"DESIGN AND DEVELOPMENT OF ROASTER FOR SOAKED SOYBEAN"

By

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DEPARTMENT OF AGRICULTURAL PROCESS ENGINEERING,
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"DESIGN AND DEVELOPMENT OF ROASTER FOR SOAKED SOYBEAN"

DISSERTATION

Submitted to

Vasantrao Naik Marathwada Krishi Vidyapeeth in partial fulfillment of the requirement for the degree of

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IN

AGRICULTURAL PROCESS ENGINEERING

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2013

AFFECTIONATELY

DEDICATED

TO

MY BELOVED

PARENTS, BROTHER,

SISTER & FRIENDS…

CANDIDATE'S DECLARATION

I, hereby declare that the dissertation or part there of has not been submitted by me to any other University or institution for a degree or diploma.

Place : Parbhani *(Mr. KHEDEKAR T. A.)*

Date : / /2013

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CERTIFICATE-I

This is to certify that the dissertation entitled **"DESIGN AND DEVELOPMENT OF ROASTER FOR SOAKED SOYBEAN"** submitted to Marathwada Krishi Vidyapeeth, Parbhani in partial fulfillment of the requirement for the award of the degree of **Master of Technology (Agril. Engineering**) in **AGRICULTURAL PROCESS ENGINEERING** embodied the results of the bonafied study carried by **Mr. KHEDEKAR TUKRAM ARJUN** under my guidance and supervision. I also certify that the dissertation has not previously submitted by her for the award of Degree or Diploma of any University or Institute.

Place : Parbhani.
Date : / /2013

Dr. (Mrs.) S.U. Khodke
(Chairman)

CERTIFICATE-II

This is to certify that the dissertation entitled **"DESIGN AND DEVELOPMENT OF ROASTER FOR SOAKED SOYBEAN"** submitted by **Mr. KHEDEKAR TUKARAM ARJUN** to the Marathwada Krishi Vidyapeeth, Parbhani in partial fulfillment of the requirement for the degree of **MASTER OF TECHNOLOGY (Agril. Engg.)** in the subject of **Agricultural Process Engineering** has been approved by the students advisory committee after oral examination in collaboration with external examiner.

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Place : Parbhani. ***(Mr. Khedekar T. A.)***

Date : / /2013

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ABBREVIATIONS

Symbols		Description
%	:	Percent
<	:	Less than
° C	:	Degree Celsius
° F	:	Degree Fahrenheit
µm	:	Micrometer
a	:	Area of belt
A.O.A.C	:	Association of Official Analytical Chemists
ANOVA	:	Analysis of variance
AR	:	Aspect ratio
CAD	:	Computer aided design
CCRD	:	Central composite rotating design
cm	:	Centimeter
CNSL	:	Cashave nut shell liquid
D	:	Diameter of shaft (mm)
db	:	Dry basis
Dept.	:	Department
e.g.	:	Example Gratia
EQD	:	Equivalent diameter
et al	:	and other
Etc	:	Etcetera
F	:	Power factor
Fig	:	Figure
Fr	:	Froude number
g	:	Gram
g	:	Acceleration due to gravity
g, gm	:	Grams
GMD	:	Geometric mean diameter
h	:	Hour
hp	:	Horse power
hrs	:	Hours

HTST	:	High Temperature Short Time
Kcal	:	Kilo calorie
kg	:	Kilogram
Kg/h	:	Kilogram per hour
KJ/kg	:	Kilo joule per kilogram
k-V	:	Kilo voltage
L	:	Length
lit	:	liter
LPG	:	Liquefied petroleum gas
m	:	Module
M.K.V	:	Marathwada Krishi Vidyapeeth
m/s	:	Meter per second
MC	:	Moisture content
Min	:	Minute
mm	:	Millimeters
Mp	:	Mega pixel
Mpa	:	Mega Pascal
MS	:	Mild steel
MT	:	Metric tonnes
N.S.	:	Non significant
n_c	:	Critical speed
No.	:	Number
Prof.	:	Professor
R	:	Radius
rpm	:	Revolution per minute
RPM	:	Revolution per minute
RSM	:	Response Surface Methodology
S, Sec	:	Second
SE	:	Standard error
SMD	:	Square mean diameter
Sp	:	Sphericity
SS	:	Stainless steel
T	:	Thickness

t/ha	:	Tonnes per hectare
TIA	:	Trypsin Inhibiter Activity
TMT	:	Thousand metric tones
USA	:	United State Of America
USDA	:	United State Department of Agriculture
viz	:	Namely
V_t	:	Unit weight
W	:	Width
wb	:	Wet basis
W_f	:	Final weight
W_i	:	Initial weight
W_T	:	Permissible tangential tooth load
x	:	Centre distance of pulleys(mm)
α	:	Groove angle (34º)
β	:	Arc of contact
λ	:	Shape factor
φ	:	Angle of repose
ω	:	Angular rotational speed

INTRODUCTION

CHAPTER I

INTRODUCTION

Soybean (*Glycine max* (L.) *Merr*.) is the 'golden bean' or 'miracle bean'. Soybean has come to be recognized as one of the premier agricultural crops today for various reasons. Soybean plays a major role in the world food trade. Soybean is an important part of the human diet in many developing countries. In brief, soybean is a major source of vegetable oil, protein and animal feed. It contains about 40% of good quality protein, 20% fat, 23% carbohydrates, 5% minerals, 8% moisture, 4% fibre and reasonable amounts of vitamins. Soy based food products are also suitable to diabetic patients as they contain less carbohydrates and low cholesterol. Soy protein is also good to people who are allergic to animal protein. Therefore, it is one of the most economical protein sources in the world (Ali, 2003). It has a wide range of geographical adaptation, unique chemical composition, high nutritional value, functional health benefits. Today soymilk, tofu, yuba, and the fermented products natto, miso, tempeh and soy sauce continue to be important foods in Asian countries. The perceived health benefits arising from consumption of soy foods have included: good nutritional profile, a reduction in heart disease through reduced blood cholesterol, a reduced risk of cancer, control of menopausal symptoms, weight control and longevity. The health benefits are related to the protein, fibre and isoflavone content of soybeans. Based on evidence of the consumption 25 g of soy protein per day can help in cholesterol reduction.

Soybean plays a major role in the world food trade. It has about 42% and 56% of area and production, respectively of total oilseeds. The current global production of soybean is around 260.0 million MT with USA being the largest producer. Globally, in 2011-12 India is the 5th ranks in the area and production of soybean after USA, Brazil, Argentina and China. The contribution of India in world soybean area and production is about 7.8% and 4.2%, and is 106.948 lakh hectare and 126.775 lakh MT respectively. In India Madhya Pradesh state contributes about 58.13 lakh hectare in total area and production of soybean is 66.85 lakh MT while Maharashtra state contributes about 32.13 lakh hectare in total area and production of soybean is 39.95 lakh MT. The state like Madhya Pradesh, Maharashtra and Rajasthan together contributes about 97% total area and 96% production of soybean in the country (The soybean processors association of India 2011-2012)

Soy processors convert soybeans into products made from whole soybeans, such as tofu, tempeh, miso, natto, soy sauce, some soy flours, soy nuts, soybean butter and soymilk. Other soybeans destined for more traditional food and technical products are graded, cleaned, dried, and cracked to remove the hull. Soybean hulls are further processed for animal feed or fiber additives for breads, cereals, and snacks.

Despite the fact that, like other legumes, soybeans contain several undesirable chemical substances termed antinutritional factors (ANFs) that are known to exert deleterious effects when ingested by human and animals. Antinutritional factors are compounds that impair health by destroying nutrients/vitamins or by reducing the uptake of such essential elements by different mechanism and giving astringent test, odor, flavor and which can cause adverse physiological responses or diminish the availability of certain nutrients. They also interfere with growth, reproduction, or health and reduce protein and carbohydrate utilization when consumed regularly even in normal amounts. The main antinutritional factors occurring in *Glycine max* include protease inhibitors (trypsin inhibitors), phytic acid, tannins and urease. Trypsin inhibitors have the ability to inhibit the action of the enzyme trypsin found in the digestive tract of humans and animals.

Roasting is one of the unit operation in soybean butter processing. The net effect of roasting techniques is increasing the nutritive value and overall acceptance through the reduction/removal of antinutrients. The perfect roast depends on visual examination, colour, appearance, hardness and flavour of seeds. Visual examination is one of the techniques to judge the roasting stage and it is widely adopted by even in industry.

Roasting significantly increases overall palatability of nuts by enhancing their flavour, color, texture and appearance characteristics. Roasting involves a number of physico-chemical changes including dehydration and chemical reactions. These changes are mainly related to drying and non-enzymatic browning during roasting. Non-enzymatic browning starts with a reaction between the carbonyl group of a reducing sugar with a free, uncharged amine group of an amino acid or protein with the loss of one mole of water. Therefore, non-enzymatic browning causes a decrease in nutritive value due to decrease protein digestibility and loss of essential amino acids.

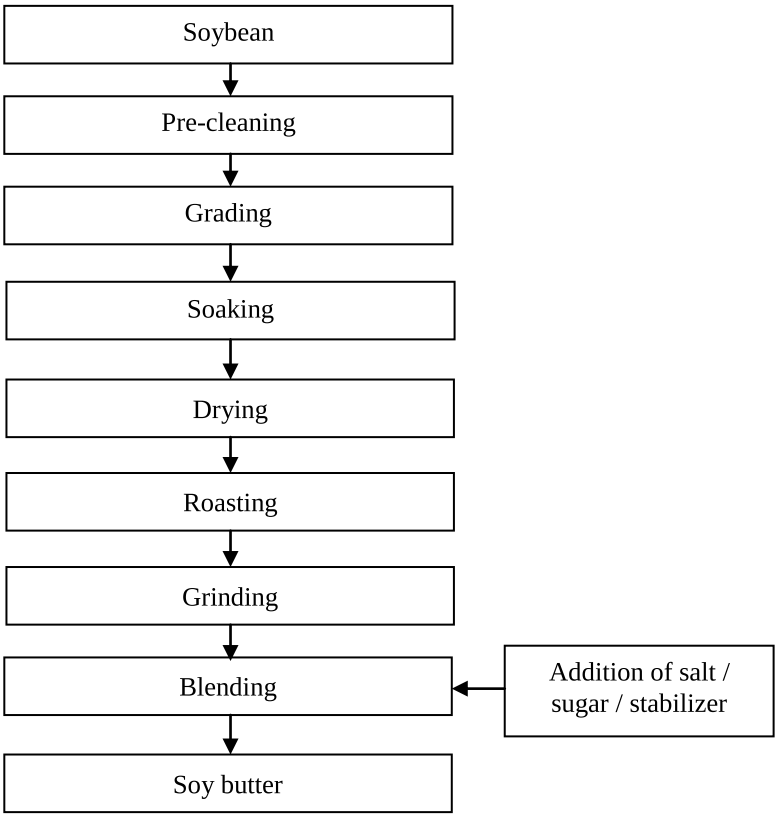


Fig. 1.1 flow chart of soy butter preparation

The process parameters of roasting are heating temperature and holding time. These parameters are most important for reduction of antinutritional factors present in soybean. There are many types of roasting techniques such as rotary drum dryer, salt-bed roasting and conventional grain dryer. The most commonly used roasting systems are the rotating drum, fluidized bed models, cascade roasting, jet-sploding, micronizing and microwave treatments. Most of these methods provide non uniform roasting of soybean with uneven temperature distributions. For preparation of soy butter the end products obtain from roasting operation is most important from nutritive and market point of view. The available roasting equipment is not suitable for roasting of soybean, so there is need to design and development of roaster for roasting soybean for preparation of soy butter.

Knowledge of engineering properties of agricultural materials and their dependence on the moisture content constitute important in the design of machines, structures, processes and controls in analyzing and determining the efficiency of a machine or an operation in developing new consumer products and in evaluating and retaining the quality of the final product. In order to design equipment used in processing of soybean, there is need to know various physical and mechanical properties as function of moisture content. The physical properties of grains are essential for design of equipment used for their handling, storing and processing. Physical properties such as dimensions, weight, shape, sphericity, aspect ratio and bulk density were used to establish machine design and operating variables for roller and hammer mills as well as selecting the optimum gap between rollers and optimum screen opening size for the abrasive dehusker.

Considering above points there is need to develop roaster for soybean, for the preparation of soy butter. Similarly optimization of process parameters such as time and temperature during roasting operation is to be done. The developed roaster may be useful for roasting multi grains. Hence it is proposed to design and develop a roaster for soaked soybean; with following objectives:

1) To determine the physical properties of soybean seed and split during its soaking conditions.

2) To design and develop a soybean roaster.

3) To optimize the process parameters of roasting operation in developed soybean roaster.

REVIEW OF LITERATURE

CHAPTER - II

REVIEW OF LITERATURE

This chapter presents the review of research work carried out by various investigators on following listed points. Literature collected is sub-divided into different groups as follows:

- Soybean.
- Soaking process.
- Changes in physical properties of grains during soaking.
- Design consideration of roaster.
- Transverse flow of grains in rotary drum.
- Roasting of soybean and other grains.
- Quality parameters of roasted soybean.
- Response surface methodology.

2.1 Soybean

The soybean (*Glycine max*) is one of the most important food plants of the world, and seems to be growing in importance. It is an annual crop, fairly easy to grow, that produces more protein and oil. It is a versatile food plant that, used in its various forms, is capable of supplying most nutrients. Soybean protein quality has been the subject of intense investigation for several decades due to soybean's increasing importance as human food resource.

2.1.1 Nutritive Value

The composition of soybeans may vary according to varieties/genotype (Qin and Chen, 1995). Dry soybean contain 36% protein, 19% oil, 35% carbohydrate (17% of which dietary fiber), 5% minerals and several other components including vitamins (Liu, 1997)

Ali (2003) reported that soybean as the 'golden bean' or 'miracle crop' because of its several uses. It is an excellent source of protein and oil. It contains about good quality protein (43%), carbohydrates (21%), minerals (5%), moisture (8%), fat (20%), fiber (4%) and reasonable amounts of vitamins. Besides utilization of soybean as vegetable, it is also used in oil industry where it occupies first place in the world oil production. Soybean containing 43% protein and 20 % oil has tremendous potential to meet the protein-calorie malnutrition of ever increasing Indian population. Soy based food products are also suitable to diabetic patients as they contain less carbohydrates and low cholesterol. Soy protein is also good to people who are allergic to animal protein. Therefore, it is one of the most economical protein sources in the world.

Dixit *et al*., (2011) reported soybean used for more than 5000 years in China and South East Asia as food. Epidemiological studies show its importance in prevention of several diseases. Recently, an upsurge of consumer interest in the health benefits of soybean and soy products is not only due to its high protein (38%) and high oil (18%) content, but also due to the presence of physiologically beneficial phytochemicals. Past several years of clinical and scientific evidences have revealed the medicinal benefits of the soy components against metabolic disorders (cardio-vascular diseases, diabetes and obesity *etc.*) as well as other chronic diseases (cancer, osteoporosis, menopausal syndrome and aneamia *etc.*). Many of the health benefits of soy are derived from its secondary metabolites, such as, isoflavones, phyto-sterols, lecithins, saponins *etc.* The proximate composition of soybeans, in fairly representative average figures, is shown in Table 2.1 (FAO, 1992).

Table 2.1 Proximate composition of soybean

Seed part	**% of whole seed weight**	**% (Moisture free basis)**			
		Protein	Lipids	Carbohydrate (incl. fiber)	Ash
Cotyledon	90	43	23	43	5
Hull	8		1	86	4.3
Hypocotyls	2	41	11	43	4.4
Whole seed	100	40	20	35	4.9

(Source: FAO, 1992)

2.1.2 Production

Soybean plays a major role in the world food trade. It has about 42% and 56% of area and production, respectively of total oilseeds. The current global production of soybean is around 260.0 million MT with USA being the largest producer. Globally, in 2011-12 India is the 5th ranks in the area and production of soybean after USA, Brazil, Argentina and China. The contribution of India in world soybean area and production is about 7.8% and 4.2%, and is 106.948 lakh hectare and 126.775 lakh MT respectively. In India Madhya Pradesh state contributes about 58.13 lakh hectare in total area and production of soybean is 66.85 lakh MT while Maharashtra state contributes about 32.13 lakh hectare in total area and production of soybean is 39.95 lakh MT. The state like Madhya Pradesh, Maharashtra and Rajasthan together contributes about 97% total area and 96% production of soybean in the country (The soybean processors association of India 2011-2012)

Today soymilk, tofu, yuba, and the fermented products natto, miso, tempeh and soy sauce continue to be important foods in Asian countries (Erickson, 1995). Soy processors convert soybeans into products made from whole soybeans, such as tofu, tempeh, miso, natto, soy sauce, some soy flours, soy nuts, soybean butter and soymilk. Other soybeans destined for more traditional food and technical products are graded, cleaned, dried, and cracked to remove the hull. Soybean hulls are further processed for animal feed or fiber additives for breads, cereals, and snacks.

Merwe *et al*., (2012) reported utilization of soybean in human nutrition whole soybean products (soymilk, tofu, okara, soy nuts, snack foods, yoghurt and soy sauce etc.), protein products (soy flour full fat : 40 - 42% protein and 20% oil, soy flour defatted : 50 - 54% protein and 1% oil, soy protein concentrate : 65 - 70% protein and 1% oil and soy protein isolates : 90 - 92% protein and 1% oil) oil products (refined oil, vegetable oil blends, salad oils, margarine, lecithin by products)

2.2 Soaking

Chopra and Prasad (1994) studied soaking of soybean during the production of traditional soy foods such as soymilk and tofu. The soaking process changes the textural characteristics of soybean and also facilitates the extraction of soy protein. It is known that textural changes of soybeans resulted from water absorption during soaking the water absorption of soybeans during soaking mainly depends upon soaking time and temperature. As the soaking time increases, the amount of water absorbed increases with an increase in temperature. The water absorption of legumes during soaking has been modeled using Peleg’s equation with reasonable accuracy found that soybeans soaked for 24 and 72 h lost its solid by 5% and 10%, respectively.

Maskan (2001) determined water uptake of three grains by soaking 2 g sample in a 20 ml test tube containing 10 ml of distilled water at 20°C, 30°C, 50°C and 70°C. Twenty test tubes were prepared for each sample. Soaking temperatures studied were 20°C, 30°C, 50°C and 70°C. Test tubes were placed in thermostatically controlled ovens at the required soaking temperature. Samples were withdrawn from the ovens at 15 min intervals. The soaked grains were through a coarse cloth and placed onto two layers of paper towels, quickly blotted 4-5 times to remove the surface water by gently rolling the grains on the towel, and weighed to an accuracy of 0.0001 g. This procedure was established based on the preliminary test results and other reported studied. The grains were allowed to cool to room temperature in order to use in volume change determination. Then, the samples were immediately placed in an oven for moisture content analysis.

Pan and Tangratanavalee (2003) studied the water absorption of soybeans and reported that, the increase in moisture is directly related to the changes in textural characteristics and grinding properties of soybean. In this study, they determined the characteristics of water absorption, solid loss, and moisture content, textural characteristics and grinding properties of soybeans at four different soaking temperatures, 101°C, 201°C, 301°C, and 401°C, and various soaking time up to 8 h. It was found that the solid loss increase significantly with the soaking temperature increased (301-401°C). The relation furthered a trend of Peleg's equation. The model ruptures force and maximum tangent and secant modulus measured by the compression test decreased as the moisture increased. The grinding property of soaked soybean was related only to the final moisture content and not to the soaking conditions. High soaking temperature could significantly reduce the required soaking time. Based on these result it has been recommend that soybeans be soaked to minimal final moisture content of 120% before grinding.

Igathinathane *et al*., (2005) has reported that traditional parboiling and soaking operation takes 1-2 days at room temperature. Modern methods use hot water, and soaking can be completed in a shorter time depending on the temperature of the water. Long-duration cold water soaking leads to microbial growth and off-flavor development, whereas hot water soaking requires high energy inputs and produces unsatisfactory coloration of kernels. They studied various treatments of hot soaking (60°C, 65°C, and 70°C) and steaming times with Brazos (medium-grain), Labelle, and Skybonnet (long-grain) varieties and found that the optimum combination of treatments depended on variety. Soaking is the most time-consuming operation in the parboiling process, followed by drying and steaming.

Kashiri *et al*., (2010) have determined kinetics of water absorption during the processing of soaking about five gram sample, soaked in 5 times weigh of distilled water at five temperatures 10, 20, 30, 40 and 50°C for 600 min. The water content of the kernel was calculated as the difference between the weight of the dry solid and soaked kernels. The variation of the moisture content of the grains with time was used to plot the kinetic curve of samples moisture. In water absorption finds out the diffusivity and activation energy of sorghum kernel during at different temperature. The kinetics of water absorption has been extensively studied for traditional food products such as cereal grains and legumes.

2.3 Changes in physical properties of grains during soaking.

The physical property of soybean are important in designing of harvesting, separating, sizing, grinding and oil extraction machines (Tavakoli *et al.,* 2009). The physical properties of seed or other grains are essential for design of equipment used for their handling, storing and processing. Physical properties such as dimensions, weight, shape, sphericity, aspect ratio and bulk density were used to establish machine design and operating variables for roller and hammer mills as well as selecting the optimum gap between rollers and optimum screen opening size for the abrasive dehusker (Sahay and Singh, 2004). Bulk density, true density and porosity are important factors in designing of storage structures. Bulk density and weight are necessary in sizing machine components and designing related equipment such as conveyors. Bulk and kernel densities which indicate grain degree of filling (Chang, 1988) are used for determining dielectric properties of grains, storage, transport and separation systems. The shape and size are important in the electrostatic separation of foreign material and in the design and development of grading and sorting machineries. Seed shape and size are a major consideration (Gupta and Das, 1997). Food grains require cook and crack process, its size, surface area and volume are required in the different handling and processing operations such as heat and mass transfer, heating and cooling in the selection and design of a screen cleaning system (Nelson and You, 1989).

In recent years, the physical properties for various crops have been studied such as sweet seed and rongai (Simonyan *et al.*, 2009); paddy (Zareiforoush et al., 2009); millet seed (Ojediran *et al.*, 2010); corn grains (Seifi and Alimardani., 2010); cardamom capsules (Balakrishnan *et al.,* 2010)., and maize seed (Sobukola *et al.,* 2013);

Kibar and Ozturk (2008) studied the physical and mechanical properties of soybean at 8-16% moisture content. In this moisture range, grain length, width, thickness, arithmetic average diameter and geometric average diameter increased from 7.24-8.19, 6.79-7.12, 5.78-6.23, 6.60-7.18, and 6.57-7.14 mm, respectively. The volume of grain and area of grain surface increased linearly from 130.97-160.32 and from 125.46 -144.39 mm^2, respectively. The sphericity, bulk density, true density and porosity decreased linearly from 0.91-0.87, 766.12-719.00, 983.33-905.67 kg/m^3 and 22.58-20.61%, respectively. The angle of internal friction increased linearly from 27.37-31.81 with the increase of moisture content.

Tavakoli *et al.*, (2009) evaluated the effect of moisture content on some physical properties and mechanical behavior under compression load of soybean grains. Four levels of moisture content ranging from 6.92-21.19 % (db) were used. The average length, width, thickness, arithmetic and geometric mean diameter, surface area and thousand grains mass were found increased as the moisture content increased from 6.92-21.19 %. As the moisture content increased from 6.92-21.19 % (db) the bulk density and true density were found to decrease from 650.95-625.36 kg/m^3 and from 1147.86-1126.43 kg/m^3 respectively. The static coefficient of friction of soybean increased linearly against various surfaces as the moisture content increased in the range of 6.92-21.19 % (db).

Singh *et al.*, (2009) have studied the geometric mean diameter, sphericity, grain surface area, 1000 grain mass, true density (toluene displacement method), terminal velocity, dynamic angle of repose, coefficient of internal friction, coefficient of static friction at different surfaces (sun mica, canvas and mild steel surfaces), specific deformation and rupture energy of the grain were found to increase 12.21%, 4.79%, 30.47%, 30.75%, 6.74%, 32.99%, 127.05%, 60%, 18.57%, 34–67%, 69.2% and 88.87%, respectively at increase of moisture content from 0.065-0.265% dry matter. However, true density (proximate composition method), bulk density, interstices and rupture force of grain was found to be decrease as 8.64%, 20.1%, 86.49% and 21.17%, respectively at increase of moisture content.

Simonyan *et al.,* (2009) investigated the effects of moisture content on the physical properties of two varieties of *Lablab purpureus* (L.) sweet seeds, 'Rongai', and 'Highworth'. The physical properties investigated include length (L), width (W), thickness (T), arithmetic mean diameter, geometric mean diameter, equivalent diameter, sphericity, seed volume and weight, roundness, bulk density, particle density and porosity at moisture range of 9.7 to 29 % wet basis (w.b.) for 'Rongai' and 10.2 to 22.6 % (w.b.) for 'Highworth'. These properties are useful in the design of planting, harvesting, processing, handling and storage equipments. Results showed that the axial dimensions, arithmetic mean diameter, geometric mean diameter and equivalent diameter, individual grain mass, and volume increased with increasing moisture content. There was a decrease in roundness, bulk density and porosity with increasing moisture content.

