2(high pitch). Three level factorial reduced cubic model of response surface methodology by using Design Expert Software was used to optimize machine parameters for better oil recovery, oil extraction efficiency and lower cake recovery. A shaft speed of 36 rpm, length of reverse worm of 50.8 mm and worm pitch P_2 (high pitch) was found to favour the oil extraction, while a oil recovery of 22.73%, cake recovery of 76.25 %, oil extraction efficiency of 84.20% & feed rate of 70.50 kg/hour, deficit oil yield of 4.27 % was observed.

Following observations from the present study:

1. The capacity of the machine increases with increasing shaft speed and length of reverse worm within a selected range of shaft speed.
2. At the shaft speed and length of reverse worm middle level of selected range i.e at 36 rpm shaft speed and 50.8 mm length of reverse worm gives maximum oil recovery, oil extraction efficiency and minimum cake recovery.
3. Oil recovery, oil extraction efficiency was found to be maximum for worm pitch P_2, the cake recovery was found to be minimum for worm pitch P_2 (high pitch).
4. The feed rate was found to be maximum for maximum level of shaft speed and minimum level of length of reverse worm and for worm pitch P_2 (high pitch).
5. The deficit oil yield was analyzed by using soxlet apparatus and found to be maximum for maximum level of shaft speed and minimum level of length of reverse worm.
6. Maximum oil extraction efficiency was found at worm pitch P_2 (high pitch) for modified input parameters.
7. For traditionally used input parameters the oil recovery was found to be 17.27%, cake recovery of 80.73 %, oil extraction efficiency of 63.97 % & feed rate of 75 kg/hour, deficit oil yield of 9.73 %
8. For the modified input parameters the oil recovery was found to be 22.73%, cake recovery of 76.25 %, oil extraction efficiency of 84.20% & feed rate of 70.50 kg/hour, deficit oil yield of 4.27 %.
9. Thus it can be observed that at modified input parameters the oil recovery and oil extraction efficiency was found to be more, cake recovery was found to be less, feed rate was found to be more and deficit oil yield was found to be less as compared to traditionally used input parameters.

10. The oil extracted was analyzed for different physiochemical properties i.e. saponification value, iodine value, acid value, viscosity and peroxide value and values were found to be in safe limits.

CHAPTER VI

SUGGESTIONS FOR FUTURE WORK

Following suggestions are put forward for further research on this subject

1) The arrangement can be made to calibrate the pressure of crushing the seeds during oil extraction.
2) The trails on length of worm pitch more than 76 mm can be checked against for possibility increasing oil recovery and oil extraction.
3) The capacity of machine can be increased by conducting more trails on length variation on reverse worm between optimum and maximum length.
4) Insulation to the feed kettle can possibly be provided to improve the ergonomic safety of the operator and reduced the heat loss.

CHAPTER VII

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APPENDIX 1

Physical properties of safflower oil seeds

Sr.No.	Length, Mm	Width, mm	Thickness, mm	Geometric Mean Diameter, mm	Sphericity
1	7.13	3	2.1	3.55	49.78
2	7.75	3.11	2.96	4.14	53.41
3	7.41	3.87	3.11	4.46	60.188
4	7.63	3.25	2.87	4.14	54.25
5	7.22	3.37	3.44	4.37	60.52
6	7.31	3.56	3.01	4.27	58.41
7	7.28	3.19	2.74	3.99	54.807
8	7.55	3.41	2.67	4.096	54.25
9	7.49	3.49	2.76	4.16	55.54
10	7.51	3.44	2.55	4.03	53.66

Properties	**Replications**	**Safflower seeds**
Oil content, %	1	26.5
	2	27.1
	3	28.3
Mean		27

APPENDIX 2

Gravimetric properties of safflower oil seeds

Properties	Replications	Safflower seeds
Bulk Density, g/cc	1	0.49
	2	0.45
	3	0.449
Mean		0.46
True Density, g/cc	1	0.901
	2	1
	3	0.76
Mean		0.89
Porosity, %	1	46.07
	2	54.54
	3	41.96
Mean		47.52

Properties	Replications	Safflower seeds
Angle of repose, degrees	1	30
	2	28.5
	3	27
Mean		30.84

Properties	Replications	Safflower seeds
Moisture Content, %	1	5.3
	2	3.9
	3	4.7
Mean		4.63

Properties	**Replications**	**Safflower seeds**
Coefficient of friction	1	5.3
	2	3.9
	3	4.7
Mean		4.63

APPENDIX 3

Effect of shaft speed, length of reverse worm and worm pitch on dependent parameters

		Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3	Response 4	Response 5
Std	Run	A:Shaft Speed	B:Length of reverse worm	C:Worm Pitch	Oil Recovery	Cake Recovery	Oil Extraction Efficiency	Feed rate	Deficit oil yiled
		rpm	mm		%	%	%	kg/hr	%
20	1	28	63.5	High pitch	20.11	78.89	74.4815	50	6.89
16	2	44	38.1	High pitch	17.99	81.01	66.6296	128.571	9.01
13	3	36	50.8	Low pitch	21.53	77.47	79.7407	60.8108	5.47
18	4	36	50.8	High pitch	22.79	75.89	84.4074	71.4286	4.21
24	5	36	50.8	High pitch	23.18	75.82	85.8519	72.5806	3.82
11	6	36	50.8	Low pitch	22.39	76.91	82.9259	60	4.61
21	7	36	63.5	High pitch	21.41	77.59	79.2963	69.2308	5.59
9	8	44	63.5	Low pitch	17.27	80.73	63.963	75	9.73
7	9	28	63.5	Low pitch	19.89	78.11	73.6667	42.8571	7.11
25	10	36	50.8	High pitch	23.38	74.56	86.5926	73.7705	3.62
15	11	36	38.1	High pitch	20.79	78.11	77	90	6.21

22	12	44	63.5	High pitch	18.79	80.21	69.5926	100	8.21
14	13	28	38.1	High pitch	19.03	79.95	70.4815	64.2857	7.97
4	14	28	50.8	Low pitch	19.16	79.74	70.963	47.3684	7.84
23	15	36	50.8	High pitch	22.51	76.91	83.3704	75.6303	4.49
19	16	44	50.8	High pitch	18.48	80.52	68.4444	112.5	8.52
26	17	36	50.8	High pitch	22.91	76.05	84.8519	74.9376	4.09
12	18	36	50.8	Low pitch	22.79	75.97	84.4074	63.8298	4.21
6	19	44	50.8	Low pitch	17.99	81.21	66.6296	90	9.01
10	20	36	50.8	Low pitch	21.67	77.67	80.2593	62.5	5.33
17	21	28	50.8	High pitch	19.59	79.41	72.5556	56.25	7.41
5	22	36	50.8	Low pitch	22.01	76.91	81.5185	62.9371	4.99
8	23	36	63.5	Low pitch	21.13	77.98	78.2593	56.25	5.87
3	24	44	38.1	Low pitch	17.27	81.99	63.963	100	9.73
1	25	28	38.1	Low pitch	18.81	80.19	69.6667	52.9412	8.19
2	26	36	38.1	Low pitch	20.51	78	75.963	69.2308	6.49

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