Zareiforoush *et al.,* (2009) studied the moisture-dependent physical properties of agricultural grains. In the current study, various physical properties of two different paddy cultivars were determined at five moisture content levels of 8, 11, 14, 18 and 21% (db). In the case of Alikazemi cultivar, the average length, width, thickness, equivalent diameter, surface area, volume, sphericity and thousand grain mass were found increased in the range of 9.83-10.05 mm, 2.65-2.76 mm, 1.92 -2.01 mm, 3.72-3.85 mm, 39.37-42.12 mm^2, 26.91-29.94 mm^3, 37.51-38.04%, and 27.63-31.20 g, respectively, as the moisture content increased from 8-21% (db). The corresponding values increased from 10.20-0 10.25 mm, 2.31-2.40 mm, 1.85-1.92 mm, 3.53-3.63 mm, 36.87-38.61 mm^2, 23.12 - 25.11 mm^3, 34.53-35.27 % and 24.43-27.80 g, respectively, for Hashemi cultivar.

Ojediran *et al.,* (2010) evaluated two varieties of pearl millet seeds (*Penisetum glaucum*) (Ex-Borno and SOSAT C88) and reconditioned to moisture contents ranging 10-20% (wb). The reconditioned seeds were then evaluated for dimensions, sphericity, bulk density, solid density, porosity, thousand seed mass, angle of repose and static coefficient of friction on five structural surfaces. Within the range of moistures analyzed, physical properties of millet seeds are related to the moisture content by polynomial equations. SOSAT C88 and Ex-Borno increased their width by 15.7% and 15.6%. Their length increased by 15.3% and 19.8% their thickness increased by 22.4% and 7.8%. Sphericity changed with the increase in moisture content with SOSAT C88 coming closer to a spherical form.

Seifi and Alimardani (2010) studied were carried out to determine the effect of moisture content on some physical properties and mechanical behavior of corn grains under compression load of two varieties of corn (Sc704 and Dc370) which are the most cultivated varieties by Iranian farmers. Four levels of moisture content ranging from 4.73-22% wet base (w.b.) and 5.15-22% w.b. for Sc 704 and Dc 370, respectively were used. The average length, width, thickness, geometric mean diameter, equivalent diameter, arithmetic diameter, sphericity, grain volume, surface area and aspect ratio were studied. The thousand grain weight increased linearly from 271.0 to 321.4 g for Sc704 and from 267.7 to 305.8 g for Dc 370. As the moisture content increased, bulk density was found to decrease from 710 to 649 kgm^{-3} and 679 to 632 kgm^{-3} for Sc 704 and Dc 370, respectively whereas true density and porosity were found to increase from 1250 to 1325 kgm^{-3} and 43.2% to 51.02% for Sc704 and 997 to 1170 kgm^{-3} and 31.90% to 45.98% for Dc 370. The static coefficients of friction on various surfaces, namely, galvanized iron, plywood and plastic also increased linearly with an increase in moisture content. The linearity of coefficients of friction data of galvanized iron and plastic for Sc 704 was higher with moisture content than Dc 370. The results showed higher correlation with moisture content for the static angle of repose of Sc 704 compared to Dc 370 variety. The mechanical properties of corn were determined in terms of average rupture force and rupture energy. The rupture force decreased for compression while rupture energy of the corn grains generally increased in magnitude with an increase in moisture content. Dc 370 had higher rupture force than Sc 704 in all moisture content levels. The variance of rupture energy data for Sc 704 was greater than those of Dc 370. The results showed that the thousand grain weight had the best linear relationship with moisture content while the surface area and true density had the worst relationship with moisture content.

Balakrishnan *et al*; (2011) were determined physical properties of cardamom capsules in the moisture range of 8.41-24.87% (w.b.). All physical properties, except bulk density and hardness, increased with the increase of moisture content. The highest static coefficient of friction was observed on mild steel surface, followed by aluminium sheet, galvanized iron sheet and stainless steel sheet. The physical properties of cardamom capsules were expressed in the form of regression equations as a moisture content function. High correlation coefficients were found at significance level of 95%.

Balasubramanian *et al.*, (2011) determined the physical properties of coriander seeds in the moisture content range of 3.5-17.7%, (db). The major axis and 1000 seeds mass were found to be decreased nonlinearly with increase in seed moisture. The medium and minor axes, geometric mean diameter, sphericity, unit volume, surface area and angle of repose increased linearly. Bulk density decreased linearly, however the true density increased non-linearly. The coefficient of static friction increased nonlinearly for different surfaces with increase in moisture level and its maximum was found for plywood surface. The rupture force and energy absorbed decreased linearly with increasing moisture content.

Shirkole *et al*., (2011) evaluated the soybean varieties (cv. TAMS-38 and JS-335) for their physical properties that are often required in order to design production processes and equipments at moisture contents of 7.30%-30.80% and 7.35%-30.70% (db) for TAMS-38 and JS-335, respectively. The grain size, thousand grain weight, and angle of repose were found linearly increased with increase in moisture contents. The grain size was found increased from 5.92-6.65 and 5.64-6.37mm, thousand grain weight 124.2-154.4 and 103.5-137.3 g and angle repose 27.37-30.37 and 28.00-30.850, respectively with the increase in moisture contents. The results indicated that the per cent increase in terminal velocity of TAMS- 38 and JS- 335 were 20.0% and 13.79%. Where, sphericity decreased from 85.1% -77.4% and 86.3% -78.3%, respectively for TAMS- 38 and JS- 335 with corresponding increase in moisture content.

Adejumo and Abayomi (2012) investigated the effect of moisture content on some physical properties of shelled and unshelled Moringa Oleifera seed at 6.8%, 10%, 15% moisture content (wet basis). The mean values of the physical properties of the seeds were determined as length 8.3 – 8.7 mm and 12.7 – 13.4 mm, width 7.4 – 7.6 mm and 10.3 – 11.0 mm, thickness 6.5 – 7.3 mm and 10.4 – 10.9 mm, geometric mean diameter 133.1 – 160.1 mm and 453.5 – 535.6 mm, sphericity 16.0 – 18.4 mm and 35.7 – 40.0 mm, thousand seed mass 316.8 – 326.7g and 318.3 – 329.3g, bulk density 0.031 – 0.032 g/cm^3 and 0.041 – 0.047 g/cm^3, true density 0.221 – 0.632 g/cm^3 and 0.300 – 0.289 g/cm^3, porosity 85.9 – 94.9% and 86.3 – 83.7%, surface area 3.19 – 2.21 cm^3 and 3.56 – 5.32 cm^3 for shelled and unshelled seeds respectively. The coefficient of friction as measured on glass was 0.466 – 0.445% and 0.510 – 0.404%, sheet metal 0.425 – 0.466% and 0.481 – 0.547%, plywood 0.740 – 0.597% and 0.525 – 0.594% for shelled and unshelled seeds respectively. The physical properties of the seeds increased with increase in moisture content but porosity however, decreased. This information will provide engineers and designer the relevant data for efficient process handling and equipment design

Sobukola *et al.*, (2013) conducted to evaluate the physical properties that affect equipment design, processing, storage and transportation of high quality protein maize (SWAM 1) seeds as a function of moisture content varying from 9.38 to 32.7% (db). The length, width, thickness and the geometric diameter increased linearly from 9.80 to 10.55, 8.60 to 9.06, 4.00 to 4.75 and 6.85 to 7.69 mm, respectively. The sphericity index, seed volume, seed surface area and thousand seed mass also increased linearly from 69.89 to 72.85, 99.36 to 138.56 mm, 124.55 to 157.76 mm2 and 240.36 to 303.71 g, respectively. Bulk density, true density and porosity decreased linearly from 1.109 to 1.057 g/m3 1.365 to 1.176 g/m3 and 18.75 to 10.12%, respectively. Static coefficient of friction was found to increase on plywood, galvanized iron, aluminium and stainless steel surfaces and it increased logarithmically from 0.55 to 0.91; 0.52 to 0.81, 0.49 to 0.70, and 0.46 to 0.68, respectively. Angle of repose increased linearly on plywood, galvanized iron, aluminium and stainless steel surfaces from 18.91 to 29.05, 17.00 to 26.96, 15.93 to 23.98 and 15.55 to 22.19°, respectively.

2.4 Design criteria for development of roaster

The seed subjected to the roasting process must be suitably prepared first so that their physical properties meet the requirements of the process. Due to the decrease in bean volume, the degree of fill for this case is lower than corresponding initial fill. Also there should be some changes in flowing properties of the beans, since the physical attributes (mass, density, texture, porosity and other) of these beans are altered with the roasting process (Cristo *et al.,* 2006) Therefore, knowledge of the physical properties of seeds before and during the process is necessary in the rational design of roasting machine.

As follow from the abbreviated algorithm for the design of the roaster (Fig. 2.1), the critical phase, affecting all the further stages of the design process, is the development of a concept and selection of optimum concept which will ensure efficiency of roasting process. If the concept under development is erroneous, no efficiency of roasting process can be expected, even if the solutions are food in itself. The type of criteria adopted and method of their to value will determine the choice of design solution which in turn will determine the effect of the operation the roaster designed.

At the initial stage of roaster design an analysis is performed which provided the basis for the development of the design criteria. The basic guidelines for the development of the design criteria for a new roaster are presented in Fig. 2.2. It is very important to make sure that the design criteria provide information on the requirement concerning the effective output of the roaster, its efficiency, and energy consumption of roasting process. It should be pointed out that these parameters are affected by the moisture of the seeds to be roasted, and by moisture related physical properties of the seeds.

2.5 Transverse flow of grain in rotary drum

Mellmann (2001) developed mathematical models to predict the transitions between the different forms of transverse motion of free-flowing bed materials in rotating cylinders: sliding, surging, slumping, rolling, cascading, cataracting and centrifuging. Model calculations of the limits between these types of bed motion compare well with measurements of experimental rotating cylinders as well as published results from industrial practice. The motion behavior can be represented on a Bed Behavior Diagram that plots wall friction coefficient and Froude number against the filling degree. From this study, scaling criteria for the bed behavior were found to be the Froude number, filling degree, wall friction coefficient, ratio of particle to cylinder diameter, angle of internal friction, and static and dynamic angles of repose. The transition criteria worked out and the Bed Behavior Diagram provides the user of rotary kilns the possibility to estimate the type of motion of the bed materials used from measured particle characteristics. As a result, the bed behavior can be influenced through selection of operating variables such as rotational speed and filling degree or installation of lifting bars and flights.

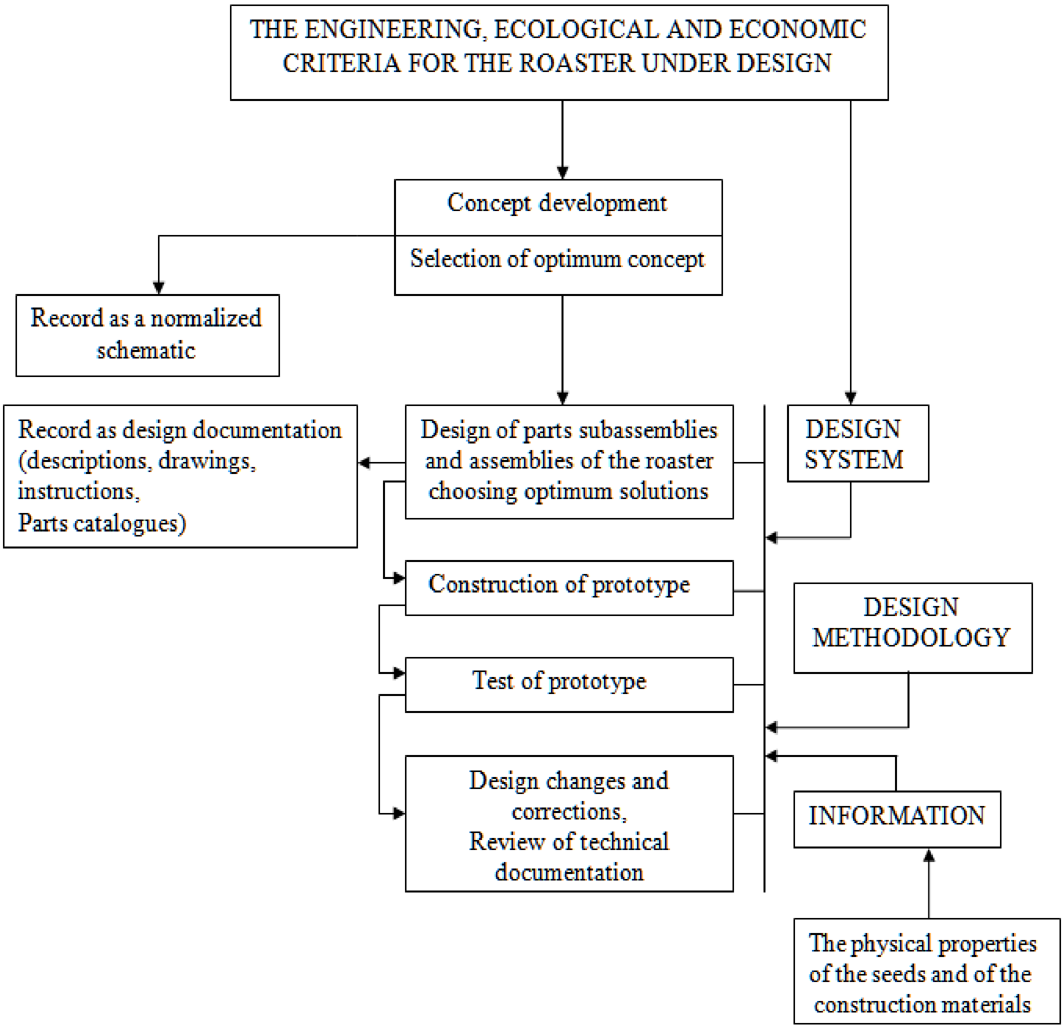


Fig. 2.1 Abbreviated algorithm for the design of the roaster.

(Source: Mieszkalski, 1997)

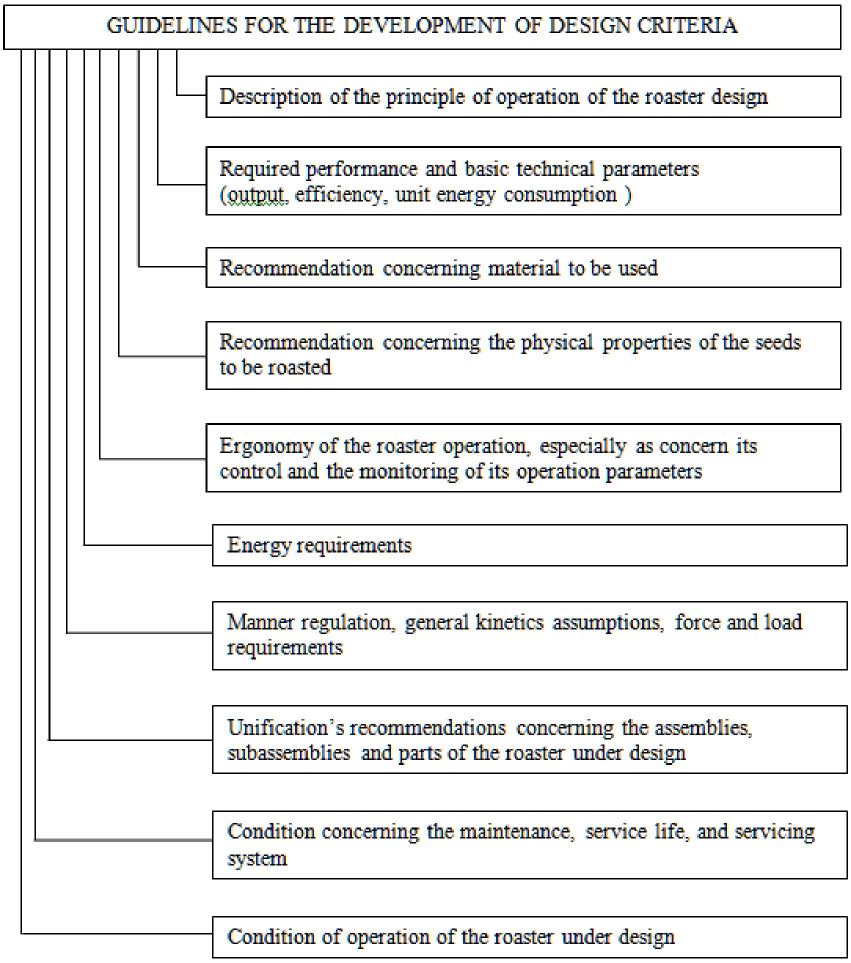


Fig. 2.2 Principal guideline for the development of the design criteria for roaster. (Source: Mieszkalski, 1997)

Ding *et al.*, (2002) investigated theoretical models for calculation of the bed turnover time in both the slumping and rolling modes and the slumping to rolling transition in rotating drums with less than 50% volumetric fill of free-flowing granular materials. It is suggested that the transition from slumping to rolling occurs when the two turnover times are equal. The model for the bed turnover time in rolling beds is compared with the data reported in the literature. Very good agreement has been obtained. The bed turnover time is also employed to define a new Froude number for constructing the bed behaviour diagram. It is shown that the bed behaviour diagram based on the new Froude number brings the data points for sand and limestone into single curves. The implications of the bed turnover time for solid mixing and heat transfer within particle beds are also discussed.

Sherritt *et al.*, (2003) Reported, horizontal drum reactors are widely used in industry for the processing of granular material. They are ideally suited for chemical processes that require high temperatures at near-atmospheric pressure. However, the complexities of these reactors have resulted in empirical design procedures that lead to very conservative and costly reactors. These studies first reviews critically the extensive literature on experimental results obtained on rotary kilns (without fights) and proposes new design equations for the axial-dispersion coefficient in terms of rotational speed, degree of 8ll, drum diameter, and particle diameter. A total of 179 data points from the literature, encompassing both the batch and the continuous operational modes, yielded design correlations for slumping, rolling/cascading and cataracting bed behaviors.

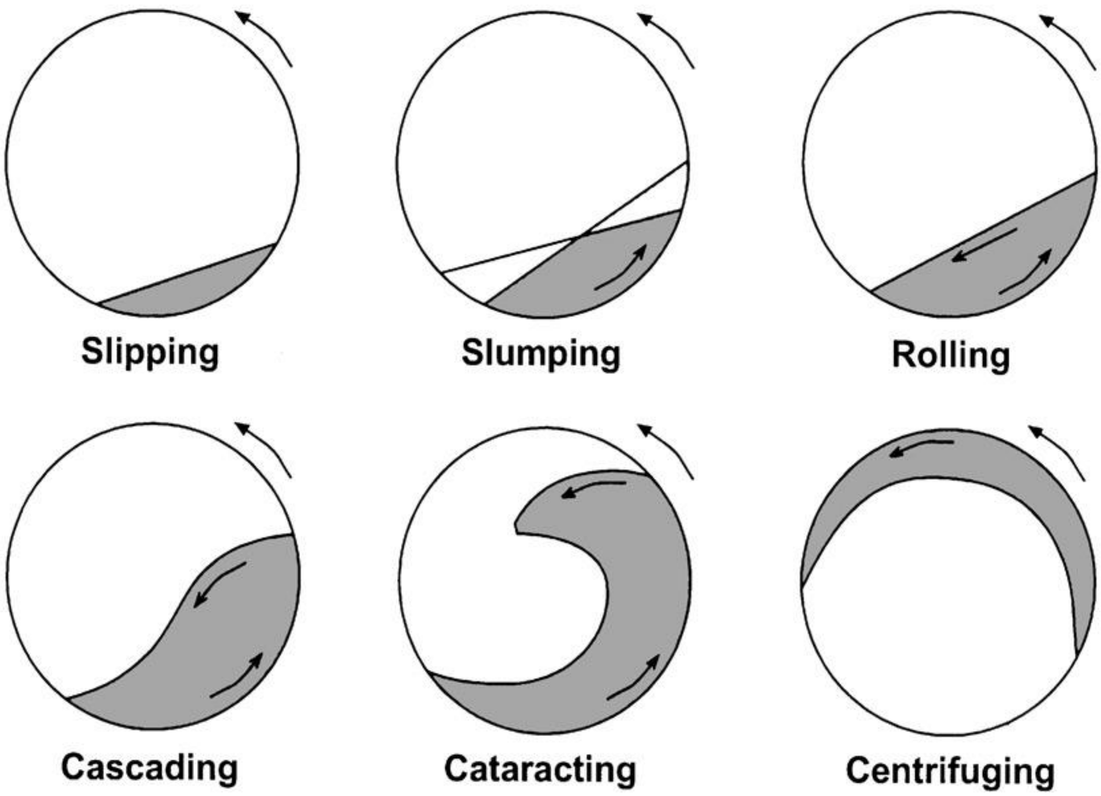


Fig. 2.3 Possible modes of transverse bed behaviour in a partially filled, horizontal, rotating drum. (Source: Sherritt *et al.*, 2003).

Finnie *et al.*, (2005) studied longitudinal and transverse mixing in horizontal rotary kilns, using a three-dimensional Discrete Element Method approach. The focus is on the effect of the main operating conditions, i.e., the filling degree and the rotational speed of the rotary kiln, on quantitative measures of longitudinal and transverse mixing. Discrete Element Method simulations have been performed for various values of the main operating conditions. Flow regimes have been determined from visualizations of the simulations. It is shown that the mixing in the longitudinal direction can be described by a diffusion equation. The dependence of the diffusion coefficient on the operating conditions has been determined from the results of the simulations. It is found that the diffusion coefficient increases linearly with rotational speed, while the influence of the filling degree is relatively small. The mixing in the transverse plane is quantified by an entropy-like mixing index. The results of the simulations show that this mixing index varies exponentially with the number of revolutions of the rotary kiln. The dependence on the operating conditions of the transverse mixing speed, as determined from the exponential behaviour of the mixing index, has been determined. This mixing speed decreases with increasing rotational speed and with increasing filling degree. The transverse mixing speed that has been determined from the results of additional two-dimensional simulations is generally larger than that observed in the corresponding three-dimensional simulations.

Cristo *et al.*, (2006) studied processing of particles in rotating cylinders heavily influenced by the types of flow regimes within the cylinders during rotation. Conventional industrial coffee roasting is performed in rotating cylinders. Coffee beans undergo drastic physical and chemical changes during roasting and, due to that fact, the types of flow regime within the roaster will also vary. The types of flow regimes will, in turn, affect the uniformity of processing and ultimately the quality of the roasting. In this study, a small scale acrylic model of a cylindrical roaster was built and used to study the different forms of transverse motion of a bed of coffee beans during rotating motion. The model has internal mixing bars similar to those of industrial roasters. The model allowed the visualization of the flow regimes and their transitions, giving a preliminary idea of the regimes to be recommended for operation of conventional industrial roasters.

Lisboa *et al.,* (2007) studied the performance of a rotary dryer in relation to number of flights. In this work a questioning was proposed to calculate the area used by the solids in two-segment flights of with any angle between the segments. From this area, the flight holdup and the length of fall of the particles were calculated for different angle positions and the results obtained were compared to experimental values. The results show an increase in dryer efficiency with the increase in number of flights up to a limit value, for ideal operational conditions. The experimental data on average residence time were compared to results obtained by calculations using equations proposed in the literature. The equation proposed for predicting flight holdup and length of fall of particles generated very accurate estimations.

Sunkara *et al.,* (2013) reported, rotary drums, installed with longitudinal flights are used to dry/cool granular materials in large quantities. Performance of such drums greatly depends on the uniform distribution of the particles over the drum cross section, which is attained by an optimal design and allocation of the flights. In this study, a mathematical model has been developed for the rectangular flight to optimize the total particle surface area which is a function of the cascading rate and falling time of the particles. The falling time in turn is a function of curtain height and can be estimated by geometrical analysis. Influence of the number of flights and the flight length ratios has been studied. It was observed that, as the flight length ratio increased the cascading rate decreased during the initial discharge, but increased rapidly at higher discharge points resulting in a bulk movement of the solids, which also determines the density of the curtains. Experiments were carried out to validate the developed model with a drum of 500 mm in diameter and 150 mm in length. The experiments were performed with different flight profiles and flight numbers (12 and 18). Good agreement was found between the experiments and the model predictions.

2.6 Roasting

Starting from 1864, roasting equipment/roasters manufactured on an industrial scale for the first time in the world. Von Gimborn (1868) invented over the design and construction on an industrial basis from which the Emmerich spherical roaster for capacities from 2.5 to 120 kg and became legendary. The spherical roaster was called Emmerich high-speed roaster that was patented in 1884. In addition, revolutionized coffee roasting technology was another roaster which was fully automatic roasting plants in the first half of the twentieth century. These also give an insight into modern roasting systems with hourly capacities up to 5000 kg and more per line, which are delivered to large-scale roasting plants in Germany and abroad.

Fig. 2.4 Emmerich spherical roaster for coffee roasting technology (charcoal as a source of heat) Source: Gimborn (1868)

Roasting process involves the application of dry heat to legume seeds using a hot pan or dryer at a temperature of 150ºC to 200ºC for short time, depending on the legume or the recipe to be made. Roasting produces a better product as far as protein quality is concerned than one produced by common wet cooking under pressure. A several food crops which need roasting before to consumption such as coffee, peanut and other legumes. Coffee roasting revealed that all coffee starts as green (unroasted) beans, which are the seeds of the coffee fruit. Taking those seeds from the plant to the coffee pot involves roasting them for several minutes between 205ºC to 260ºC. . During the first few minutes of roasting, green beans begin to turn yellow and develop a vaguely grassy or grainy smell as their water content causes them to steam from within the coffee. As the internal temperature of the beans rises, the coffee gives off a fragrant smoke and begins to make a crackling noise as the sugar caramelize and the essential oils released. The beans puff up to almost double their size the roast becomes darker until a second more volatile phase of cracking begins. At this point, the beans are done, or can be roasted further for a ‘dark roast’ variety.

Gopaldas *et al*., (1985) roasting which is a simple and more commonly used household level technology which is more effective for grinding and milling of agriculture materials. Pre-cooked the ingredients used in food grains and oil seed based mix and increased the self life and acceptability of product Roasting improve the flavor, texture and nutritive value of grains and elimination most anti- nutritional or toxic effect of legumes.

Thomason (1987) conclude that recommended that the exit temperature of the beans should be between 110 and 113ºC for monogastrics and roughly 116ºC for ruminants, so as to increase the percentage of protein that cannot be degraded by the rumen. This process reduces the initial moisture of the bean by 30%, but without breaking down the cellular structures, or releasing their oil. For this reason, the beans must be further milled or laminated before being used as food.

Lessire *et al*., (1988) involved the direct and intensive application of dry heat (roasting) for around 20 seconds.

Faldet and Satter (1991) roasted the soybeans in a direct-fired roaster with air temperature between 430°C and 450°C. They controlled the process so that soybeans exiting the roaster were 146°C, ensuring sufficient heat was applied but without overcooking the beans and, therefore, not reducing their protein quality..

Moura *et al*., (1991) investigated the optimum roasting time for soybeans using moist heat at a temperature of 115ºC for 29 kg pigs. Their productivity rose as the time was increased, with the best results being obtained for duration of 30 minutes. Qin *et al.* (1996) obtained similar results for piglets with soybeans roasted at 102ºC for 40 minutes and at 134°C for only 90 s.

Bressani (1993) reported that pressure cooking black beans for 10 to 30 min at 121ºC improved the utilization of black bean, as compared to raw beans. Bressani (1993b) also reported that the in vitro digestibility of navy beans was improved by mild heat treatment. Excessive heating reduced the nutritive value of beans due to the destruction or in activation of certain essential amino acids.

Bates (1994) reported that use direct heat to the soybeans or heat through steam. The original model used a direct flame through which the product passed as the drum rotated. The roaster is a cylinder, or drum, situated inside a chamber with a motor that causes it to rotate and which controls both the entry and exit of the beans. The seeds remain inside the chamber for between 2 and 5 minutes and the heat produced by the gas flame increases the temperature and reduces the moisture. The beans reach an exit temperature of between 110 and 130ºC (Marty and Chavez, 1993). One problem of the original system was the variations in the treatment of the beans, which led to losses of productivity of the animals to whom they were fed.

Satter *et al.,* (1994) studied the roasting of soybean in a revolving finned cylinder which lifts the beans through jets of flame. Trough this roasting is popular, it is done subjectively base on the degree of color of the beans exiting the roaster. The data showed several combinations of temperature and time (140°C-120 min, 150°C - 60 min or 160°C-30 min) resulted in the roasted soybean with an optimal or near optimal protein protection. Secondly, roasted soybean were checked for exiting temperatures and held without cooling (steeped or conditioned) for 0, 15, or 30 mm to give 12 soybean treatments. Increases in exiting temperatures and/or steeping reduced the ruminal protein degradation and improved post ruminal lysine availability the purpose of steeping was to allow heat to equilibrate throughout the whole soybean.

Aldrich *et al.*, (1995) reported roasting soybeans did not spare the unsaturated longchain fatty acids in soybeans from hydrogenation in the rumen but increased digestibilities of total C18 and total fatty acids. Nutrient digestibilities by steers fed diets containing soybeans roasted at 149 or 157°C were similar to digestibilities by steers fed diets containing soybeans roasted at 141°C.

Katic *et al.,* (1996) reported that roasting is a process that has its origins in prehistoric times, but that has been modified somewhat by industry to meet with today's needs. Several models exist, including conventional 'dry' systems, similar to those used to dry out cereals, and moist heat systems. The heat used for the latter can be generated by an oven, a coal burner or directly by a flame. The temperature reached varies between 110 and 170ºC depending on the equipment used.

Ordonez and Palencia (1998) processed soybeans via dry roasting (Termal processori mario tovar & arturo watemberg, barranquilla, colombia) at 113, 120, 130, 135 and 150ºC. The dwell time inside the machine they used was adjusted by changing the inclination of the cylinder according to the desired temperature. They chose times of 3.0, 4.5, 6.5, 7.0 and 9.5 minutes respectively. The trypsin inhibiting activity was reduced from 56,300 units/g for raw beans to 8,850 for beans that were dry heated at 113ºC and to less than 5,000 for the remaining treatments. Likewise, the KOH protein solubility fell from 94% for raw beans to 79% for beans heated to 135ºC. A temperature of 150ºC for 9.5 minutes reduced the solubility to 69%. The live weights of chickens of 42 days were similar for temperatures of between 120 and 150ºC and were higher than those obtained for raw and roasted beans at 113ºC (1.12c, 1.80b, 1.97[a], 2.03[a], 1.95[b] and 1.94[b], for raw beans processed at 113, 120, 130, 135 and 150ºC, respectively). The authors recommended remaining below 130ºC for a duration of 6.5 minutes for this type of machine.

Demir *et al.,* (2002) studied the colour changes during the dry roasting of hazelnuts and determined the magnitude of parameters for a corresponding colour change model. Roasting times from 5 to 1900 min and a number of roasting temperatures in the range from 100 to 180 °C were analyzed. The order of the reaction was found by plotting isothermal curves of colour change against time at a number of different roasting temperatures. Statistical analysis of the data demonstrated that the colour parameter. Theoretical equations, based on the exponential integral function, to predict first-order quality changes when product temperature is varying exponentially were developed.

Akinoso *et al.,* (2004) designed 300kg/h cashew nut roasting machine, which uses charcoal as its source of heat energy, was developed. Performance evaluation of the roaster was carried out by roasting 15 kg of raw cashew nut (*Anarcardium occidentale*) in cashew nut shell liquid (CNSL) at different moisture content of the nut, roasting temperature and time. Sensory evaluation was carried out on the kernels after roasting. The result of the evaluation shows that the roaster could roast 15 kg of raw cashew nut having a moisture content of 12% wet basis in 3 minutes at a roasting temperature of 130^{o}C, once this optimum temperature was attained.

Mac Isaac *et al*., (2005) studied the roasting of soybean at 130.5°C using an open flame propane-fired roaster. After roasting, the beans were steeped for 45 min. The brooding temperature was 32°C from d 1 to d 7 after which the temperature was reduced 3°C/week until it reached 21°C at 28 d of age where it remained for the duration of the experiment. The level of roasted full-fat soybeans used in the starter diets was 0 or 15%.Within the starter groups, the ratios of roasted full-fat soybeans to soybean meal in the grower and finisher diets. There appears to be no detrimental effect of including 15% roasted soybeans in starter diets or replacing 100% of soybean meal with roasted soybeans in grower and finisher diets on growth performance or carcass composition of female broiler turkeys.

Perren (2005) pointed out that besides structure resistance forces, driving forces are required in order to achieve a volume expansion. During roasting, a considerable quantity of moisture and dry mass is evolved. The quantity of carbon dioxide and moisture evolved during High-Temperature-Short-Time (260ºC, 170 s) and Low-Temperature-Long-Time (228ºC, 720 s) roasting process was determined using Near-Infrared-Absorption technique (NIR). In both processes, a maximal moisture evaporation rate caused by the evaporation of initially present moisture was observed before the roasting process was stopped. Under HTST conditions, carbon dioxide evolution rate increased exponentially at temperatures above 180 - 200°C, whereas under LTLT conditions, carbon dioxide evolution rate was rather constant above 180 - 200°C until the end of the roasting process. Finally, the weight ratio of carbon dioxide and moisture in the total roast loss were calculated and a mass balance for the roasting process was developed.

Kabri *et al.,* (2006) studied performance evaluation of drum ground seed roaster with the aim of achieving efficient roasting of ground nut by improving method of roasting groundnut and eliminating the drudgery associated with the roasting of ground nut. The machine was designed, constructed and tested in the department of Agricultural Engineering, Federal University of Technology, Yola, Nigeria using locally available materials. It consist of three paddles (stirrer) attached to a shaft, which rotates and stir the groundnut seed constantly inside a drum. There is a charcoal tray and a fan assembly is directly below the drum, which supplies the heat to the drum. The paddle and fan assembly are directly driven through chain and sprocket. The frame is made of angle iron which the entire assembly is mounted. The machine is operated manually through the handle. The machine performance evaluation was carried out using SAMNUT-10 (RMP-9), SAMNUT-10 (RMP-12) and ICGV-SM-93523 as Groundnut sample. The machine roasting capacity was found to be .5 kg/min, with roasting efficiency 95%, material efficiency of 97.2% and effective roasting time of 3 minutes. It was concluded that efficient and improvement groundnut roasting could be better achieved with this machine than with the traditional method of roasting which takes about 8-9 minutes.

Mridula *et al.*, (2007) studied effect of roasting on the important physical properties and sensory acceptability of soybean for making sattu formation was studied at three temperature (180,200 and 220°C) and time (45, 60 and 75). The GMD of soybean was found increased with in roasting temperature at 75 s. Hardness, toughness and average rupture force decrease with increase in roasting temperature and time expected 200 and 220°C for 75 sec time. The lower hardness of soybean roasted at 200°C for 60 sec as compared to higher temperature and highest mean sensory score for different attributes for soybean flour prepared the soybean roasted at 200°C for 60 s make this temperature and time combination best for roasted soybean for incorporation in sattu formulation. Roasted soy flour can be incorporated up to 20% level but the best sensory acceptability of sattu formulation was observed with 10% soy flour level with 50% barley and 40% bengal gram.

Osman (2007) reported the effect of different processing methods on nutrient composition, anti-nutritional factors and in vitro protein digestibility of Dolichos lablab bean. The trypsin inhibitor values were significantly reduced ($P<0.05$) by the different treatment methods, with cooking being the most effective. Soaking of the beans overnight reduced the trypsin inhibitor activities (TIA) by 6.3% and cooking of the soaked beans caused further reduction in the TIA content by 66.7%.

Makeri *et al.*, (2011) studied the effects of roasting conditions (time-temperature) on the rate of extraction and quality of oils from two peanut (*Arachis hypogea* L.) cultivars (namely, Kampala and ex-Dakar). The oils were extracted at 50 ml hot-water 250 g peanut paste. High extraction rates were obtained by roasting the peanuts at 140°C for 20 min with Kampala yielding highest oil. Above 140°C per 20 min treatment, the rate of extraction decreased for both peanuts. Ex-dakar responds faster to heat treatment than did Kampala assessed by colour. Crude fat and total carbohydrates were found to be high in Kampala and protein high in ex-Dakar. Free fatty acids contents of both oils were below 20% and peroxide values were below rancidity level of 10 Meq/kg for both oils at 0 week. At treatment 140°C/20 min for both oils, ex-Dakar oil deteriorates faster than Kampala assessed by FFA and PV levels after nine weeks storage under laboratory conditions.

Sathyendra Rao *et al.,* (2009) developed continuous process for production of cereal flakes at CFTRI, Mysore. Roasting of pre-soaked grains in a gram roaster is a critical step in the process flow which decides the quality of flakes. The roaster consists of a rotating drum having two concentric sections. There are two helical screws inside the drum one for carrying sand-grain mixture forward (inner section) and another for carrying sand backward (outer section). In the outer section, sand that is heated from below is lifted by troughs into the inner section. Moist conditioned grains are fed to the inner section where they are enveloped by hot sand resulting in heat and mass transfer. Roasting has to be done in an optimal range (distinctly different for different grains) to get the desired quality of parboiling. Degree of roasting depends on parameters like, moisture content of the feed material, ratio of feed material to heat transfer medium (vol/vol), particle size of sand, temperature of sand – process temperature, rate of heat input, feed rate and speed of roaster drum apart from the variety of grain being roasted. Large variations in the product temperature (5-10^{o}C) were observed in the manual type unit (C type roaster: 300-400 kg h^{-1}) that resulted in non uniformity of products. Studies on the effect of process variables (manipulated) on the controlled variable (product temperature) were conducted for modeling. A PLC based PID control system was developed for the set point control of product temperature. Automation was achieved by sensing product temperature with thermocouples and the PID controller, based on the deviations, correspondingly adjusting rpm of the roaster drum and the augur feeder, indirectly controlling the residence time of grains inside the roaster. By incorporating this control system, product temperature tolerance could be brought down to 1-2^{o}C. The system response was found to be quick and linear. System was tested for roasting of paddy, jowar and maize. The control system can be easily retrofitted to the existing units

2.7 Response Surface Methodology

The quality parameters of roasted soybean are roasting time, temperature of roaster drum, sensory attributes of beverage aroma, flavour, colour (L, a, b-value), yellowness index, hardness and work done. Various researcher studied these parameters are given below.

Mendes *et al.*, (2001) studied to optimize the roasting of robusta coffee (Coffea canephora Conillon), a two factor central composite design (11 samples) was used to optimize the settings for roasting time and the initial internal temperature of the roaster drum on response variables of acceptance with 25 consuming assessors, for the sensory attributes of beverage aroma, flavour and colour. Predictive models were also obtained for the instrumental measurement of the colour of the beans and ground coffee. The optimum range for roasting was shown to be a time of 22-28 min at a temperature of 225-230ºC, corresponding to the degree of roasting characterized by the following range of colour of roasted robusta beans: L* between 37.05 and 40.69, a* between 2.29 and 4.15 and b* between 2.70 and 6.29.

Ozdemir and Devres (2000) analyzed hazelnut roasting using response surface methodology to find out the effect of process variables on color development during roasting and to establish prediction models. The roasting temperature was found to be the main factor affecting color development. Developed prediction models satisfactorily described color development as a function of roasting temperature and exposure time for L-value, a-value and b-value of whole-kernel, ground-state and cut-kernel measurements. Whole-kernel measurements were significantly lighter in color compared to ground-state and cut-kernel measurements due to internal browning of the hazelnuts during roasting. The results also indicated that the L-value of ground-state measurements, which take into account internal browning during roasting, should be used to monitor roasting of hazelnuts.

Shakerardekani *et al.*, (2011) studied roasting of whole-kernels is an important step in the production of pistachio paste. The effect of hot air roasting temperatures (90-190°C) and times (5-65 min) on the hardness, moisture content and colour attributes (‘L’, ‘a’ and ‘b’ values and yellowness index) of both whole-kernel and ground-state were investigated using response surface methodology (RSM). Increases in roasting temperature and time caused a decrease in all the responses except for ‘a’ value of ground-state. The interaction and quadratic models sufficiently described the changes in the hardness and colour values, respectively. The result of RSM analysis showed that hardness and colour attributes (‘L’ and ‘b’ values, yellowness index) of kernels and ‘a’ value of ground-state could be used to monitor the roasting quality of whole-kernels. This study showed that the recommended range of roasting temperature and time of whole-kernel for the production of pistachio paste were 130-140°C and 30-40 min, respectively.

Farah *et al.*, (2012) studied roasting is an important process that contribute to formation of flavour compounds in cocoa beans. Pyrazines, a by-product of Maillard reaction is one of the character impact compounds that contribute to unique cocoa flavour. Unfortunately during roasting, carcinogenic acrylamide are also produced through Maillard reaction. Therefore, this study was focussed on optimising the roasting conditions using Central Composite Design (CCD) to produce superior quality cocoa beans with high concentration of pyrazines and low concentration of acrylamide. The roasting conditions used were temperatures in the range of 110^{o}C to 160^{o}C and time ranging from 15 min to 40 min. Roasting conditions significantly ($p<0.005$) affect the concentration of pyrazines in cocoa beans. However, the RSM analysis shows that the concentration of acrylamide in the beans was not influenced by the roasting conditions. Statistical optimization based on maximum pyrazines and minimum acrylamide at temperature of 116^{o}C and a time of 23 min produced the desirable value of 0.73. Hence, the optimized roasting conditions were able to produce high quality cocoa beans.

Youn and Chung (2012) used response surface methodology (RSM) to determine the optimal roasting temperature and time for preparing a coffee-like beverage from maize kernels. Maize kernels were roasted at different temperatures (160-240ºC) for different lengths of time (10-50 min) and subsequently extracted with hot water. Yield, levels of free sugar and phenolic compounds, antioxidant activity, and sensory scores for overall preference of the maize beverage were significantly affected by the roasting conditions. Roasting temperature was the most important factor affecting the quality indicators of the maize beverage. Surface and contour plots indicated that the optimal roasting temperature and time were 207ºC and 24 min, respectively.

THEORETICAL CONSIDERATIO

CHAPTER III

THEORETICAL CONSIDERATIONS

3.1 General consideration in the design of soybean roasting equipment.

While designing the soybean roasting equipment, all properties of the material considered in designing various component viz. rotating drum, shaft, pulley, belt, gear, outlet chute, collecting tray and motor. Hygienic design includes four important sphere of activity in the design and fabrication of soybean roasting as follow:

1) Right selection of construction material
2) Actual design of machine
3) Construction and fabrication methods
4) Surface finishes

3.2 Design consideration

1. Thickness of rotating drum is selected as 3 mm and material of this drum is stainless steel.
2. The inner diameter and length of drum are 300 mm and 900 mm, respectively.
3. For drum, diameter and length of shaft is 30 mm and 350 mm, respectively and for intermediate shaft is 20 mm and 210 mm, respectively.
4. Diameter of pulley which is mounted on the motor shaft is 50 mm and diameter of pulley mounted on intermediate shaft is 250 mm.
5. The velocity of V-belt is 3.76 m/s.
6. Weight of rotating unit is 75.0 kg.
7. The revolution of intermediate shaft and drum shaft are 288 rpm and 60 rpm, respectively.
8. The angle of emptying the drum is 45º.
9. The size of inlet and outlet opening is 150×100 mm^2.
10. The number of teeth of pinion gear which is mounted on intermediate shaft is Z=25T and that of spur gear mounted on drum shaft is Z=120T.
11. Eight numbers of baffles (2 mm thick, 26 mm length and 50 mm width) is welded on inner side of drum.
12. The angle between three lines of baffles is 120º and distance between two baffles in single lines is 60 mm.

13. The length of heating source (burner) is 900 mm.
14. Thickness of glass wool which is keeping in the cavity is 150 mm.
15. The dimension of collecting tray is 500×500×200 mm^3.
16. All the food contact material is made by stainless material.

3.3 Theoretical consideration in design calculation of soybean roaster components:

1. Dimensions of roaster drum were selected considering the 30 % filling of soaked soybean.
2. The theoretical capacity of the soybean roaster was computed by using equation.
3. Maximum torque requirement was computed by multiplying the radius of drum and total weight of the roasting unit.
4. The power requirement was determined by using relationship between torque and speed.
5. The required rpm of driven pulley as well as rotating drum shaft were selected by using velocity ratio formula.
6. The size of the shaft and bearing were calculated by relevant formulae.
7. The number of teeth of pinion and spur gear were calculated by speed reduction formulae.
8. Nearest available values of the above components are selected in design of machine.

3.4 Determination of diameter of driven pulley

Selecting diameter of drive pulley was 50 mm and considering the required rpm of driven pulley was reduced to 288 rpm.

The velocity ratio of V-belt (Khurmi and Gupta, 2005)

$$\frac{\mathrm{Di}}{\mathrm{Dm}} = \frac{\mathrm{Nm}}{\mathrm{Ni}}$$

Where,

Di	:	Diameter of intermediate shaft pulley (drive pulley).
Dm	:	Diameter of motor shaft pulley (driver pulley).
Ni	:	Rpm of drive pulley.
Nm	:	Rpm of driver pulley.

.5 Theoretical velocity of rotating drum (Roasting unit)

The velocity of rotating drum was calculated as (Khurmi and Gupta, 2005)

$$V = \frac{\pi DN}{60}$$

Where,

D	:	Diameter of rotating drum
N	:	Revolution per minute of drum.

$$V = \frac{\pi \times 0.30 \times 60}{60}$$

V= 0.94 m/s (56.4 m/min)

3.6 Theoretical design of V-belt

3.6.1 Velocity of V-belt

$$V = \frac{\pi DiNi}{60}$$

Where,

Di	:	Diameter of driven pulley.
Ni	:	Revolution per minute of driven pulley.

$$V = \frac{\pi \times 0.25 \times 288}{60}$$

V= 3.76 m/s

Theoretical velocity is less than the optimum value 10 m/s hence accepted, (Khurmi and Gupta, 2005)

3.6.2 Length of V- belt

Based on the power to be transmitted (746W) and according to Indian Standards (IS: 2494-1974), belt type B was selected (Table 3.1)

According to Khurmi and Gupta (2005), belt length was calculated as (Fig 3.1)

$$L = \frac{\pi}{2}(D_1 + D_2) + 2x + \frac{(D_1 - D_2)^2}{4x}$$

where,

D_1	:	Larger pulley diameter
D_2	:	Smaller pulley diameter
L	:	Belt length
x	:	Centre distance of pulleys

$$L = \frac{\pi}{2}(250 + 50) + 2x317 + \frac{(250-50)^2}{4 \times 317}$$

$$L = 1136 \text{ mm}$$

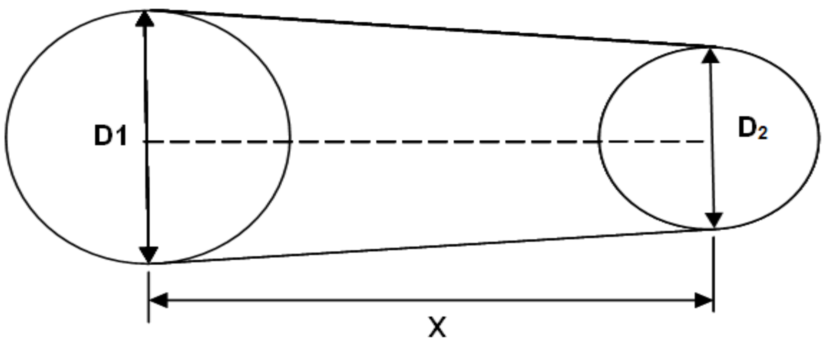


Fig. 3.1 Open belt drive

Table 3.1 Dimensions of standard V-belts

Types of belt	Power ranges (kw)	Minimum pitch diameter of pulley (D, mm)	Top width (b, mm)	Thickness (t, mm)
A	0.7 - 3.7	75	13	8
B	2 – 15	125	17	11
C	7.5 – 75	200	22	14
D	20 – 150	355	32	19
E	30 – 350	500	38	23

Source: Khurmi and Gupta, 2005

3.6.3 Arc of contact of V-belt

The arc of contact (β) is given by PSG Tech (1982) as

$$\beta = 180^o - 60^o \left(\frac{D_1 - D_2}{x} \right)$$

where,

D_1 : Large pulley diameter

D_2 : Smaller pulley diameter

x : Center distance of pulleys

$$\beta = 180^o - 60^o \left(\frac{250 - 50}{317} \right)$$

$$\beta = 142.14^o$$

3.6.4 Cross sectional area of belt

The cross-sectional area of belt (Fig. 3.2) was calculated from Table 3.1, top width (b = 17 mm), thickness (t = 11 mm) and by calculation, bottom width (x) was obtained as 8 mm. Thus,

$$(\text{Area of triangle 1}) + (\text{Area of triangle 2}) + (\text{Area of triange 3})$$

$$a = \frac{t}{2}\left(\frac{b-x}{2}\right) + xt + \frac{t}{2}\left(\frac{b-x}{2}\right)$$

$$a = \left(\frac{b-x}{2}\right)t + xt$$

Therefore c/s area of belt is (a) $= \left(\frac{17-8}{2}\right)11 + 8 \times 11$

$$a = 137.5 \text{ mm}^2$$

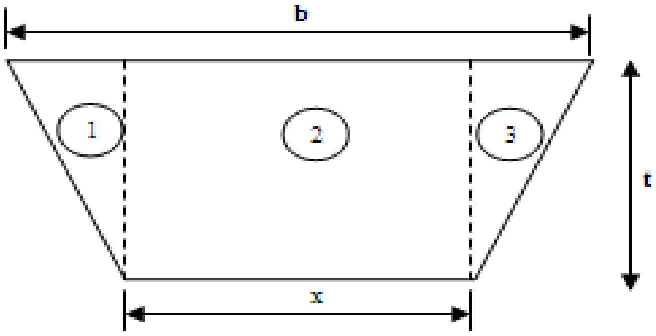


Fig 3.2 Cross-section of V-belt

Table 3.2 Coefficient of friction between belt and pulley

Belt material	Pulley material						
	Cast iron, steel			Wood	Compressed	Leather	Rubber
	Dry	Wet	Greasy		Paper	face	face
Leather oak tanned	0.25	0.2	0.15	0.3	0.33	0.38	0.40
Leather chrome tanned	0.35	0.32	0.22	0.4	0.45	0.48	0.50
Convass-stitched	0.20	0.15	0.12	0.23	0.25	0.27	0.30
Cotton woven	0.22	0.15	0.12	0.25	0.28	0.27	0.30
Rubber	0.30	0.18	-	0.32	0.35	0.40	0.42
Balata	0.32	0.20	-	0.35	0.38	0.40	0.42

Source: Khurmi and Gupta, 2005

3.7 Power requirement

The total power requirement to rotate the roasting unite was given by

$$P = \frac{2\pi NT}{60 \times \eta}$$

Where,

P : power in watt

N	:	revolution of drum per minute
T	:	torque on roasting unite
η	:	efficiency

3.7.1 Torque on rotating unit

The torque on rotating unit was calculated as

T= Total load × radius of rotating unit

3.7.2 Total load

Total load = weight of material used for making roasting unit + weight of soybean to be roasted

Total load = 60 + 15

= 75 kg

∴ Torque = 75 × 0.3× 9.81

= 220.72 N-m

$$\therefore \text{Power requirement} = P = \frac{2\pi \times 60 \times 220.72}{60 \times 0.7}$$

= 1981.22 W

3.8 Theoretical design of shaft

In order to transmit required torque of 220.72 N-m, the diameter the shaft worked out by the following equation,

$$D = \sqrt[3]{\frac{16 \times T}{\pi S_s}}$$

Where,

D	:	diameter of shaft
T	:	torque on shaft
S_s	:	safe shear stress

Ultimate safe stress = 3523 kg/cm^2

$$\therefore \text{Safe shear stress} = \frac{\text{Ultimate safe stress}}{\text{Factor of safety}}$$

$$= \frac{3523}{8}$$

= 440.375kg/cm^2

$$\therefore D = \sqrt[3]{\frac{16 \times 220.72}{\pi \times 440.37}}$$

D = 1.37 cm

The theoretical calculated shaft diameter was less than actual shaft diameter used to drive the roasting unit. Thus the design of shaft considered safe.

3.9 Theoretical design of gear

The $14^{1/2\circ}$ composite system was used for pinion and spur gears. The tooth profile of this system has cycloidal curves at the top and bottom and involute curve at the middle portion. The teeth were produced by formed milling cutters or hobs. The tooth profile of the $114^{1/2\circ}$ full depth involute system was developed for use with gear hobs for spur and pinion gears.

3.9.1 Module

$$m = \frac{D}{T}$$

where,

m	:	Module
D	:	Diameter of pitch circle
T	:	Number of teeth on wheel

The recommended series of modules in Indian Standard are 1, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 32, 40 and 50 (Khurmi and Gupta, 2005)

$$\therefore m = \frac{37.5}{25} = \frac{180}{120}$$

$$m = 1.5$$

3.9.2 Tangential tooth load

Based on the type, spur and pinion gear design as given (Khurmi and Gupta, 2005) were selected. The design tangential tooth load is obtained from the power transmitted and the pitch line velocity by using the following relation.

$$W_T = \frac{P}{v} \times C_S$$

where,

W_T	:	permissible tangential tooth load (N)
P	:	power transmitted (W)
C_s	:	service factor (1.53)
v	:	pitch line velocity (m/s)

$$v = \frac{\pi DN}{60}$$

where,

D	:	pitch circle diameter of gear.

N : Revolution per minute of gear.

$$v = \frac{\pi \times 0.037 \times 288}{60}$$

$\therefore$ v = 0.56 m/s

Table 3.3 Values of service factor

Type of load	Type of service		
	Intermittent or 3 hours per day	8-10 hours per day	Continuous 24 hours per day
Steady	0.8	1.00	1.25
Light shock	1.00	1.25	1.54
Medium shock	1.25	1.54	1.80
Heavy shock	1.54	1.80	2.00

Source: Khurmi & Gupta, 2005 (In case of non-enclosed and grease lubricated gears, the values given in the above table should be divided by 0.65.)

Therefore tangential tooth load (W_T) = $\frac{202}{0.56} \times 1.53$

W_T = 551.89 W

Table 3.4 Standard proportions of gear systems.

Sr. No.	Particulars	$14^{1/2°}$ composite or full depth involute system	20° full depth involute system	20°stub involute system
1	Addendum	1m	1m	0.8m
2	Dedendum	1.25m	1.25m	1m
3	Working depth	2m	2m	1.60m
4	Minimum total depth	2.25m	2.25m	1.80m
5	Tooth thickness	1.5708m	1.5708m	1.5708m
6	Minimum clearance	0.25m	0.25m	0.2m
7	Fillet radius at root	0.4m	0.4m	0.4m

(Sourc: khurmi & Gupta, 2005)

The selected module of gear is 1.5 with $14^{1/2o}$ composite depth involute system, therefore design parameters of gear are given below;

1	Addendum	:	1m	=	1.5 mm
2	Dedendum	:	1.25m	=	1.87 mm
3	Working depth	:	2m	=	3 mm
4	Minimum total depth	:	2.25m	=	3.37 mm
5	Tooth thickness	:	1.5708m	=	2.35 mm
6	Minimum clearance	:	0.25m	=	0.37 mm
7	Fillet radius at root	:	0.4m	=	0.6 mm

3.10 Capacity of roasting drum

3.10.1 Volume of drum

The volume of drum was calculated as

$$V = \pi r^2 l$$

Where,

V	:	volume of drum
r	:	radius of roasting drum
l	:	length of drum

$$\therefore V = \pi \times 150^2 \times 900$$

$$= 6, 36, 17, 251.24 \text{ mm}^3$$

$$= 0.0636 \text{ m}^3$$

By taking average filling volume = $\frac{30\,\% + 40\,\% + 50\,\%}{3}$

$$= 40\,\%$$

$\therefore$ 40 % filling volume of drum V= 0.0636 × 0.40

$$= 0.0254 \text{ m}^3$$

3.10.2 Capacity of drum

$$Q = \rho \times V$$

Where,

Q	:	capacity of drum (kg)
ρ	:	density of soaked soybean (600 kg/m^3)
V	:	volume of drum (m^3)

$$\therefore Q = 600 \times 0.0254$$

$$Q = 15.24 \text{ kg } (\simeq 15 \text{ kg})$$

MATERIAL AND METHODS

CHAPTER IV

MATERIALS AND METHODS

This chapter deals with the materials and methods employed during the study viz,

1. Physical properties of seed and split soybean
2. Transverse motion required for soybean roaster
3. Design and development of soybean roaster
4. Optimization of process parameters of soybean roaster using response surface methodology

4.1 Measurement of physical properties of seeds and splits

4.1.1 Collection and sample preparation

For determination of physical properties, soybean seed (*JS- 335 var*.) samples harvested in the year 2012 were obtained from the farm section of Central Institute of Agricultural Engineering, Bhopal (India). The soybean seed were cleaned by using CIAE pedal cum power operated air screen cleaner (Plate 4.1). The seeds were subjected to dehulling by CIAE dehuller (Plate 4.2). The initial moisture content of sample was determined (Ranganna, 1986). The soybeans seed and splits had an initial moisture content of 13% and 12% wb. The samples were cleaned manually to remove foreign materials, broken, cracked and damaged grains. The sound grains were sealed in polyethylene bags and stored at room temperature (30±2^{o}C). To determine the dimension and different physical properties of soybean seed and splits, approximately 2±0.5g (screened for uniformity of size) of sample was weighed using an digital electronic balance (Precisa 310 M, Adair Dutt Pvt. Ltd, Calcutta) having a last count of 0.001g and soaked for 4 h in 10 ml tap water.

4.1.2 Dimension measurement

The water absorption of soybean during soaking is directly related to the changes in dimension, textural characteristics and roasting properties of soybeans etc. In order to determine the dimension of sample, soybean seed and split were randomly selected from soaked soybean sample. For each grain, the three principal dimension of sample viz., length (L), width (W) and thickness (T) were measured using an

Plate 4.1 CIAE pedal cum power operated air screen grain cleaner

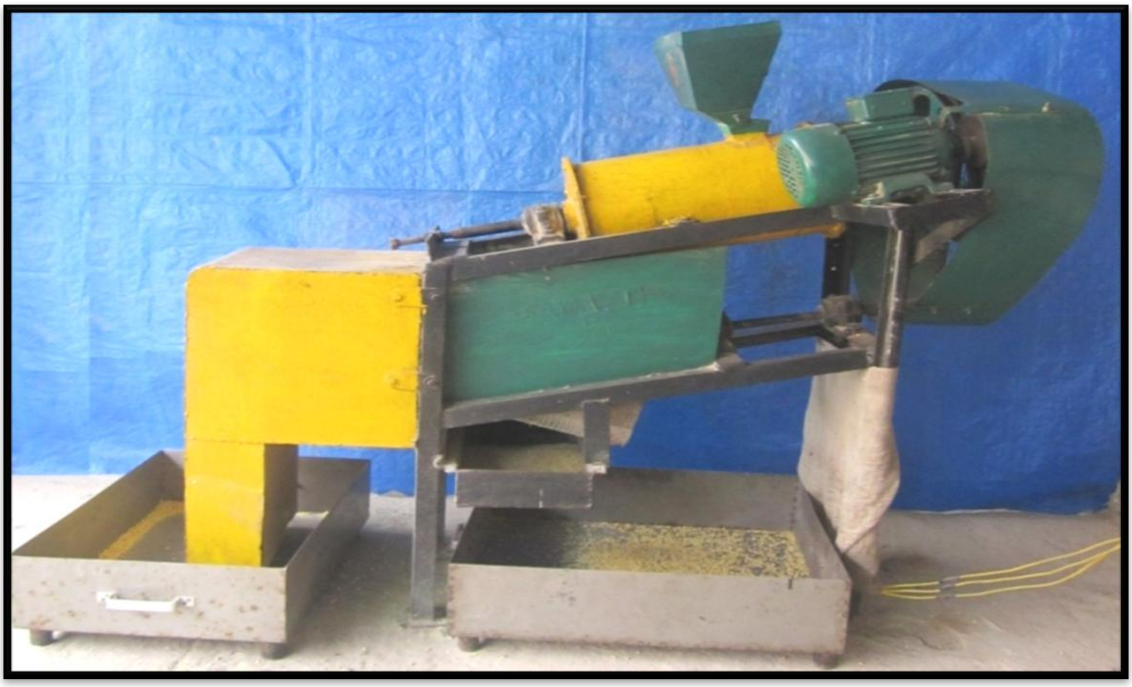


Plate 4.2 CIAE Soybean dehuller

electronic digital vernier caliper (GENERAL ULTRATECH, Gurgaon, New Delhi) having a resolution of 0.01 mm at room temperature (30±0.2^{o}C) for time interval of 15 min (Plate 4.3) during soaking soybean. The increase in sample mass during soaking in water was considered to reflect the increase in moisture content of the sample.

4.1.3 Determination of physical property

The physical properties viz., size, shape, surface area, volume, density and many more properties are important in designing particular equipment or determining the behavior the product for its handling.

4.1.3.1 Geometrical property

In order to determine various physical properties, one hundred grain were randomly picked from each sample. The length (L), width (W) and thickness (L) were measured using an electronic digital vernier caliper. The arithmetic mean diameter (AMD), geometric mean diameter (GMD), square mean diameter (SMD), equivalent diameter (EQD), degree of sphericity (Sp), aspect ratio (AR), shape factor (λ) and unit volume of seed and split were calculated using the following equations (Mohsenin,1996).

$$AMD = \frac{L+W+T}{3} \quad ...(4.1)$$

$$GMD = \sqrt[3]{LWT} \quad ...(4.2)$$

$$SMD = \sqrt{LW + WT + TL} \quad ...(4.3)$$

$$EQD = \frac{AMD+GMD+SMD}{3} \quad ...(4.4)$$

$$S_p = \frac{GMD}{L} \quad ...(4.5)$$

$$AR = \frac{W}{L} \quad ...(4.6)$$

Where,

L : length (mm)

W : width (mm)

T : thickness (mm)

AMD	:	arithmetic mean diameter
GMD	:	geometric mean diameter
SMD	:	square mean diameter
EQD	:	equivalent diameter
Sp	:	degree of sphericity
AR	:	aspect ratio

Major dimension was used to calculate the surface area (S) of single grain (Jain, 1997) as details below.

$$S = \frac{\pi \times GMD \times L^2}{2L - GMD} \qquad \ldots(4.7)$$

The unit volume of single grain (Jain, 1997) was calculated as

$$V_t = \frac{\pi \times GMD^2 \times L^2}{6(2L - GMD)} \qquad \ldots.(4.8)$$

where,

V_t	:	unit volume
L	:	length (mm)
GMD	:	geometric mean diameter

Shape factor (λ) based on unit volume and surface area of grain was determined (McCabe and Smith, 1984) as

$$\lambda = \frac{b}{a} \qquad \ldots.\ (4.9)$$

where,

$$a = \frac{Vt}{W^4} \qquad \ldots.(4.10)$$

$$b = \frac{S}{6W^2} \qquad \ldots.(4.11)$$

V_t	:	unit volume
W	:	width
S	:	surface area (mm^2)

4.1.3.2 Thousand grain weight

A grains weighing approximately 1 kg was roughly divided into 10 equal portions and then 1000 numbers of grains were randomly picked from each portion and weighed using a digital electronic balance. The measurement was repeated for 5 times and the mean value was taken.

4.1.3.3 Bulk density

A known volume of cylindrical beaker was filled with grains and gently taped. Bulk density was calculated as the ratio of weight of soaked soybean to the volume of beaker. Average of 5 replications was carried out.

4.1.4 Determination of moisture content

The moisture content of sample is determined with the help of hot air oven (Plate 4.4) by maintaining 105±2ºC temperature for 8 h. The moisture content in wet basis as

$$mc = \frac{W_i - W_f}{W_i} X\ 100 \qquad (4.12)$$

where,

mc	:	Moisture content (%, wb)
W_i	:	Initial weight of material (g)
W_f	:	Final weight of material (g)

4.2 Experimental setup to study various rotating motions required for soybean roaster

The transverse motion of grain in rotating drum affects the machine performance. The rotational speed of drum is selected such that cascading mode of motion occurs. The cascading mode of motion was generally used for roasting, processing and mixing of grains. As speed increases there is a change in flow regime from one mode of motion to another. The six basic modes of motion were studied for different filling (10-50%) with increasing rotational speed gradually. A mild steel cylinder (160 mm diameter and 170 mm length) was used for the experiment (Plate 4.5). The cylinder was an exact replica of the lab roaster employed for roasting the soybeans. The front end plate was made of acrylic material to allow the complete visualization of the flow regimes in the transversal section of cylinder. The cylinder was attached to a shaft with handle to facilitate the rotation. A digital camera (Kodak, 12 Mp, Easy share) was employed in recording the motion of grain bed in the

Plate 4.3 Electronic digital vernier calliper

Plate 4.4 Hot air Oven

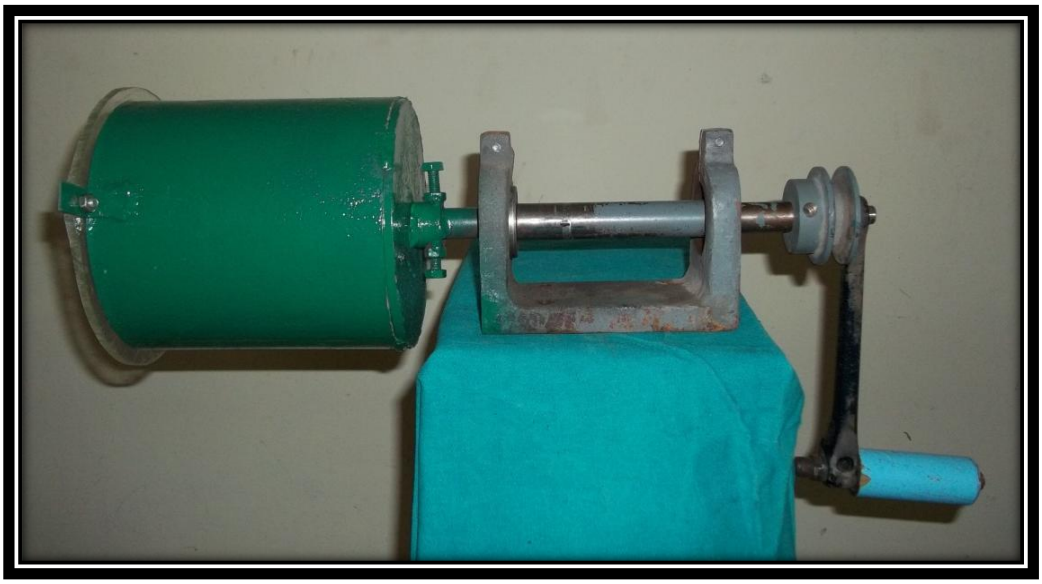


Plate 4.5 Experimental setup for soybean motion study

Plate 4.6 Digital non-contact type tachometer

transversal section of drum. The camera was positioned in such a way that the centre of the camera lens points exactly to the centre of rotating drum.

The captured motion pictures were converted to .jpg images at 0.03 s interval by using an online video to jpg converter. A digital tachometer (non-contact type) was used for measuring the speed of the rotating drum (Plate 4.6). The samples were placed in the mild steel cylinder and the rotation of cylinder began at a low speed (about 2 rpm) and was gradually increased, with the transitions of one regime to another being recorded as a function of the rotational speed.

The transitions from one regime to another were determined solely by visual inspection. Each test performed three times and the tests were performed in a randomized way. The rotation speed was increased until the bed achieves a centrifugal motion within the cylinder. This procedure was repeated for all initial degrees of fill and those of their corresponding degrees of roast. The recorded transitional rotation speeds are used in the calculation of the peripheral Froude number, given

$$Fr = \frac{\omega^2 R}{g} \qquad \text{…(4.13)}$$

where,

□ : angular rotation speed (/s)
R : radius of the cylinder (m)
g : acceleration due to gravity (m/s).

The peripheral Froude number represents a balance between centrifugal and gravitational forces. It provides a good understanding of the flow regimes, and their respective transitions, when plotted against parameters such as filling degree of cylinder.

4.3 Principle of roasting

Roasting is high temperature short time process in a closed system. The liquefied petroleum gas (LPG) was used as heating source. A digital stop watch and thermocouple were used for the measurement of roasting time and temperature, respectively. Roasting significantly increases the overall palatability of nuts by enhancing their flavor, color, texture and appearance characteristics. These changes are mainly related to drying and non-enzymatic browning during roasting (Buckholz *et al.*, 1980; Mayer, 1985; Moss & Otten, 1989; Perren & Escher, 1996a, b). The possibility of enzymatic browning is low, since the enzymes responsible for enzymatic browning are denatured due to the high temperatures employed during roasting of nuts (>100°C) (Troller, 1989; Driscoll & Madamba, 1994).

4.4 Design and development of soybean roaster

Soybean roaster was designed and developed in Agro Produce Processing Division (APPD) at Central Institute of Agricultural Engineering (CIAE) Bhopal. The procedure in design and construction of roaster machine are explained as follows. A set number of design consideration points were carried out during the design of soybean roaster. The concepts and ideas were put in design of each component and the model/detailed CAD was prepared using CREO ELEMENTS / PRO (5.0). Such points include the cost of construction, power requirement of machine and operational labour requirement. Also, ease of design component parts replacement in case of damage or failure was taken in to consideration.

4.4.1 Design of machine parameters

The primary factors which influence the machine capacity, efficiency and power requirement were identified as listed below

1. Roasting temperature
2. Filling degree
3. Residential time

4.5 Design of machine elements

Based on preliminary design criteria and functions of roaster following different machine components were prominent for consideration.

i. Main frame
ii. Roasting drum with baffles
iii. Heating source
iv. Thermal insulation
v. Inlet and outlet opening
vi. Collecting tray
vii. Power transmission unit
    a. Motor

b. Driving assembly
c. Belt and pulley
d. Intermediate and drum shaft
e. Spur and pinion gear
f. Bearing

The dimensions of these components are selected by adopting the following design procedure.

4.6 Design of roaster for soybean

Principle properties of the soaked soybean were considered to design the roaster for soaked soybean.

4.6.1 Main frame

The main frame is having dimensions 1114 mm x 454 mm x 650 mm and size of MS angle is 30 mm x 30 mm x 3 mm. The pulleys, bush bearings, intermediate shaft, drum shaft, roasting unit, power transmission unit, heating unit are mounted on this frame. All these accessories are mounted with the help of hexagonal nut-bolts (Fig. 4.2).

4.6.2 Rotating drum with baffles

The rotating drum is an important component. It is fabricated from 3 mm thick stainless steel, having a dimension of 300 mm diameter and 900 mm length. It is mounted on a shaft (MS, 30 mm diameter). The drum thickness was decided by considering the temperature to be attained and its retention capacity. Eight numbers of baffles (2 mm thick, 260 mm length, and 50 mm width) were provided inside the drum surface so as to keep three lines with 120^o angle. The baffles were arranged 60 mm away from each other in line, and other line arranged parallel to each other in a zigzag manner (Fig. 4.1).

4.6.3 Heating source

The heating source used for heating the drum is liquid petroleum gas (LPG). The dimension of burner is 900 mm x 60 mm and positioned just below the drum. A gas flow regulator is provided to control the heating rate of the rotating drum.

4.6.4 Thermal insulator

To minimize the heat loss from drum during its operation, glass wool (30 mm) thick was used. The upper and lower side of the drum were covered by glass wool carves in such a way that 150 mm clearance between two side cover for keeping gas burner.

4.6.5 Inlet and outlet opening

The rectangle shape of opening was designed to feed the soaked soybean for roasted and discharge the roasted products. The size of opening is 150 mm x 100 mm for both the sides of drum.

4.6.6 Collecting unit

The material used for making the collection unit was 16-gauge SS sheet. The size of product discharge chute is 200 mm x 300 mm x 100 mm and collecting tray is 500mm x 500 mm x 300 mm.

4.6.7 Power transmission unit

The power transmission unit consist of 1 hp motor, pulley (50 & 250 mm diameter), pinion gear (Z=25T), spur gear (Z=125T) and V- belt (B-42). The power transmission drives used for the machine are belt, pulley and gear (Table 4.1).

4.6.7.1 Specifications of electric motor

An electric motor of following specification was selected

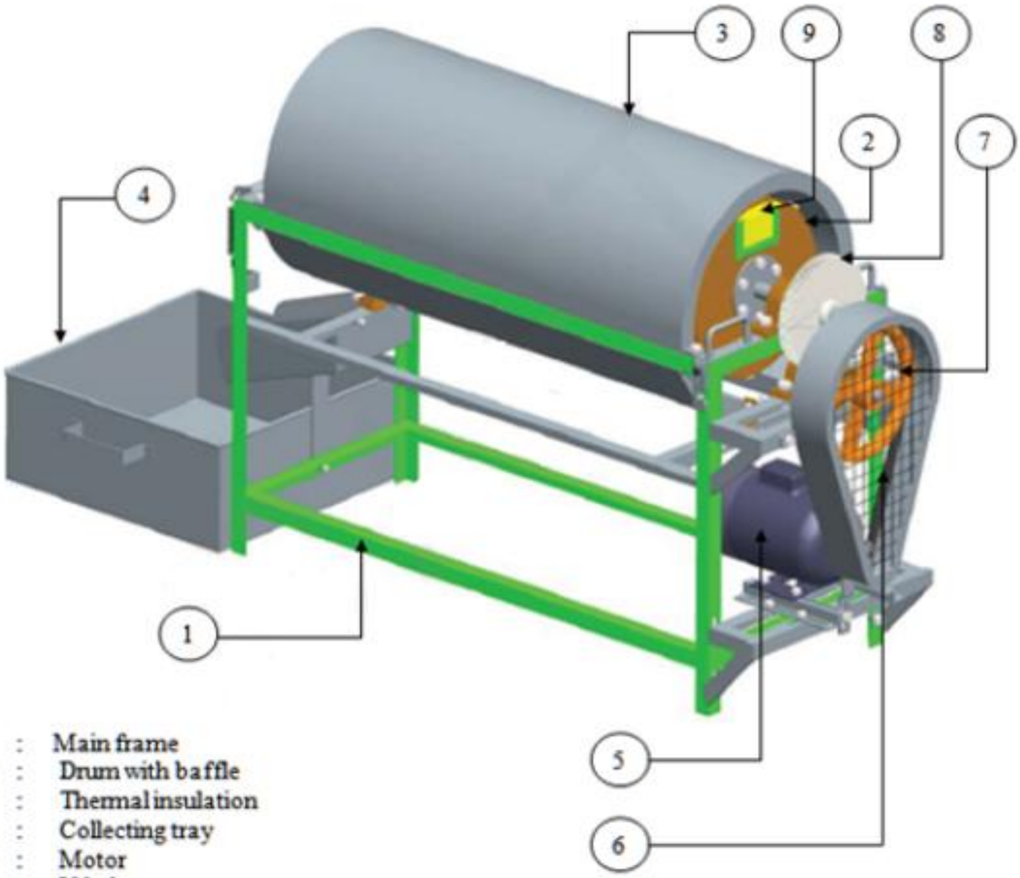
Power (P)	:	0.75 kW (1 hp)
Rational speed (N)	:	1440 rpm
Phase	:	Single
Frequency	:	50 Hz
Voltage	:	230 V

4.6.7.2 V-Belt

A synthetic rubber belt of B-type was used for transmitting the power from drive pulley to driven pulley.

4.6.7.3 Pulley/sheave

Two pulleys of diameter 50 mm and 250 mm were used for transmission of power from motor to intermediate shaft. The 50 mm diameter pulley mounted on



1 : Main frame
2 : Drum with baffle
3 : Thermal insulation
4 : Collecting tray
5 : Motor
6 : V-belt
7 : Pulley
8 : Spur gear
9 : Feed inlet

Plat 4.7 Solid model of roaster for soybean

motor shaft and 250 mm pulley mounted on intermediate shaft. The speed of intermediate shaft was chosen as 288 rpm for transmission of motion from motor to intermediate shaft.

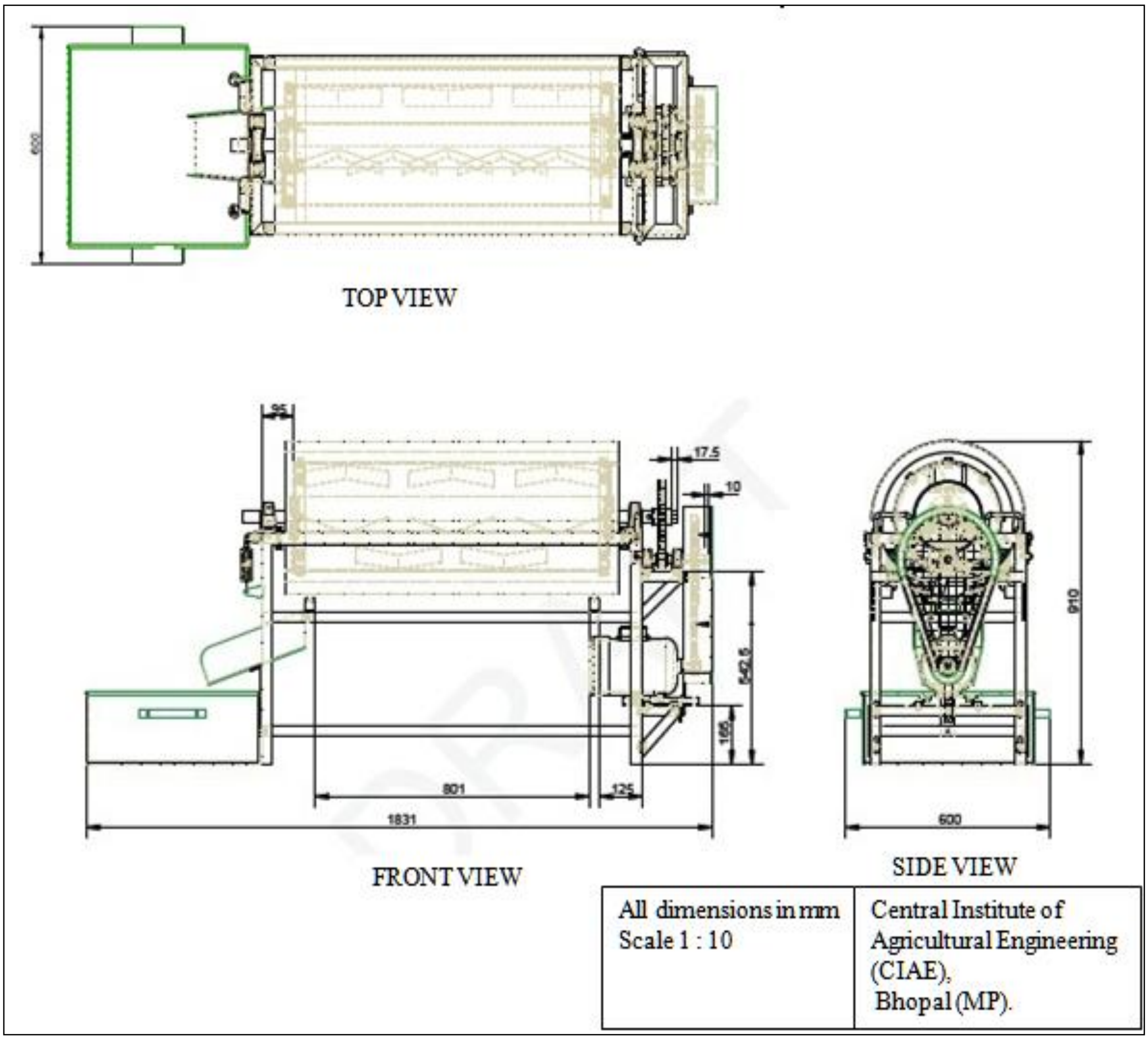
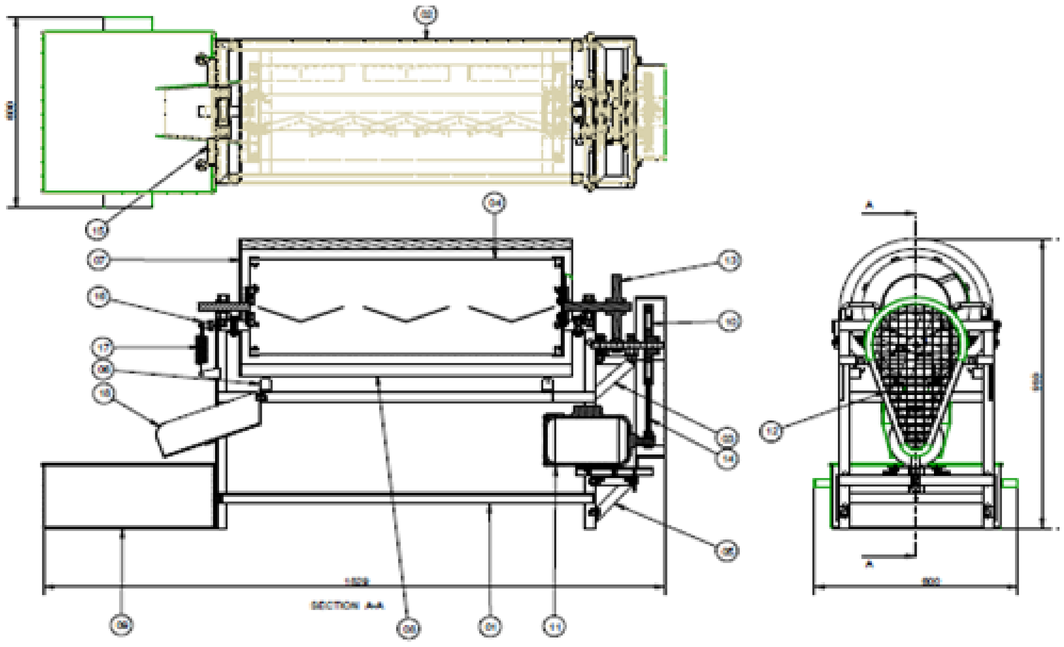


Fig 4.1 Different view of designed soybean roster

Table 4.1 Specification of materials/equipment/gadgets/instrument used for the development and performance evaluation of soybean roaster

Raw materials
Stainless steel sheet (2 & 3 mm)
Stainless steel plate (3 mm)
Stainless steel bolts and nuts (M10)
Mild steel rod (22 mm, 30 mm)
Steel sheet (1.2 mm)
Mild steel angle (30x30x5 mm)
Purchased items
Electric motor (1 hp)
‘V’ pulley (50 mm & 250 mm diameter)
‘V’ belt (B-42)
Thermal insulator (fibre glass wool, heat resistance of 1000°C)
Electric wire/cable
Nuts and bolts
Machines used
Arc welding machine
Automatic lathe machine
Shearing machine
Universal drilling machine
Hand drill machine
Hand grinding machine
Portable cutting machine
Gadgets/instruments
Thermocouple (K-type)
Digital type stop watch (Racer sport timer)
Balance (Precisa 310 M, Adair Dutt & Co. Pvt. India)
Digital photo type Tachometer (HTM-560)
Multimeter (P-3, SANWA India)
Clamp meter



1	:	Frame Assembly	10	:	Pulley 10 inch
2	:	Frame angle	11	:	Motor 1 hp
3	:	Frame angle	12	:	Safety guard
4	:	Roaster drum	13	:	Spur gear 125T
5	:	Motor support	14	:	Belt b-42
6	:	Burner holder	15	:	Hinge pin
7	:	Roaster cover	16	:	Spring support flat
8	:	Roaster cover	17	:	Spring
9	:	Collecting tray	18	:	Chute sheet

Fig 4.2 Different parts of designed roaster

Plate 4.8 Soybean roaster

4.6.7.4 Shaft

According to power transmission the diameter of shaft were selected for design and fabrication. The 30 mm and 20 mm diameters of drum shaft and intermediate shaft were selected.

4.6.7.5 Gears

Based on the type of gearing, the spur and pinion gear were selected for design. The spur gear is drive gear having Z=120T number of teeth which is mounted on drum shaft and pinion gear is driver gear having Z=25T number of teeth, mounted on intermediate shaft.

4.6.7.6 Bearing

The bush bearing of standard designation (P-204 & P-206) were selected. It is a medium series bearing with 20 mm and 30 mm inner diameter, respectively (Khurmi and Gupta, 2004). This selection was based on the type of load to be supported during rest/operation and shaft diameter.

4.7 Machine performance evaluation

4.7.1 Testing

Testing is a vital step in the process of machine development. After the design and construction, testing is necessary in order to (i) determine the performance of the machine, (ii) expose defect and area of possible modification and (iii) appreciate the level of success in the research. Thus, it is important to test run a machine to determine its performance. In order to evaluate the batch wise capacity of the machine, the input and output streams were carefully weighed with a weighing balance and rate of input and output calculated. The time required to roast the sample was different for different treatment were measured with the help of digital type stop watch (Plate 4.9). The investigated machine performance was evaluated with the help of following formulae,

$$\text{Machine capacity}\left(\frac{\text{kg}}{\text{min}}\right) = \frac{Q_f}{t_n} \quad \ldots(4.14)$$

$$\text{Through put machine capacity} = \frac{\text{wt.of grain after roast (kg)}}{t_n} \quad \ldots(4.15)$$

Percentage of weight loss after roasting (%)

$$= \frac{\text{wt. of soybean before roasting} - \text{wt. of soybean after roasting}}{\text{wt of soybean before roasting}} \quad \dots (4.16)$$

where,

Q_f : quantity of soybean in the drum (kg)

t_n : time taken to roast soybean (min)

4.7.2 Thermocouple

To determine the temperature of roasting drum, a K-type thermocouple (Omega K, chromel alumela, made in Japan) and Handy calibrator 710 (CA-12, made in Japan) was used (Plate 4.10). The thermocouple probe was placed touching the drum during roasting, and immersed in roasted grains.

4.7.3 Power requirement

The power consumption of roaster at no-load and at different load conditions were measured using multimeter (P-3, SANWA India) and clampmeter (Plate 4.11). The power requirement was calculated using the following equation.

$$\text{Power} = V \times I \times \cos\phi \quad \dots(4.17)$$

where,

V : input voltage (V)

I : input current (A)

Cos ϕ : power factor (0.8)

4.8 Experimental design for optimization of process parameters

Response surface methodology was used to optimize the roasting condition of soybean roaster having the prominent parameters viz., roasting time and roasting temperature. After preliminary tests, upper and lower levels for these variables were established. A central composite rotatable design (CCRD) was prepared to select variables level i.e. roasting time 9-12 min, outer temperature of roasting drum 125-175^{o}C (Table 4.2). The RSM was performed using two-factors (x_1 and x_2) with three levels central composite design. The responses studied are hardness, work done, L-value, a-value, and b-value of the roasted soybean. The x_1 and x_2 reflect the roasting time and roasting temperature, respectively. Since the functional relationship between the responses and factors was unknown, the first order or second order polynomial expressions for a selected experimental region (9-12 min and 125-175°C) was used to

Plate 4.9 Stop watch

Plate 4.10 Thermocouple

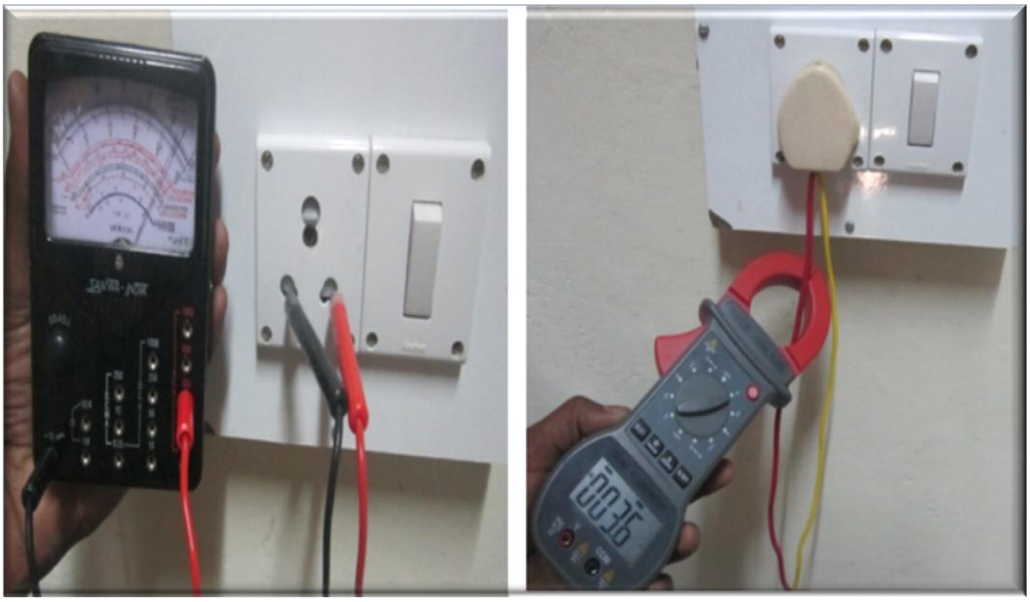


Plate 4.11 Multimeter and clampmeter for power measurement

estimate the actual response surfaces (Montgomery, 2009). The levels of these variables along with the experimental plan have been given in Table 4.2. For the analysis of experimental design by the response surface, it was assumed that n-mathematical functions, f_k (k=1, 2….. n), Y_k in terms of m independent processing factors X_i (i=1,2, …., m) existed for each response variable. $Y_k = f_k (X_1, X_2, ...X_m)$, in this case, n = 2, m = 3. Full second-order equation was fitted in each response to describe it mathematically and to study the effect of variables. The equation was as follows:

$$Y_K = \beta o + \sum_{i=1}^{m} \beta_i X_i + \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} \beta_{ij} X_I X_j + \sum_{i=1}^{m} \beta_{ii} X^2{}_i \qquad (4.18)$$

where,

Y_k	: Response variable
β_0	: Value of the fitted response at the centre point of design i.e. (0,0)
β_i, β_{ij}, β_{ii}	: linear, quadratic and interactive regression coefficients
X_i & X_j	: Coded independent variable

Table 4.2 Coded levels of independent variables used in developing experimental design for soybean roasting

Independent variables	Symbols		Levels	
	Uncoded	Coded	Uncoded	Coded
Roasting time (min)	t	X_1	8	-1.4142
			9	-1
			12	0
			15	1
			16	1.1442
Roasting temperature (ºC)	T	X_2	115	-1.4142
			125	-1
			150	0
			175	1
			185	1.1442

4.9 Preparation of soybean for roasting

The soybean The soaked (4 h) split soybean were dried (4 h) in cabinet dryer (60±5ºC) in order to remove surface moisture. The soaked dried sample (5 kg) was roasted in rotating drum roaster with temperature (115-185ºC) and roasting time (8-16 min) combination according to Table 4.2 and started to give characteristics aroma and flavour of roasted product. The roasted sample cooled at room temperature were packed at in low density poly ethylene bags (75 µ) and stored under ambient condition in plastic container till further use.

4.10 Texture Analysis

Texture of roasted soybean sample was measured using texture analyzer (TA. XT. Plus Texture Analyser, Stable Micro System, UK) using its testing setting viz., Test mode (compression), pre test speed (0.5 mm/s), test speed (0.1 mm/s), post test speed (1 mm/s), type of mode strain, strain (50%), testing force (0.05 N), (Plate 4.12). A kernel was placed horizontally on the plate and compression was applied using a cylindrical probe (P75). The test was performed for five times. The five roasted soybeans from each sample were selected for texture analysis. The measurements were taken for each sample. The maximum peak of the first compression (N) in the force time curves indicates the hardness value (Kayaoglu and Kaya 2006; Meullenet and Gross, 1999).

4.11 Colour measurement

All colour measurements were conducted within 2 days of roasting experiment. The poor quality roasted split seeds were removed before performance of colour measurement. The colour of roasted sample was measured using a hunter colour lab (Labscan XE Hunterlab, Plate 4.13). Before testing the sample, the instrument was calibrated with standard black and white tiles supplied with the instrument. The colour readings were expressed in terms of L, a and b-values. The L-value represents the light-dark spectrum with range of 0 (black) to 100 (white), the a-value represent green-red spectrum while the b-value represent the blue-yellow spectrum (Moss and Otten, 1989; Driscoll and Madamba, 1994; kahyaoglu, 2008). The five replication readings were taken for each sample. These values are dependent on measurement factors such as type and size of material, the angle of

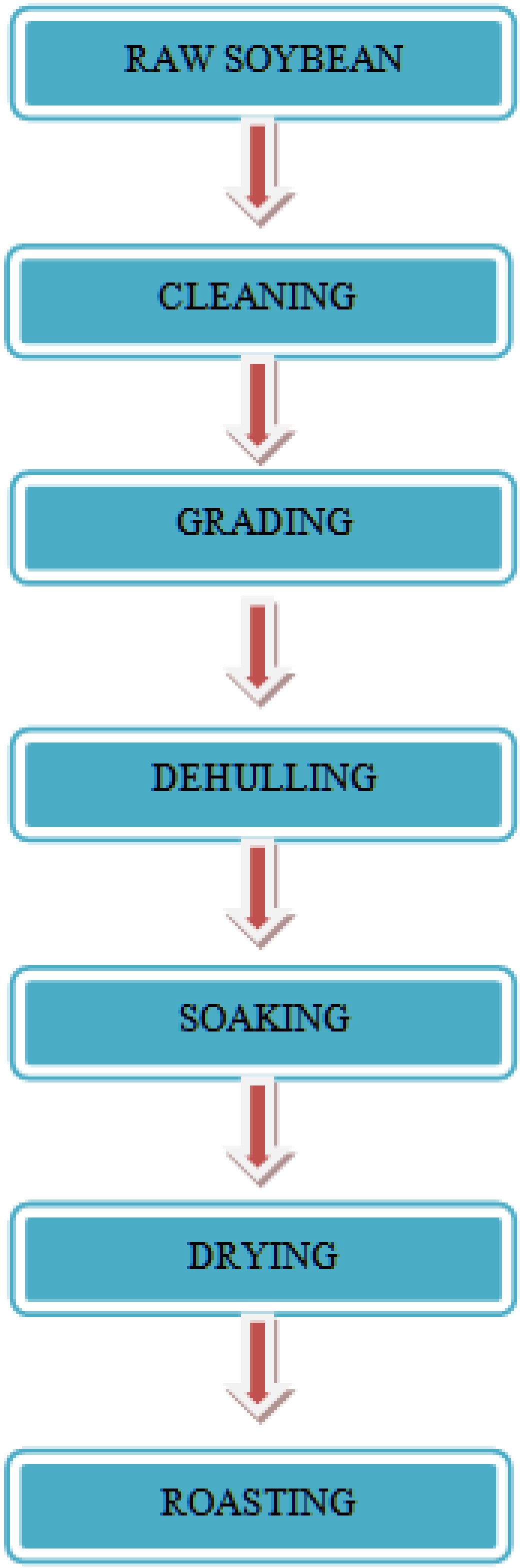


Fig. 4.3 Flow chart of sample preparation

measurement and stability of reference standards (Driscoll and Madamba, 1994). The colour measurement was carried out by randomly selected five samples from each designed treatment (Table 4.2). The average value was used for the response surface method (RSM) analysis.

4.12 Statistical analysis

Response surface methodology (RSM) was adopted in experimental design and analysis (Khuri and Cornpell, 1987). Multiple regression analysis was used to fit the model, represented by an equation, to the experimental data. Maximization and minimization of the polynomials thus fitted was done by numeric techniques, using the numerical optimization technique given in the software package (Design expert, 8.0.7.1, Minneapolis, MN, USA). The response surfaces for the models were plotted as a function of the two variables while keeping the other one at optimum level. The storage data were analyzed using the analysis of variance (ANOVA) (Snedecor and Cochran; 1968) using factorial completely randomized design (CRD). The partial F-test for individual term and an analysis of residuals were performed. ANOVA tables were generated, and the effects and regression coefficients of individual linear, quadratic, and interaction term in the polynomial were determined statistically by calculating the F-value at a probability (p) of 0.01 or 0.05. The regression coefficients were used to make statistical calculations to generate contour maps from the regression models.

Plate 4.12 Texture analyser

Plate 4.13 Hunter lab Colourimeter

RESULTS AND DISCUSSION

CHAPTER V

RESULTS AND DISCUSSION

This chapter deals with the research work carried out along with the result and discussion of the soybean roaster as listed below.

1. Physical properties of soaked soybean seed and splits.
2. Design and development of soybean roaster.
3. Transverse motion required for soybean roasting
4. Optimization of process parameters of soybean roaster using response surface methodology.

5.1 Physical properties

5.1.1 Geometrical properties of soybean seed and splits

The average value of three principal dimensions, determined in this study at different moisture contents are presented in Table 5.1. The sample size increased linearly in length (7.63-10.81 and 5.98-11.42 mm), width (6.72-7.77 and 4.28-6.30 mm), thickness (5.09-6.47 and 2.36-3.62 mm), arithmetic mean diameter (6.48-8.35 and 4.20-7.11 mm), geometric mean diameter (6.39-8.16 and 3.92-6.38 mm), square mean diameter (11.14-14.29 and 7.05-11.66 mm), equivalent diameter (8.00-10.26 and 5.06-8.38 mm), unit volume (140.35-302.72 and 35.86-169.25 mm^3) and surface area (131.77-222.58 and 54.85-159.02 mm^2), where in sphericity (0.83-0.75 and 0.65-0.55), aspect ratio (0.88- 0.71 and 0.71-0.52) and shape factor (1.05-0.95 and 1.09-0.98) were decreased linearly with the increase in moisture content from 13-25.9% and 12-34.4% (wb) for soybean seed and splits, respectively. It was found that the geometric mean diameter was lower than the major axis and sphericity of soybean seed and splits were much lower than the reported values of spherical shaped black pepper and okra seeds, and higher than for locust and faba bean seeds (Murthy and Bhattacharya, 1998).

Table 5.1 Physical properties of soybean seed and split at different moisture content (wb)

Moisture content (% wb)	Axial dimension (mm)			AMD (mm)	GMD (mm)	SMD (mm)	EQD (mm)	Sp	AR	SF(λ)	SA (mm^2)	Unit Volume (mm^3)
	Length	Width	Thickness									
Seed												
13.00	7.63	6.72	5.09	6.48	6.39	11.14	8.00	0.83	0.88	1.05	131.77	140.35
19.88	7.72	6.83	5.13	6.56	6.46	11.28	8.10	0.83	0.88	1.05	134.95	145.46
21.60	7.81	6.94	5.18	6.64	6.54	11.42	8.20	0.83	0.88	1.05	138.31	150.94
22.46	8.06	7.08	5.28	6.80	6.70	11.70	8.40	0.83	0.87	1.05	145.30	162.35
22.46	8.31	7.23	5.39	6.97	6.86	11.99	8.61	0.82	0.87	1.05	152.75	174.83
22.46	8.61	7.36	5.46	7.14	7.02	12.27	8.81	0.81	0.85	1.04	160.29	187.55
22.46	8.95	7.46	5.50	7.30	7.16	12.53	8.99	0.80	0.83	1.04	167.80	200.27
22.46	9.03	7.46	5.83	7.44	7.32	12.78	9.18	0.81	0.82	1.01	174.72	213.25
23.32	9.09	7.46	6.17	7.57	7.47	13.03	9.36	0.82	0.82	0.99	181.42	226.17
23.32	9.10	7.57	6.33	7.66	7.58	13.20	9.48	0.83	0.83	0.99	185.81	234.84
23.32	9.14	7.65	6.47	7.75	7.67	13.36	9.59	0.83	0.83	0.99	190.00	243.10
23.32	9.66	7.65	6.47	7.92	7.81	13.63	9.79	0.80	0.79	0.97	199.32	259.77
24.18	10.23	7.65	6.47	8.11	7.97	13.92	10.00	0.77	0.74	0.95	209.81	278.71
24.18	10.49	7.68	6.47	8.21	8.04	14.07	10.11	0.76	0.73	0.95	215.13	288.56
25.90	10.78	7.71	6.47	8.32	8.13	14.23	10.23	0.75	0.71	0.94	221.08	299.64
25.90	10.80	7.74	6.47	8.33	8.14	14.26	10.25	0.75	0.71	0.94	221.93	301.36
25.90	10.81	7.77	6.47	8.35	8.16	14.29	10.26	0.75	0.71	0.95	222.58	302.72
Split												
12.00	5.98	4.28	2.36	4.20	3.92	7.05	5.06	0.65	0.71	1.09	54.85	35.86
18.27	6.65	4.77	2.59	4.67	4.34	7.82	5.61	0.65	0.71	1.09	67.46	48.87
20.96	7.39	5.18	2.77	5.11	4.73	8.54	6.13	0.64	0.70	1.09	80.82	63.76
22.75	7.93	5.40	2.85	5.39	4.96	8.98	6.44	0.62	0.68	1.08	89.90	74.32
25.44	8.36	5.66	2.90	5.64	5.15	9.37	6.72	0.61	0.67	1.08	97.94	84.20
27.23	9.88	5.73	2.96	6.19	5.51	10.13	7.28	0.53	0.57	1.03	118.67	109.04
29.92	10.34	5.79	3.10	6.41	5.70	10.48	7.53	0.53	0.55	1.03	127.93	121.62
31.71	10.63	5.99	3.10	6.57	5.82	10.73	7.70	0.53	0.56	1.02	133.88	129.92
31.71	11.01	6.07	3.10	6.72	5.91	10.94	7.86	0.53	0.55	1.02	139.93	138.00
32.61	11.27	6.13	3.38	6.92	6.15	11.30	8.13	0.54	0.55	0.99	149.99	153.93
32.61	11.36	6.18	3.44	6.99	6.22	11.42	8.21	0.54	0.55	0.99	153.08	158.88
33.50	11.37	6.25	3.51	7.04	6.29	11.52	8.28	0.55	0.54	0.99	155.45	163.09
33.50	11.41	6.28	3.56	7.08	6.34	11.60	8.34	0.55	0.54	0.99	157.41	166.39
34.40	11.41	6.30	3.62	7.11	6.38	11.66	8.38	0.55	0.54	0.98	158.87	169.04
34.40	11.41	6.30	3.62	7.11	6.38	11.66	8.38	0.55	0.53	0.98	158.87	169.04
34.40	11.42	6.30	3.62	7.11	6.38	11.66	8.38	0.55	0.53	0.98	159.02	169.25
34.40	11.42	6.30	3.62	7.11	6.38	11.66	8.38	0.55	0.52	0.98	159.02	169.25

5.1.2 Statistical analysis

All the dimensions and physical properties of soybean samples were significantly and positively correlated to seed moisture content. A relationship was observed between moisture content to axial dimensions and physical properties as shown in Table 5.2. The change in soybean seed and splits dimension during soaking could be best expressed by a modified exponential relationship with the R^2 for equation fitting, respectively, The results were statistically analyzed for all physical properties of soaked soybean seed and splits.

Table 5.2 Regression equations for physical properties of soybean seed and splits

Properties	Soybean seed			Soybean splits		
	Range	**mx+c**	**R^2**	**Range**	**mx+c**	**R^2**
Geometric property						
Length (mm)	7.63 -10.81	0.0117x + 7.5727	0.9637	5.98 -11.42	0.0598x + 5.8264	0.9838
Width (mm)	6.72 -7.77	0.009 x + 6.7261	0.9829	4.28 - 6.30	0.0199x + 4.446	0.9672
Thickness (mm)	5.09 -6.47	0.0117x + 4.9105	0.9142	2.36 - 3.62	0.0088x + 2.4185	0.9710
AMD (mm)	6.48 -8.35	0.0109x + 6.3891	0.9934	4.20 - 7.11	0.03x + 4.2409	0.9951
GMD (mm)	6.39 -8.16	0.0112x + 6.2831	0.9929	3.92 -6.38	0.0235x + 4.0038	0.9965
SMD (mm)	11.14 -14.29	0.0192x + 10.979	0.9935	7.05 – 11.66	0.0459x + 7.1698	0.9963
EQD (mm)	8.00 - 10.26	0.0138x + 7.8837	0.9935	5.06 -8.36	0.0331x + 5.1382	0.9963
Sphericity	0.83 - 0.75	- 0.0001x + 0.832	0.7863	0.65 -0.55	- 0.0016x + 0.6709	0.8956
Aspect ratio	0.88 - 0.71	- 0.0002x + 0.889	0.9367	0.71 -0.52	- 0.0023x + 0.7454	0.912
Shape factor	1.05 - 0.95	- 0.0004x + 1.0678	0.938	1.09 -0.98	- 0.0011x + 1.1152	0.8983
Surface area (mm^2)	131.77 - 227.58	0.4671x + 127.27	0.9915	54.85 -159.02	1.0361x + 51.968	0.9946
Unit volume(mm^3)	140.35- 302.72	0.7862x + 131.91	0.9908	35.86 -169.25	1.2553x + 29.309	0.9926

X: moisture content, % wb.

5.1.3 Dimension changes

Changes occurring in grains dimension viz., length, width and thickness during soaking are presented in Fig. 5.1and 5.2. The different range of dimensional change in length, width and thickness were 7.63-10.81 and 5.98-11.42 mm, 6.72-7.77 and 4.28 - 6.30 mm, 5.09-6.47 and 2.36-3.62 mm, respectively, for soybean seed and splits. It is shown that dimension changes ratio increase with time, but not very sharply. Further, the seed and splits elongation was more pronounced during the initial stages of soaking. This result indicated that the seeds and splits expanded in length, width, thickness and geometrical properties within the moisture range. The axial dimensions increased with increase in moisture content due to absorption of

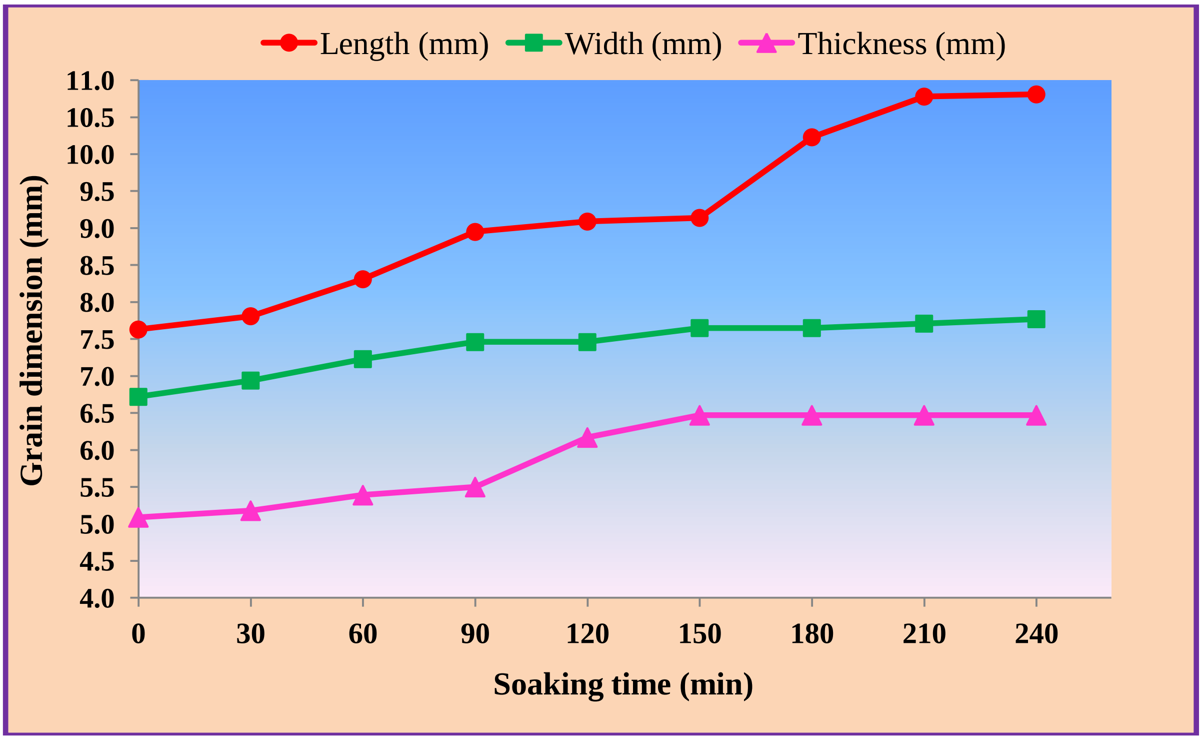


Fig. 5.1 Dimension changes occurring in length, width and thickness of soybean seed during soaking.

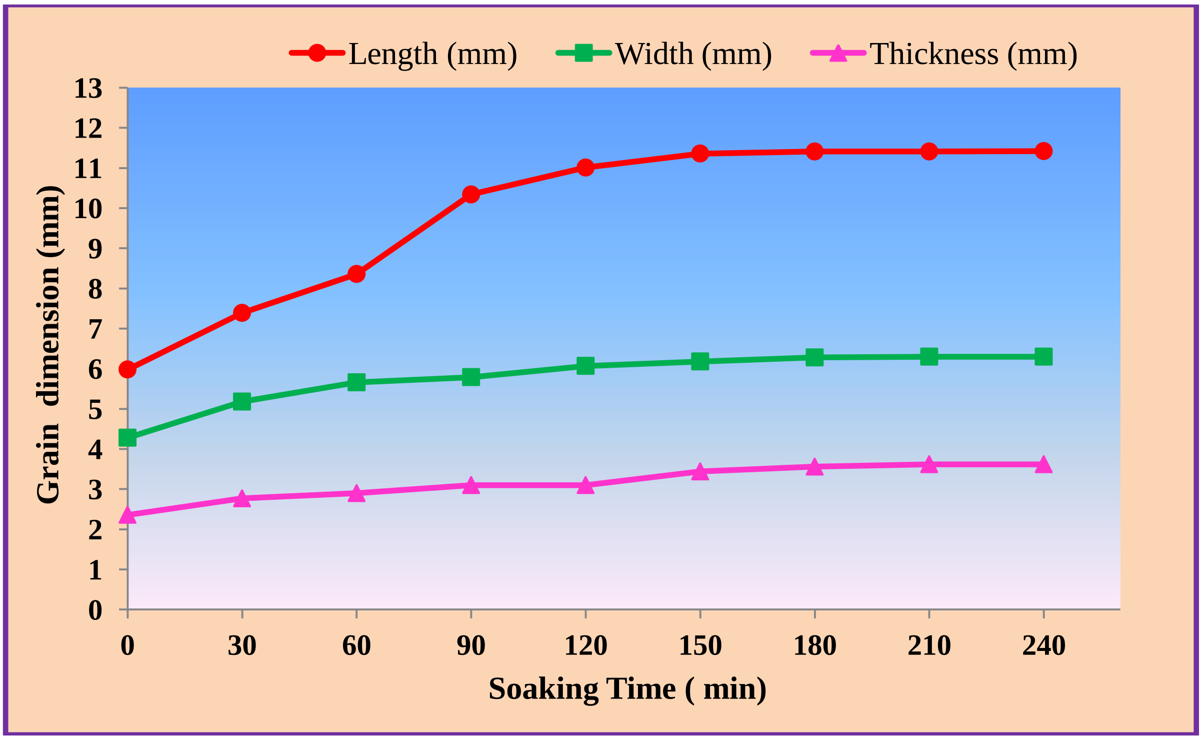


Fig. 5.2 Dimension changes occurring in length, width and thickness of soybean split during soaking.

moisture, which resulted in swelling of capillaries, stretching of longitudinal ridges on the soybean seed and splits surface and, finally, expansion in medium and minor axes. Similar trends were showed for coriander seeds (Coskuner and Karababa, 2007). The results of soybean seed and split size at different moisture content were displayed in Table 5.1. All the dimensions increased with moisture content in the moisture range of 13-25.9 % and 12-34.4 % (wb), respectively.

5.1.4 Water absorption level

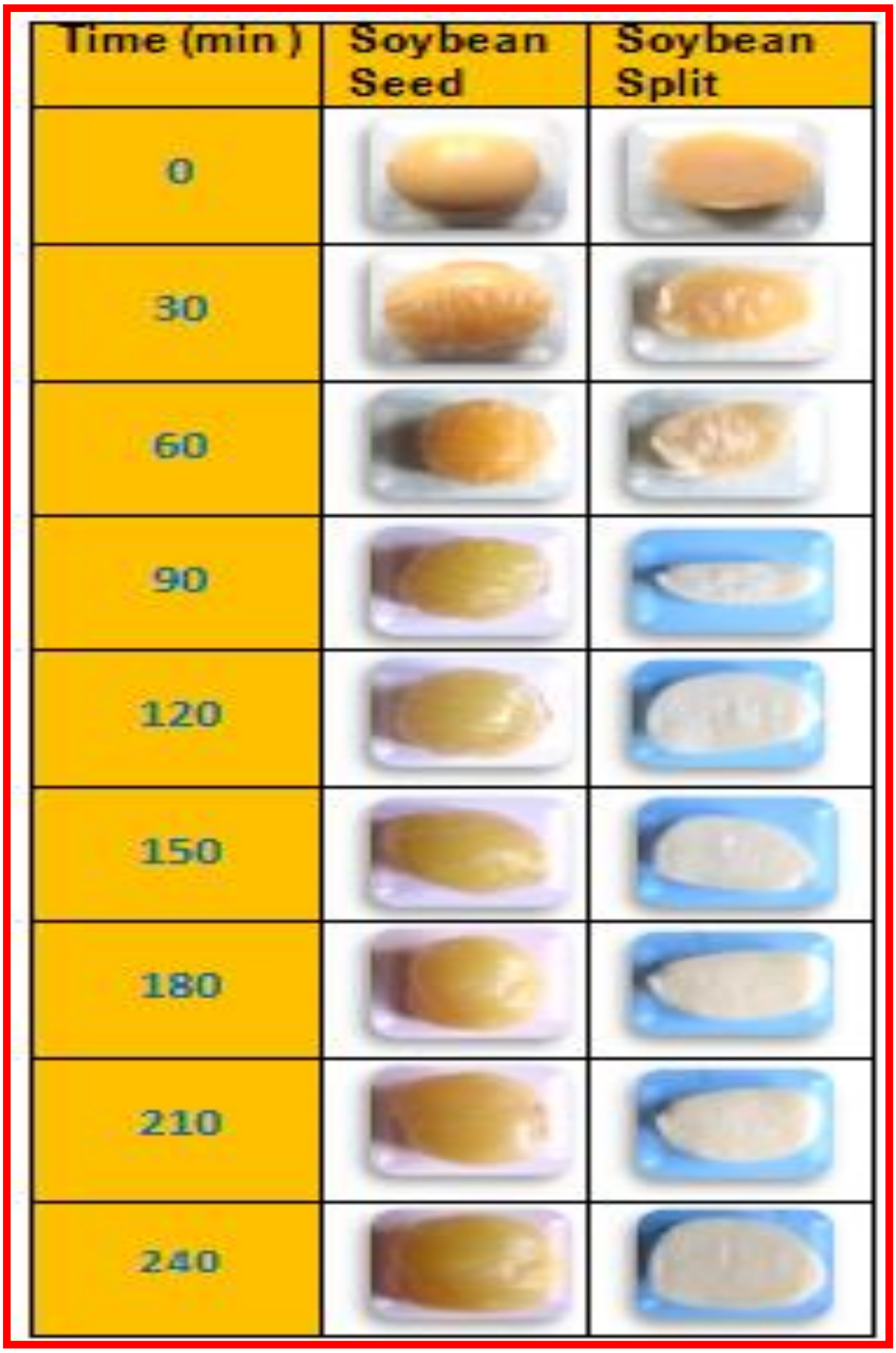
The effect of soaking on soybean seed and split is shown in Fig. 5.3. The graph showed that the sample dimensions increased marginally in the beginning for a very short period and were followed by a rapid increase. The initial moisture content for seed and split were 13% and 12%, respectively. The water absorption level were found increased as 3.1-5.2 mm for soybean seed and 3.5-6.3 mm for split reached after soaking for 4 h. Generally, the rate of water absorption was high for the first 30 min, after which it slowed for both seed and splits. Also observed that the physical appearance of compressed seed and splits were different from other grains with lower moisture. When the seed sample was soaked for 4 h and reached to high moisture level, the seed coat lost its strength to the water compression force.

5.1.5 Variation of moisture content

In the soybean soaking study, moisture content increased linearly with respect to soaking time. The moisture difference study of soaked soybean seed and split shows in Fig.5.4. The increased volume of sample during soaking the volumetric changes/expansion in the samples was similar with respect to the water uptake. The increased moisture content were from (13 to 25.9 %) for soybean seed and (12 to 34.4%) for split in 4 h soaking duration with respect to 15 min time interval.

5.2 Transverse motion required for soybean rotating

For design of cascading mode of motion, the various modes of motion were studied for soybean. The rpm of various modes of motion noted and determine the rpm required for cascading mode. In this study, the filling degree of soaked increased from 10 % to 50 % and rpm was gradually increased. For each degree of filling, all the modes of motion were recorded by camera and rpm were noted. The various typical images of transversal flow regimes of soybeans splits are illustrated in Plate 5.2.



Time (min)	Soybean Seed	Soybean Split
0		
30		
60		
90		
120		
150		
180		
210		
240		

Plate 5.1 Typical changes in images of soybean seed and split during soaking states

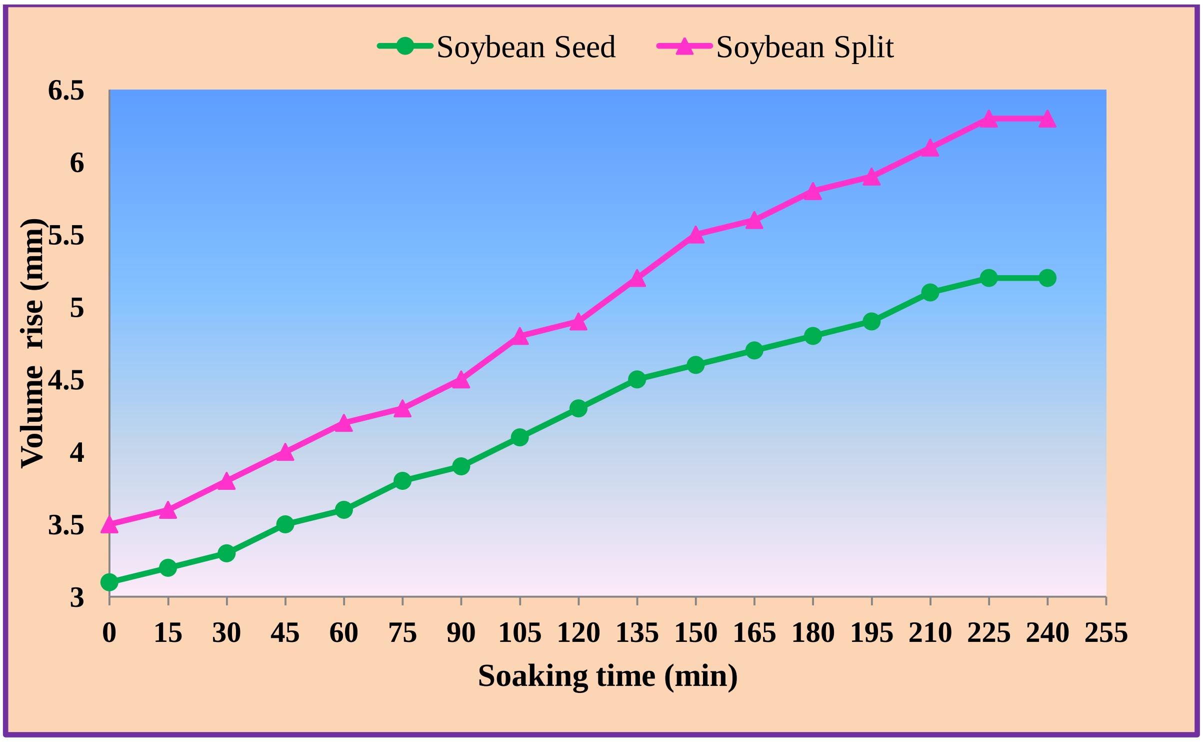


Fig. 5.3 Water absorption level at different soaking time for soybean seed and split.

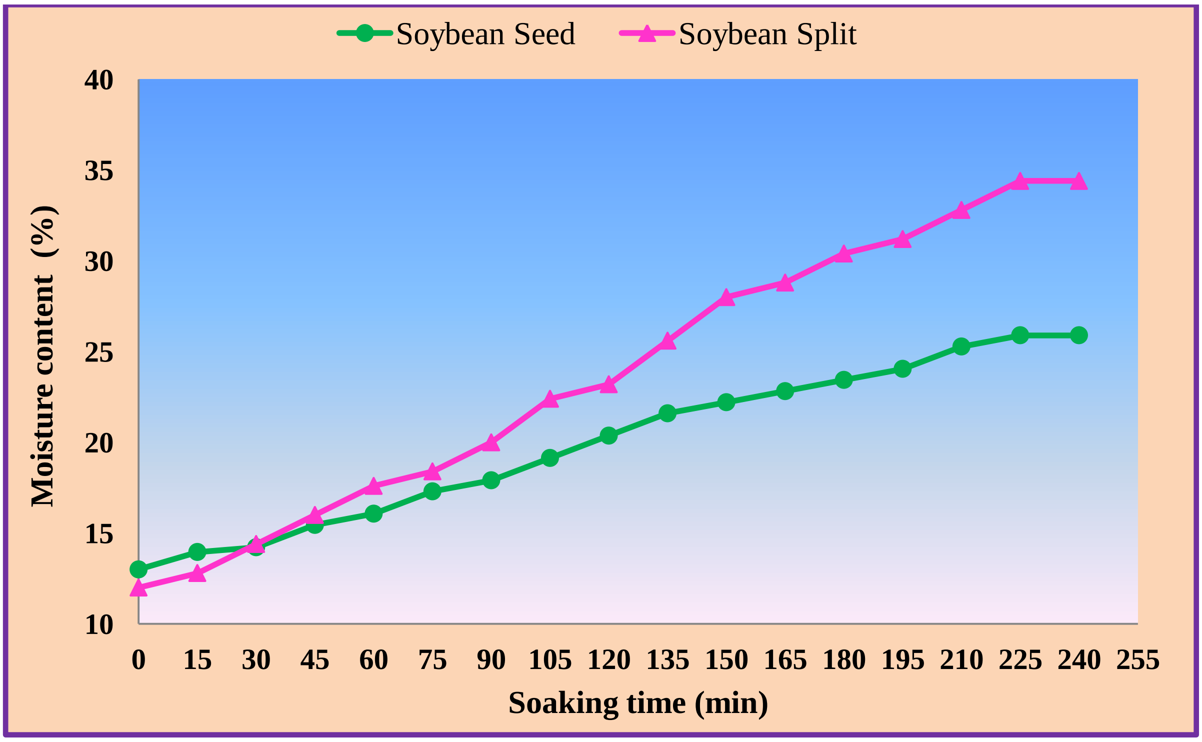


Fig. 5.4 Variation in moisture contents of seed and split with soaking time.

5.2.1 Sliding

Plate 5.2a represents the 10% filling of soybean splits for slipping motion behaviour with rotational speed < 10 (Fr: 0.0016-0.0087). The solid bed adheres on the rotating wall up to a certain angle of deflection and subsequently slides back on the wall surface. No particle mixing takes place in slipping motion. As a result, the product quality decreases. Slipping is an undesirable behaviour in which the bed of particle remains at rest and slips on the surface of the drum wall. Slipping usually occurs at low volumetric fill (Sherritt et al. 2002).

5.2.2 Slumping

When the rotational speeds are low (< 3% of critical speed), *slumping* of the bed can occur. Through solid body rotation with the rotational speed of the cylinder wall, the solid bed is continuously elevated, being leveled off again and again by successive avalanches at the surface Plate No.5.2b. The slumping frequency is dependent on rotational speed, particle size and cylinder diameter (Henein, 1983). As speed of rotation increases transition of flow takes place from slumping to rolling.

5.2.3 Rolling

The experimental data showed that the rolling mode of motion was occurred in rotational speed from 16 to 46 rpm (Fr: 0.045-0.37) depending on filling degree. For lower filling degree (10-20%) the rolling mode took place at rotational speed from 16 to 20 rpm (Fr: 0.045-0.071), where for higher filling degree (40-50%) the rolling mode took place at rotational speed of 22 to 46 rpm (Fr : 0.086-0.37). (Cristo *et al*., 2006) have also reported similar results for coffee beans. The same experiment was carried out for soaked soybean sample, the rolling mode of motion was occurred in rotational speed from 20 to 25 rpm (Fr: 0.078-0.011) depending on the filling degree. The length of active layer in rolling motion of soaked soybean split bed will be shorter than raw beans, due to the higher filling degree of the former. Also, the low velocity core is larger and thus the mixing can be considered to be poorer than for the raw soybeans bed in the same type of flow regime. (Cristo *et al*. 2006 and Liu *et al*. 2005) have also reported a similar result for the effect of filling degree on the transition from slumping to rolling for coffee beans, gravel, limestone, and sand.

(Henein *et al*. 1983) found that for a range of materials, the bed operating in the rolling regime ($Fr>10^{-3}$) at their lowest filling degree of 0.40. (Mellmann 2001) also showed that rolling beds typically occur at Froude numbers between 10^{-4} and 10^{-2} with a filling degree greater than 0.10. (Dury *et al*. 1998) found that there was a transition from slumping to rolling ($Fr \approx 1.2x10^{-3}$) at 50% filling degree for mustard seeds in a 69 mm diameter drum. The rolling behaviour of grain bed is an advanced stage of slumping mode of motion. Rolling behaviour occurs between 3% and 30% of the critical speed. Rolling behaviour, which occurs at lower bed depth and fraction of the critical speed than cascading behaviour, is characterized by a flat upper surface as illustrated Plate No. 5.2c.

5.2.4 Cascading

The experimental study shows that the cascading mode of motion was occurred in rotational speed from 40 to 66 (Fr: 0.28-0.77) for raw soybean sample and from 41 to 63 (Fr: 0.30-0.70) for soaked soybean depending on filling degree. In Plate No. 5.2d bed of raw soybean has been shown to be flowing in a transitional rolling-to-cascading-type of motion, in the transversal section. It is clearly seen that the flow is divided in two different layers: the active layer in the upper part of the flowing bed, and the passive layer that moves at the same angular rotation speed as the cylinder wall. It is also observed that there is a segregated core, located near the central axis of the cylinder. In this segregated core, the beans velocities are rather low compared to the rest of the bed. Thus, the mixing in that region is poor. As the rotation speed is increased, and the flow regime changes to a full cascading-type of motion, the segregated core tends to reduce or even disappear, improving the mixing of particles in that portion of the bed. The transition from rolling to cascading is also dependent on particle size. The height of the arch of the kidney-shaped bed increased with increased rotational speed. Both rolling and cascading behaviors occur between 3% and 30% of the critical speed (Sherritt *et al.*, 2003).

5.2.5 Cataracting

The transition of bed from cascading to cataracting takes place by increasing rotational speed of the bed (Plate No.5.2e) so that the individual particle detach from the bed and are thrown off in to the free space of the drum. The cataracting mode of motion occurred at rotational speed from 70 to 150 (Fr: 0.87-4.02) for raw soybean and rotational speed from 81-170 (Fr: 1.17-5.16) for soaked soybean. The rotational speeds for cataracting modes of motion were different for different filling. In the cataracting mode of motion there was a breaking of soaked and raw samples takes place. Hence, this type of motion is not recommended for roasting of soybean in conventional roaster. As rotational speed increases, the cascading motion is so strongly pronounced that individual particles detach from the bed and are thrown off into the free space of the cylinder. The release of particles is a characteristic feature of cataracting motion (Boateng *et al* 1996). Drums rotating at more than 30% of critical speed were assumed to have cataracting behaviour (Sherritt *et al* 2003).

5.2.6 Centrifuging

The centrifuging behaviour is observed at high rotational speeds when the centrifugal force at the wall exceeds the gravitational force. The particles remain fixed to the wall. The speed at which centrifuging begins to occur is referred to as the critical speed and can be determined using the following equation (Sherritt *et al.,* 2003).

$$n_c = \frac{60}{2\pi}\sqrt{\frac{g}{R}} \qquad \ldots(5.1)$$

where,

n_c : critical speed (rpm)

R : inner radius of drum (m)

g : acceleration due to gravity (m/s).

The centrifuging motion of soybean (Plate No. 5.2f) for rotational speed from 100 to174 (Fr: 1.78-5.41) and from 101 to 210 (Fr: 1.82-7.88) for raw and soaked soybean splits, respectively. In this type of motion, the flowing bed will be characterized as a uniform film evenly distributed along the wall of cylinder, with a weak showering of particles in the upper right half of cylinder transversal section. This type of regime is not recommended for any kind of process, since there isvirtually no mixing of the particles. For the soaked beans, with a higher filling degree, centrifuging motion is different from raw beans. In the extreme case of cataracting motion, further increases of the rotational speed, particles on the outer paths $r \approx R$ begin to adhere to the wall and, centrifuging, occurs. Theoretically, centrifuging reaches its final stage when the entire solid material is in contact with the cylinder wall as a uniform film. This state is however only achieved, and only approximately as well, at extremely high rotational speeds (Diedrich, 1961).

Table 5.3 Various modes of motion for 10–50% degree of filling of soaked split soybean

Sr. No	Modes of motion	10 % filling		20% filling		30 % filling		40% filling		50% filling	
		rpm	Fr.	rpm	Fr.	rpm	Fr.	rpm	Fr.	rpm	Fr.
1	Sliding	6	0.0064	7	0.0078	5	0.0044	4	0.002	3	0.0094
2	Slumping	13	.030	15	0.040	11	0.021	13	0.030	10	0.017
3	Rolling	21	0.078	20	0.071	22	0.086	25	0.11	24	0.10
4	Cascading	41	0.30	60	0.70	43	0.33	41	0.30	47	0.39
5	Cataracting	105	1.97	170	5.16	81	1.17	89	1.41	84	1.26
6	Centrifuging	182	5.92	210	7.88	170	5.16	101	1.82	113	2.28

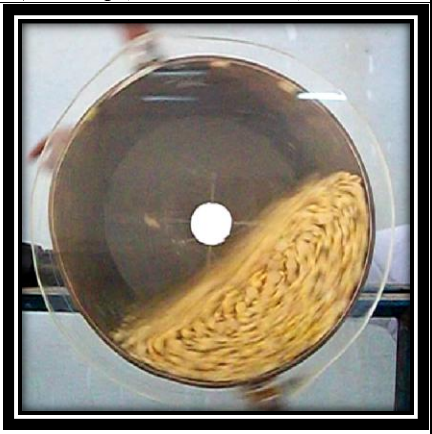
Fig. 5.5 & 5.6 represent the flow regime with varying rotational speed (peripheral Froude No.), for 10%, 20%, 30%, 40% and 50% degree of filling of raw soybean. The six points on each curve represent sliding, slumping, rolling, cascading, cataracting and centrifuging modes of motion of that filling degree. The transitions from one regime to another are sensitive to both the variation in the bin physical properties and degree of fill of the cylinder (Helder *et al*., 2006).

5.3 Design parameter of roaster machine

The design parameters of roaster are shown in Table 5.3. The motor was selected on the basis of power requirement. A 1 hp electric motor was selected. The intermediate shaft of soybean roaster was used to mounted large pulley (250 mm) and pinion gear (Z=25T), the length and diameter of this shaft is 210 mm and 20 mm, respectively. The speed of intermediate shaft was chosen as 288 rpm for rotation of

a) Sliding (N<10, Fill 10%)

b) Slumping (N=10-15, Fill 30%)



c) Rolling (N=16-46, Fill 30%)

d) Cascading (N=40-66, Fill 30%)

e) Cataracting (N=70-100, Fill 30%)

f)Centrifuging (N=100-174, Fill30%)

Plate 5.2 Transition flow of soybean splits at various motion modes

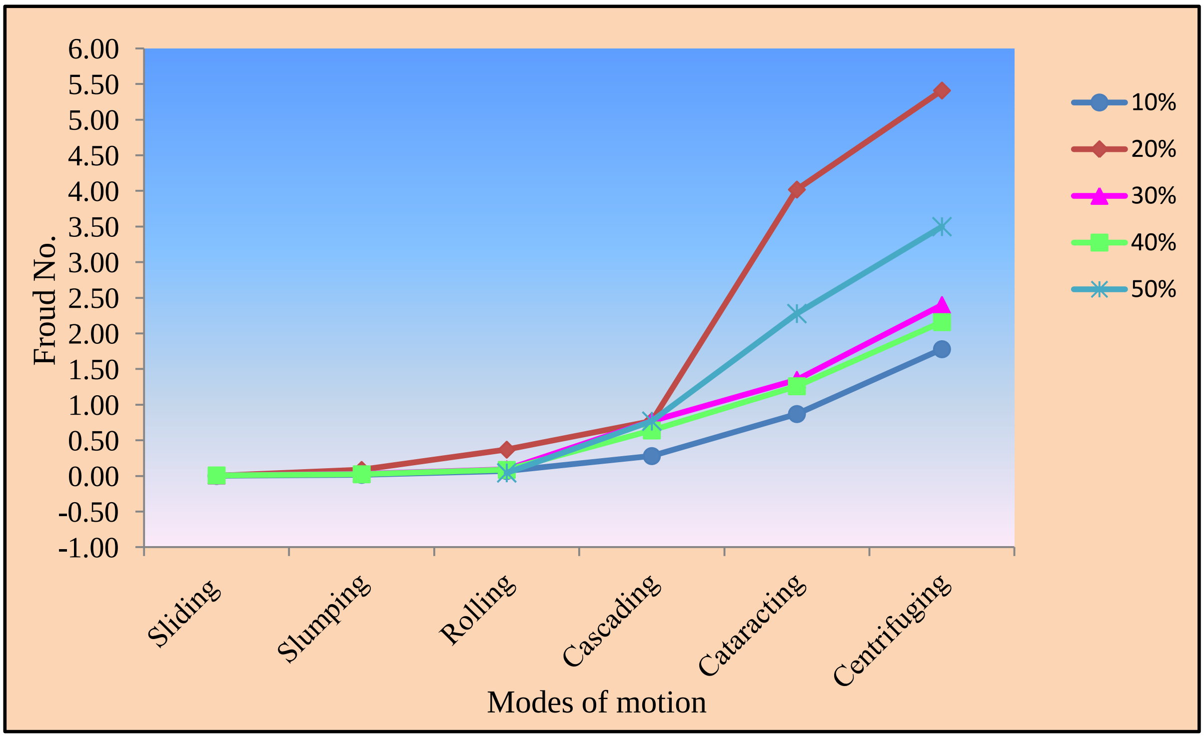


Fig.5.5 Different types of flow regime for varying degree of filling of split soybeans

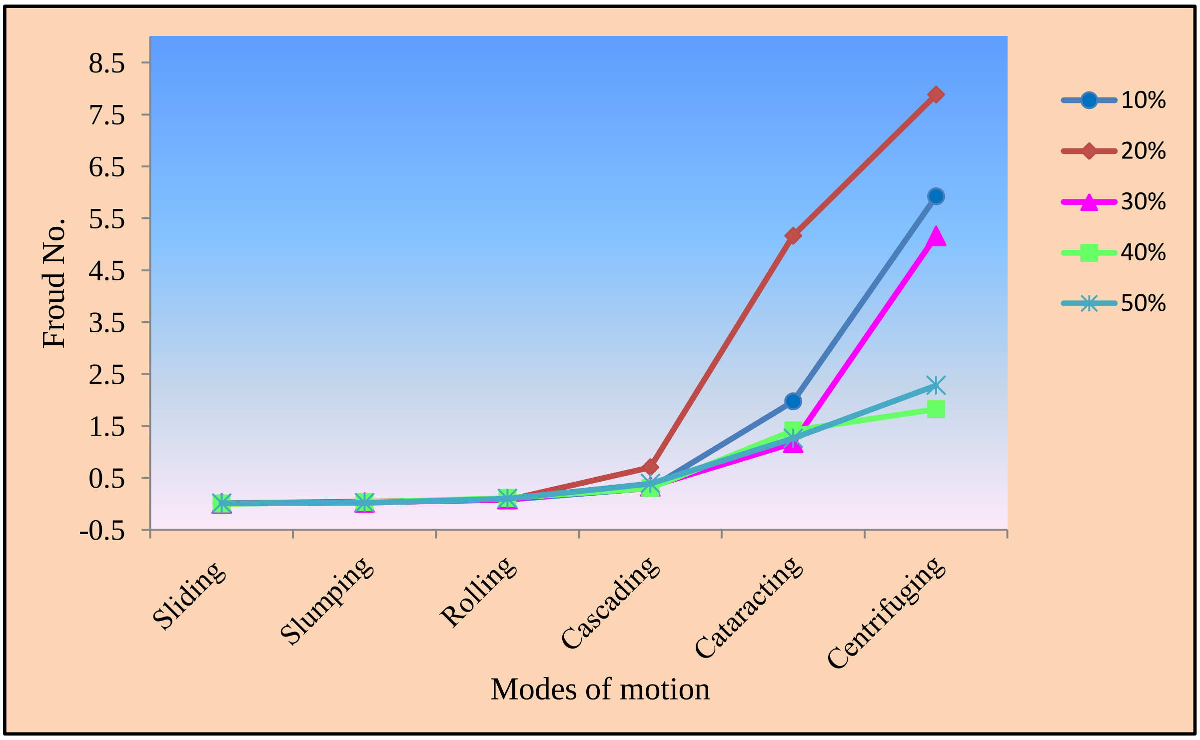


Fig. 5.6 Different types of flow regime for varying degree of filling of soaked split soybeans

pinion gear. The speed of drum shaft has length and diameter 350 mm and 30 mm, respectively, was chosen as 60 rpm for rotation drum. The diameter 300 mm and length 900 mm was chosen for design of drum. The volume of drum is 6.3×10^7 mm^3 (Table 5.3). The bush bearing of standard designation P-204 and P-206 were selected. The developed roaster occupied 1831×910 mm^2 floor area having 132.4 kg weight.

Table 5.4 Design specification of soybean roaster machine

Component	Parameters
Electric motor	Frame shaft, pulley and capacity design 1,440 rpm, 1.0 Hp
Pulley	
Pulley (large)	OD = 250 mm, ID = 210 mm
Pulley (small)	OD = 50 mm, ID = 10 mm
Gears	Module = 1.5 Pitch = 5 mm
Spur gear Pinion gear	OD = 203 mm, ID= 30 mm, Z = 125 T OD = 43 mm, ID= 20 mm, Z = 25 T
Speed ratio	
Intermediate Shaft	N_1 = 288 rpm, D = 20 mm, T= 65.97×10^3 N-mm
Drum shaft	N_2 = 60 rpm, D = 30 mm, T= 22.26×10^4 N-mm
Belt	B-42, D= 300 mm, x= 317mm, d= 50 mm, L= 1104 mm
Drum	D = 300 mm, L = 900 mm, V= 6.36×10^7 mm^3
Arc of contact	D= 250, d= 50mm, x =317, β = 142.14^o
Power requirement	V= 225 V, I = 13.49 Amp, 2.068 kW

5.4 Investigation on the optimum machine capacity

It is important to evaluate the machine performance in order to detect the optimum capacity. The details of methods employed, experiment conducted and evaluation are provided the previous section. Its capacity was evaluated based on the preliminary formula such that initial weight of soaked soybean divided by the time taken for roasting. Five kilograms of soaked soybean were roasted in the roaster to investigate the performances and capacity of the machine. The machine performance investigation was based on the experimental designed. The time required to roast soybean sample and temperature attained during operation was observed. The results showed that the input capacity and throughput capacity are15 kg/batch and 13.5 kg/ batch and drum speed was as 60 rpm.

5.4.1 Bulk density

The bulk densities of roasted samples were determined as shown in Table 5.5 It ranges from 563.27 kg/m^3 – 707 kg/m^3. The bulk density varies from treatment to treatment.

5.4.2 Percentage of weight loss

The percentages of weight losses of roasted sample were determined is shown in Table 5.6. The percentage of weight loss weight varies from 2.40% to 17.4%, depending on roasting condition.

5.5 Performance of soybean roaster

The designed soybean roaster was operated by a 1 hp single phase electric motor and a drum speed of 60 rpm. This machine can roast soaked soybean with a help of LPG as a heating source. The temperature of drum was controlled manually with the help of flow control knob. The driving mechanism of gear and pulley was designed in such a way that the V-belt was safe from heating source and was able to transmit required speed to the intermediate shaft from the motor. The pinion and spur gear were designed in such a way that required to reduce the speed of drum shaft. The specifications of developed roaster are shown in Table 5.7.

Table 5.5 Bulk density determination

Expt. No.	wt of sample(gm)	Volume of sample (cm^3)	Bulk density (kg/m^3)
1	490	763.4	641.87
2	430	763.4	563.27
3	490	763.4	641.87
4	440	763.4	576.37
5	500	763.4	654.96
6	500	763.4	654.96
7	500	763.4	654.96
8	450	763.4	589.47
9	540	763.4	707.36
10	490	763.4	641.87
11	500	763.4	654.96
12	480	763.4	628.77
13	460	763.4	602.57

Table 5.6 Percentage of weight loss

Sample No.	Before roasting weight	After roasting weight	Weight loss (%)
1	5	4.38	12.4
2	5	4.55	9.00
3	5	4.39	12.2
4	5	4.88	2.40
5	5	4.44	11.2
6	5	4.39	12.2
7	5	4.23	15.4
8	5	4.60	8.00
9	5	4.60	8.00
10	5	4.60	8.00
11	5	4.13	17.4
12	5	4.18	16.4
13	5	4.41	11.8

Table 5.7 Specification of soybean roaster

Name of machine	Soybean roaster
Purpose	Roasting of soaked soybean
Mode of operation	Batch type
Overall dimension (mm)	1831 x 600 x 910
Roasting drum	
Diameter (mm)	300
Length (mm)	900
Emptying angle (^{o})	45^o
Volume (mm^3)	$6.36x10^7$
Power unit (Electric motor)	
Power rating (Hp)	1 hp, single phase motor
Working speed (rpm)	60
Capacity (kg/batch)	15 Kg/batch
Weight (kg)	132.4 Kg (including motor)
Floor area (mm^2)	1831 x 600

5.6 Response surface methodology

5.6.1 Diagnostic checking of the fitted models

The actual values of the test variables and the experimental results viz., hardness, work done, L-value, a-value and b-value were ranged as 103.74-154.23, 356.98-672.56, 38.55-52.97, 6.95-11.79, and 14.98-21.75, respectively (Table 5.8). All main, linear, quadratic and interactive effects were calculated for each model. The correlation coefficients for the responses, i.e. hardness, work done, L-value, a-value and b-value were 0.998, 1.000, .975, 0.999 and 0.999, respectively, indicating that all the values were equal to or more than 97%. The calculated F-values were more than the table F-value indicating the adequacy of the models. All five responses were considered adequate to describe the effect of variables on the quality of roasted soybean samples.

5.6.2 Effect of variables on hardness

Hardness is an important parameter that needs to be controlled during roasting of soybean. Both time and temperature had a significant ($p \leq 0.05$) positive effect on the hardness at the linear level. The hardness value of soybean during roasting varies from 103.74 N to 154.234 N while roasted at 175ºC for 15 min, and 185ºC for 12 min (Table 5.8). Fig. 5.7 represents the effect of roasting time and temperature on hardness (force). The decrease in hardness showed the same deformation trend and the force required to break the soybean was smaller as roasting time and temperature were increased. Similar result obtained by Shakerardekani *et al*., (2011) for roasting of pistachio kernels. This finding is concurrent with Nikzade and Sedaghat (2008) who observed a similar reverse relationship between roasting temperature and hardness of pistachio nuts. The decrease in hardness with the increase in roasting time had also been reported by Kahyaoglu and Kaya (2006) for sesame seeds. Time had a significant ($p \leq 0.05$) negative effect on hardness at quadratic level. Temperature had a significant ($p \leq 0.05$) positive effect on hardness at quadratic level.

5.6.3 Effect of variables on work done

The time had a significant ($p \leq 0.01$) negative effect on work done on the linear level, and significant ($p \leq 0.05$) positive effect on work done on the quadratic level.

Table 5.8 reveals that work done increases with an increase in level of roasting time and temperature. Temperature had a significant ($p \le 0.05$) positive effect on work done on the linear level and quadratic level. The workdone value of roasted soybean were found varied from 356.986 J to 672.568 J while roasted at 125ºC for 15 min, and 150ºC for 16.2 min (Table 5.8). Fig. 5.8 represents the effect of roasting time and temperature on workdone.

5.6.4 Effect of variable on colour

Colour of roasted soybean is an important quality factor for consumers. During roasting of most nuts, brown pigments generally increase as browning and caramelisation reactions where in progress (Sena *et al*., 2001). The observed colour (L-value, a-value, b-value) values of roasted soybean with different time and temperature combination are presented in Table 5.8. The L-value varied between 38.550 and 52.976, a-value varied between 6.958 and 11.793, and b-value varied between 14.896 and 21.750 within combination of variable studied. Table 5.9 revealed that roasting time had negative effect ($p \le 0.01$) on L-value at linear level. The roasting temperature had a significant ($p \le 0.05$) positive effect on L- value at linear level. (Kaur et al., 2011) also found increased brightness of wheat pasta incorporated with barley and oat bran. Fig. 5.9 represents the changes in lightness of roasted soybean as a function of roasting time and temperature. Both time and temperature had significant ($p \le 0.01$) negative effect at L-value on quadratic level and interception level. Roasting temperature had significant ($p \le 0.01$) negative effect on a-value at linear level and quadratic level. Both time and temperature had significant ($p \le 0.01$) negative effect on a-value on linear and quadratic level. Fig. 5.10 represents changes in redness of roasted soybean as a function of roasting time and temperature. In this study, it was observed that both roasting temperature and time influence the changes in colour attributes of soybean but the effect of temperature is more important than time. Similar findings were observed by Demir *et al*. (2002) and Ozdemir and Devres (2000b) in their studies for hazelnuts.

5.6.5 Analysis of variance

When a model had been selected, an analysis of variance was calculated to assess how well the model represented the data. F-value for all the responses indicated that all the two variables affected the responses significantly ($p \leq 0.05$) (Table 5.10). On this basis, it can be concluded that the selected models adequately represented the data for hardness and work done of roasted samples.

5.6.6 Optimization of independent variable levels

Optimization of level of variables was done by selecting the response i.e. hardness, work done, L-value, a-value and b-value. On the basis that the responses had direct effect on the quality and acceptability of the roasted soybean as shown by their respective R^2 value. Graphical as well as numerical optimization was done. Table 5.11 showed the criteria used, upper and lower limit, the predicted and actual value of the responses. Numerical optimization was carried out for the level of ingredients to obtain the best product. The desired goals for each factor and response were chosen and different time and temperature were assigned to each goal to adjust the shape of its particular desirability function (Table 5.11). Among the solutions obtained, the solution with maximum desirability was selected as optimum ingredients composition. The observed experimental values and values predicted by the equations of the model are presented in Table 5.11. Closeness between the experimental and predicted values of the quality parameters indicated the suitability of the corresponding models. Fig. 5.12 depicts overlay plot showing the optimum level of ingredients and corresponding response values ie, roasting time as 10 min 42 sec and outer temperature of roasting drum as171.5

Table 5.8 Central composite design arrangement and responses

Exp. No.	Roasting time (min)	Roasting temperature (^oC)	Hardness (N)	Work done (J)	L	a	b
1	0.00	0.00	153.054	638.295	46.538	11.734	21.57
2	1.41	0.00	152.982	672.568	38.55	10.388	14.896
3	0.00	0.00	141.054	638.255	45.53	11.744	21.58
4	-1.00	-1.00	151.474	653.999	47.168	9.368	19.096
5	0.00	0.00	144.32	638.277	44.778	11.713	21.550
6	0.00	0.00	142.154	638.235	47.545	11.739	21.670
7	1.00	-1.00	115.427	356.986	47.374	8.282	19.608
8	-1.41	0.00	125.104	684.508	43.228	10.222	17.318
9	1.00	1.00	103.742	572.298	39.236	11.118	16.060
10	0.00	0.00	143.254	638.255	45.578	11.793	21.750
11	0.00	-1.41	145.72	637.042	42.48	10.032	20.314
12	0.00	1.41	154.234	667.428	48.752	9.348	19.912
13	-1.00	1.00	132.384	580.374	52.976	6.958	21.122

Table 5.9 Estimated coefficients of fitted quadratic equation for different responses

Factors	Estimated coefficients				
	Hardness (N)	Work done (J)	L	a	b
β_0	142.77	638.26	45.99	11.74	21.62
β_1	9.86	-4.22	-1.65	0.059	-0.86
β_2	3.01	10.74	2.22	-0.24	-0.14
$\beta_1\beta_2$	1.85	72.23	-3.49	1.31	-1.39
β_1^2	-1.86	20.14	-2.55	-0.72	-2.76
β_2^2	3.60	6.99	-0.19	-1.03	-0.76
$\beta_1^2\ \beta_2$	-10.70	24.68	-2.80	0.35	-0.24
$\beta_1\ \beta_2^2$	-26.03	-72.05	-1.73	0.71	-0.28
$\beta_1^2\ \beta_2^2$	-18.75	-124.47	3.44	-1.07	0.86
R^2	0.998	1.000	0.975	0.999	0.999

Table 5.10 Analysis of variance of different models

Response	Sources of variance	Sum of squares	d.f.	Mean square	F-value
Hardness	Model	2723.72	8	340.46	225.42
	Residual	6.04	4	1.51	
	Cor.Total	2729.76	12		
Work done	Model	85164.82	8	10645.60	2.022E+007
	Residual	2.106E-003	4	5.265E-004	
	Cor.Total	85164.82	12		
L	Model	175.56	8	21.95	19.21
	Residual	4.57	4	1.14	
	Cor.Total	3.44	12		
a	Model	28.18	8	3.52	4043.24
	Residual	3.485E-003	4	8.713E-004	
	Cor.Total	28.19	12		
b	Model	63.32	8	7.91	1117.92
	Residual	0.028	4	7.080E-003	
	Cor.Total	63.35	12		

Table 5.11 Constraints, criteria for optimization, solution along with predicted and actual response values

Constraints	Goal	Lower limit	Upper limit	Predicted values	Actual response values
Roasting time (min)	is in range	-1	1	10.42	-
Roasting temperature (^oC)	is in range	-1	1	171.50	-
Hardness (N)	is in range	140	148	142.212	142.30±0.13
Work done (J)	Minimise	550	650	544.878	544.50±0.17
L-value	is in range	44	47	44.3926	44.40±0.02
a-value	is in range	9	11	9.97897	9.98±0.14
b-value	is in range	18	21	18.9799	18.98±0.15

a)Expt 1, (0.0, 0.0) | b) Expt 2, (1.41, 0.0) | c) Expt 3, (0.0, 0.0)

d) Expt 4, (-1.0, -1.0) | e) Expt 5, (0.0, 0.0) | f) Expt 6, (0.0, 0.0)

g) Expt 7, (1.0, -1.0) | h) Expt 8, (-1.41, 0.0) | i) Expt 9, (1.0, 1.0)

j) Expt 10, (0.0, 0.0) | k) Expt 11, (0.0, -1.41) | l) Expt 12, (0.0, 1.41 | m) Expt 13, (-1.0,1.0)

Plate 5.3 Roasting of Soybean

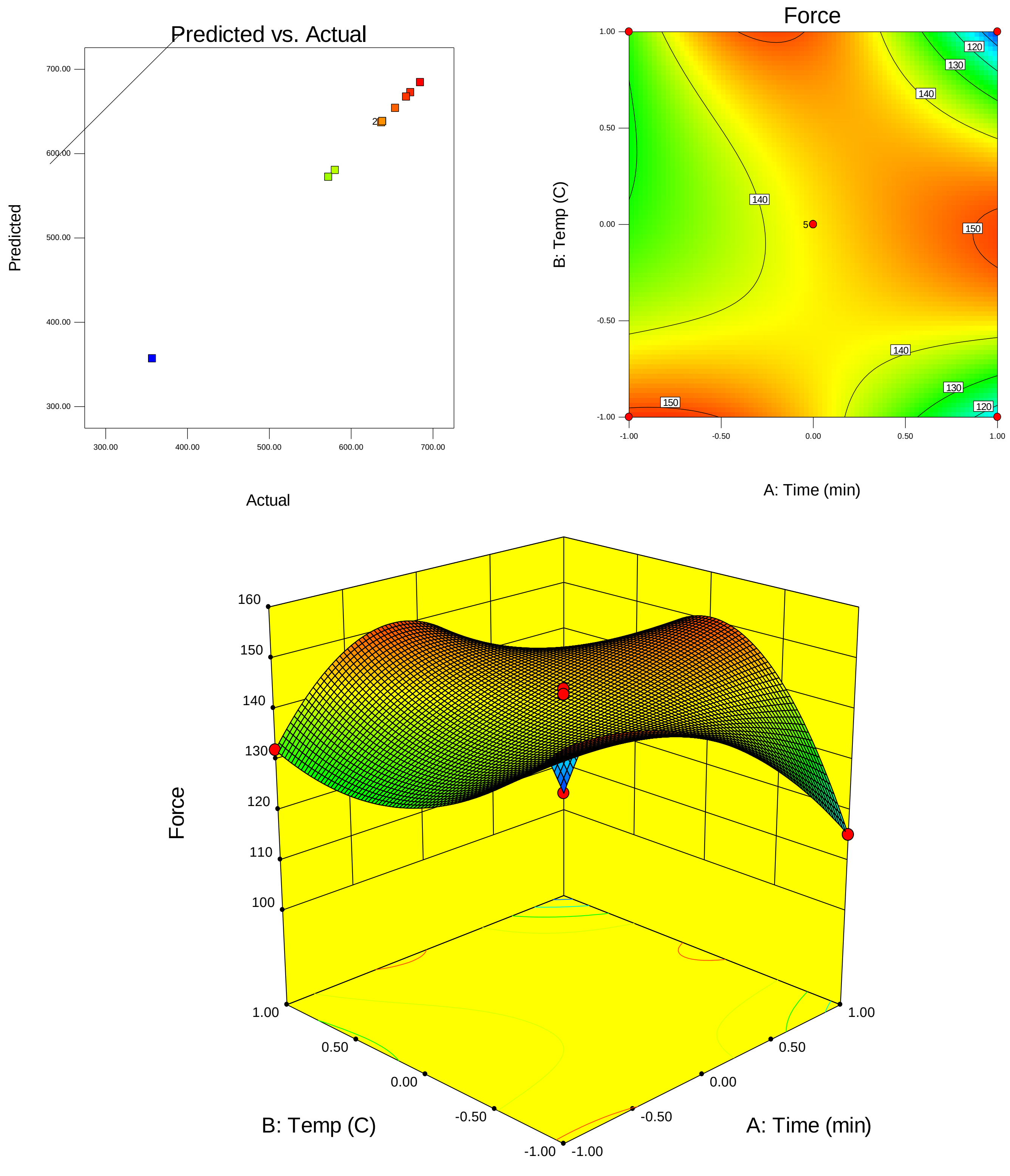


Fig 5.7 Effect of roasting time and temperature on force

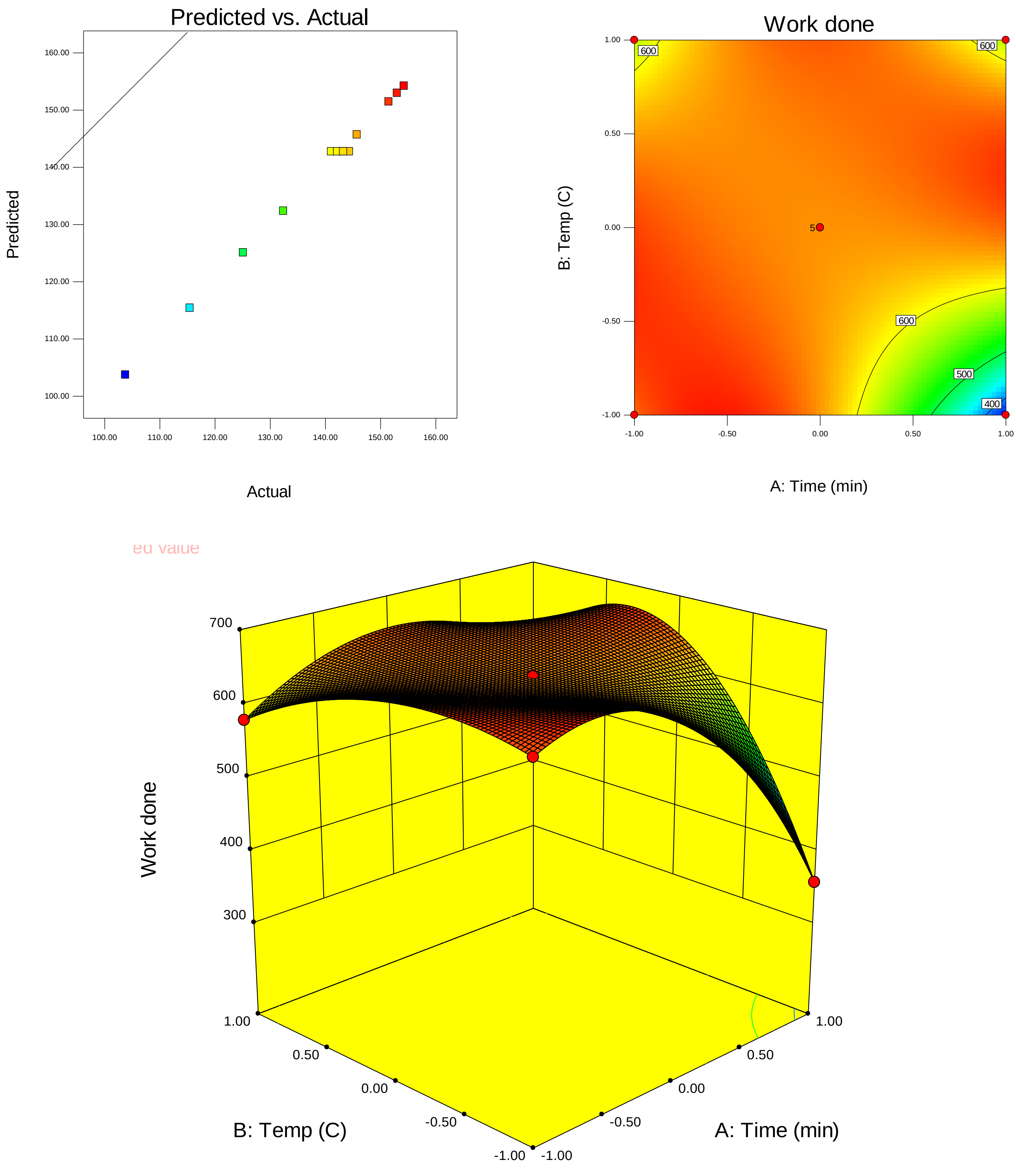


Fig 5.8 Effect of roasting time and temperature on workdone

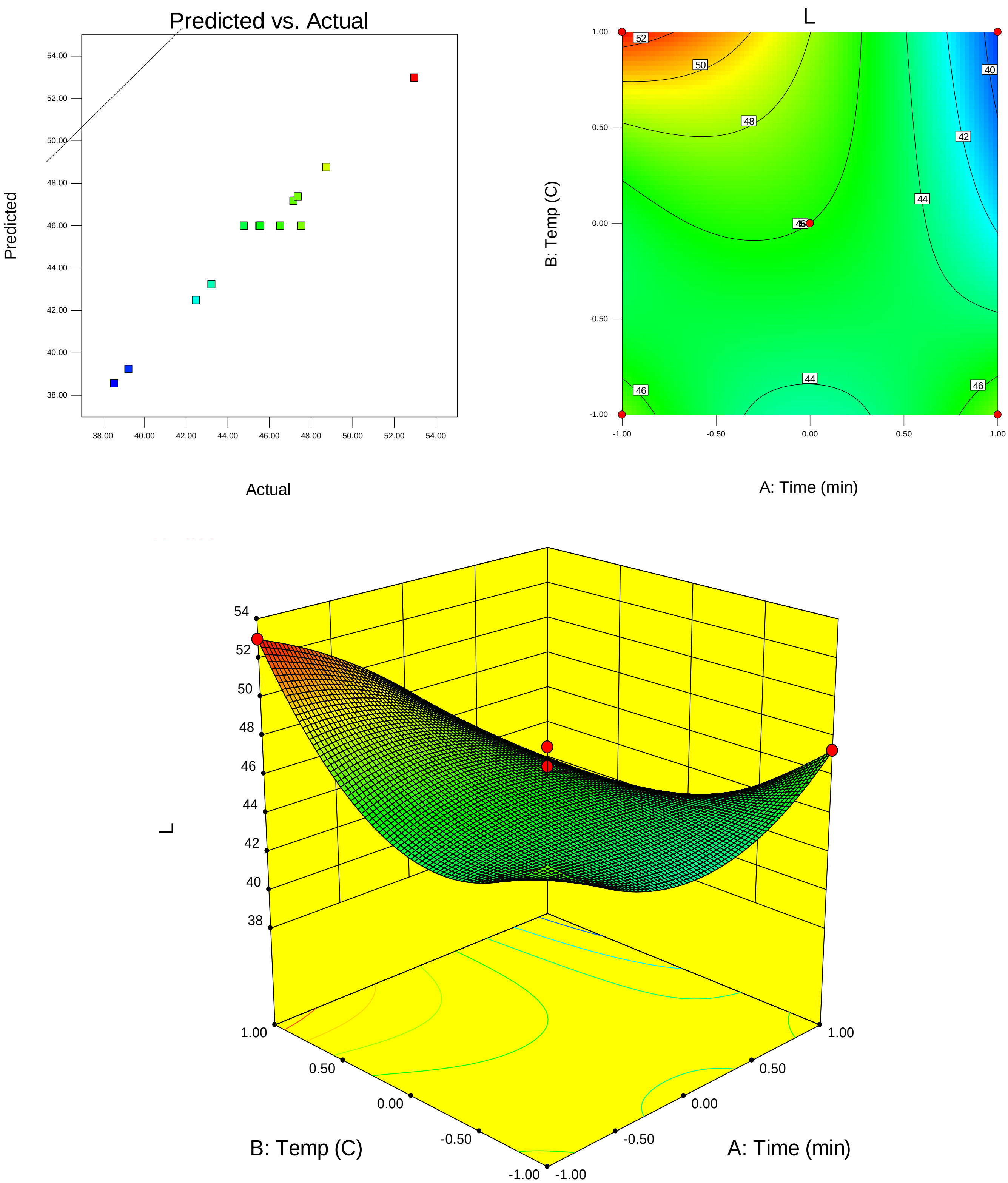


Fig 5.9 Effect of roasting time and temperature on L-value

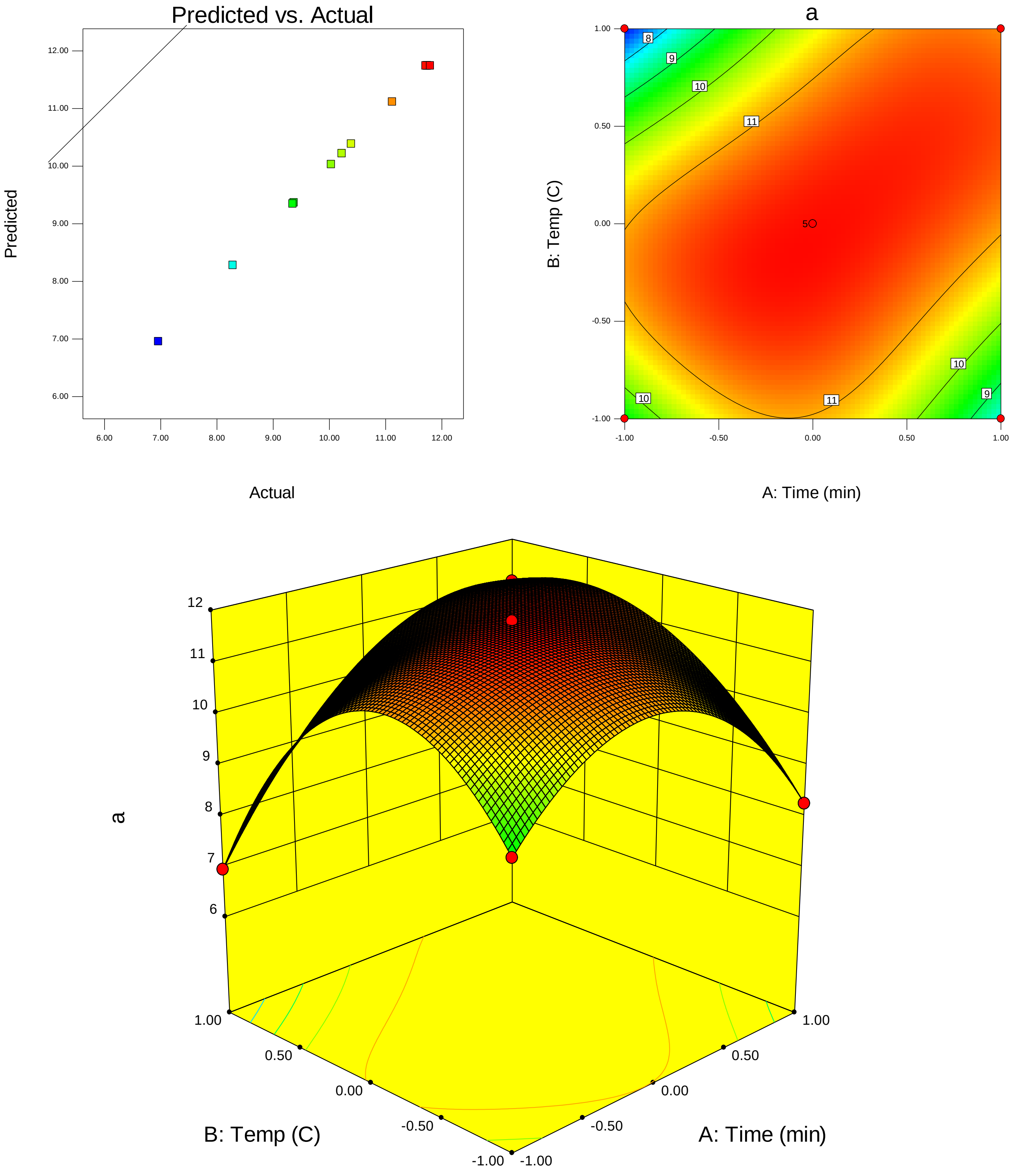


Fig 5.10 Effect of roasting time and temperature on a-value

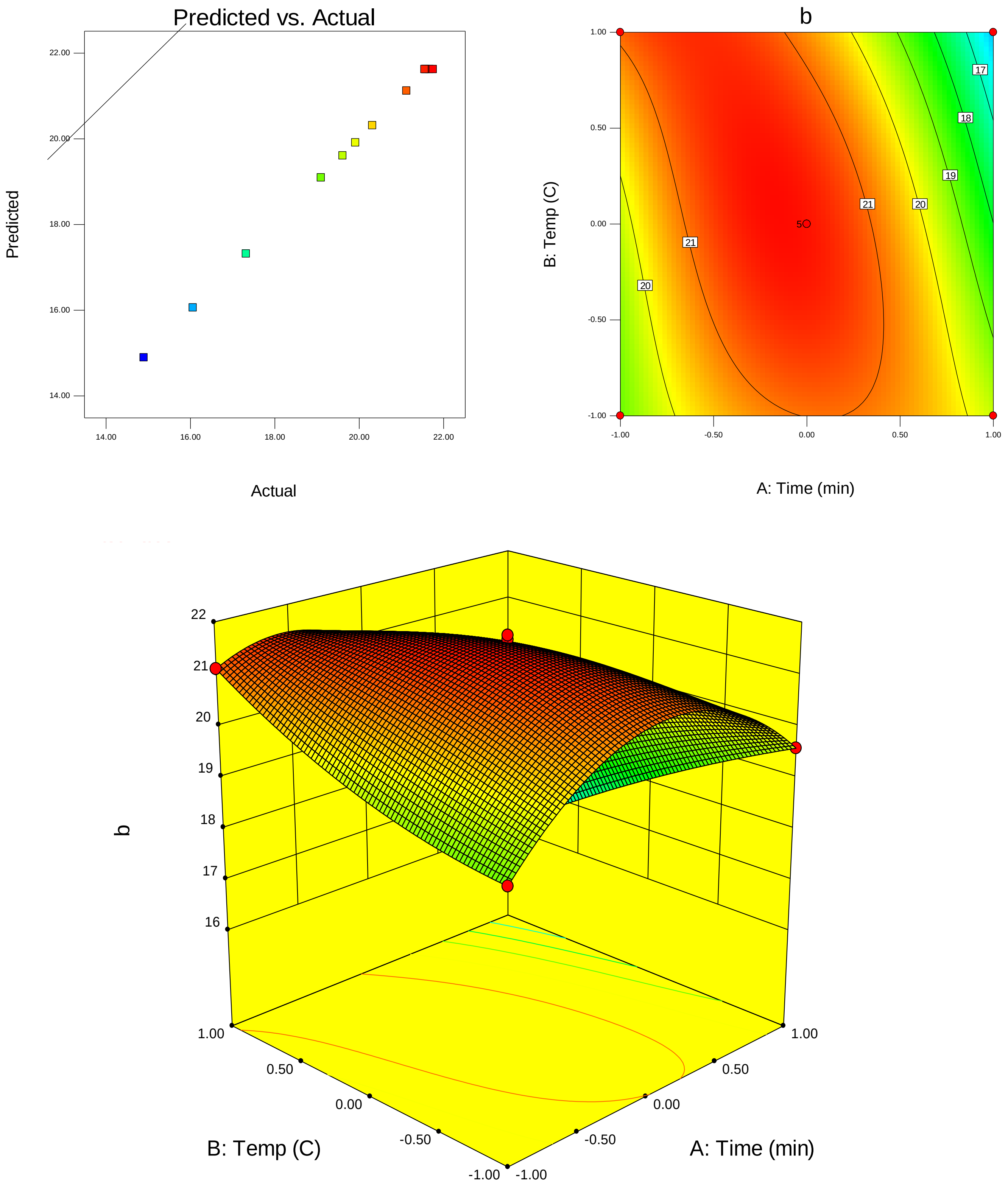


Fig 5.11 Effect of roasting time and temperature on b-value

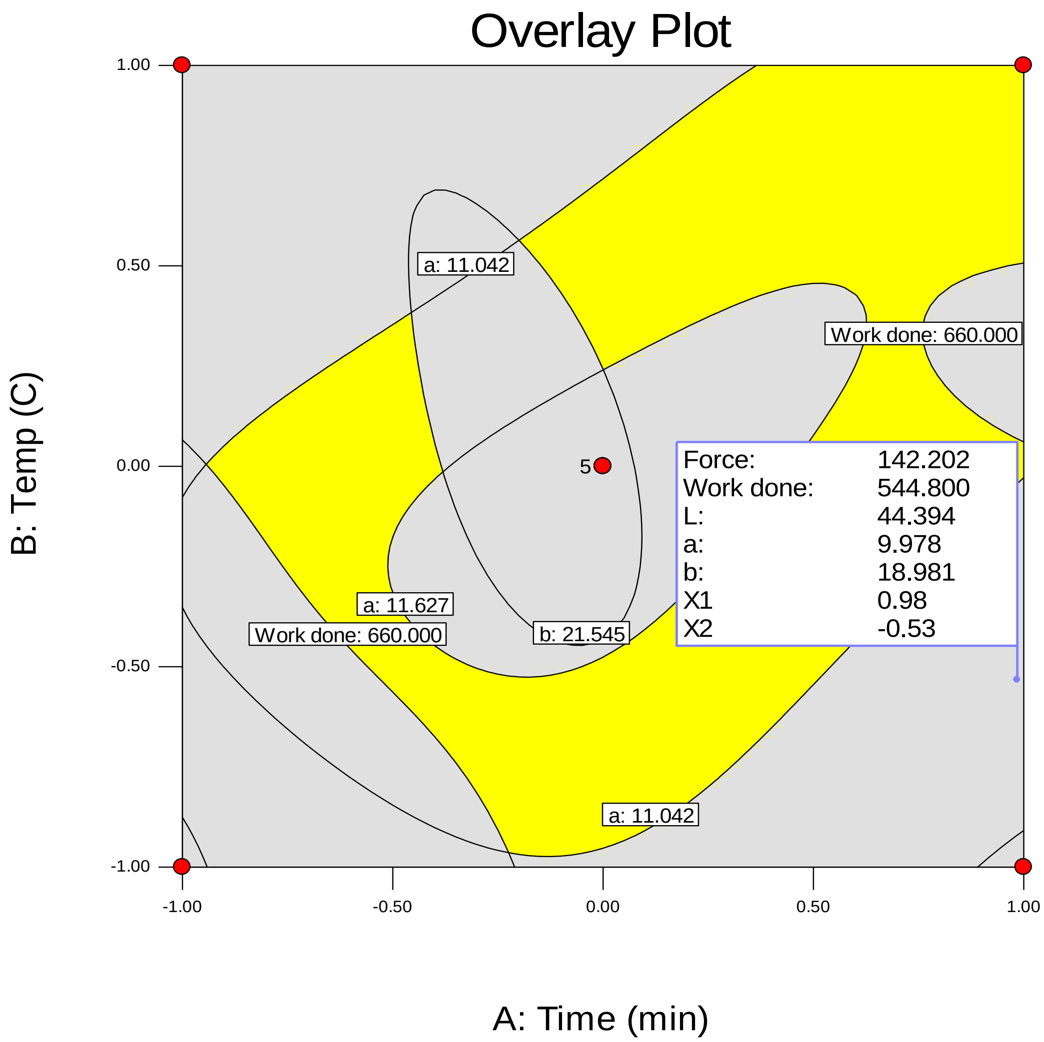


Fig 5.12 Overlay plot showing optimized variables and responses

SUMMARY AND CONCLUSION

CHAPTER VI

SUMMERY AND CONCLUSION

Soybean (*Glycine max* (L.) *Merr*.) is the 'golden bean' or 'miracle bean'. Soybean has come to be recognized as one of the premier agricultural crops today for various reasons. Soybean is a major source of vegetable oil, protein and animal feed. It contains about 40% of good quality protein, 20% fat, 23% carbohydrates, 5% minerals, 8% moisture, 4% fibre and reasonable amounts of vitamins. Soy based food products are also suitable to diabetic patients as they contain less carbohydrates and low cholesterol. Soy protein is also good to people who are allergic to animal protein. Therefore, it is one of the most economical protein sources in the world.

The process parameters of roasting are heating temperature and holding time. These parameters are most important for reduction of antinutritional factors present in soybean. There are many types of roasting techniques such as rotary drum dryer, salt-bed roasting and conventional grain dryer. The most commonly used roasting systems are the rotating drum, fluidized bed models, cascade roasting, jet-sploding, micronizing and microwave treatments. Most of these methods provide non uniform roasting of soybean with uneven temperature distributions. For preparation of soy butter the end products obtain from roasting operation is most important from nutritive and market point of view. The available roasting equipment is not suitable for roasting of soybean, so there is need to design and development of roaster for roasting soybean for preparation of soy butter.

Considering above points there is need to develop roaster for soybean, for the preparation of soy butter. Similarly optimization of process parameters such as time and temperature during roasting operation is to be done. The developed roaster may be useful for roasting multi grains. Hence it is proposed to design and develop a roaster for soaked soybean; with following objectives:

1. To determine the physical properties of soybean seed and split during its soaking conditions.
2. To design and develop a soybean roaster.
3. To optimize the process parameters of roasting operation in developed soybean roaster.

For the preparation of soy butter, the designed roaster was developed at Central Institute of Agricultural Engineering, Bhopal. The soybean roaster consists of mainly rotating drum, power transmission unit with belt, pulley and gear arrangement, collecting unit and heating source. The rotating drum consist of eight numbers of baffles were arranged inner side of the drum for enhancing mixing during roasting operation. The power transmission unit consists of V-belt, two pulleys, spur and pinion gear arrangement to obtained 60 rpm from 1440 rpm of one hp motor. The LPG was used as a heating source, and burner was kept in such a way that the efficient heating of drum, the distance between drum and gas burner was about 110 mm. The drum temperature was observed with the help of thermocouple.

For design capacity roster moisture dependent physical properties of soybean were studied. Physical properties of soaked soybean were measured in laboratory. With the help of physical properties the volume of drum was decided. The soaking study of soybean seed and split, most of the physical properties showed a linear increase and decrease trend with increased moisture content range. Arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter and unit volume increased however, sphericity, aspect ratio and shape factor showed a decreasing trend with the increase in moisture content. The water absorption level and variation in moisture content determine at different levels of moisture content for soybean seed and split.

For the design of rpm and filling degree of roasting drum, the transverse flow of soaked soybean seed and split were studied. In transverse motion study of raw soybean and soaked soybean, the transition from one region to another region was dependent of physical properties and degree of filling of beans in the drum. The best performance in transversal mixing of beans, were rolling and cascading type of modes. The filling degree also affected on the flow regime of beans, the recommended degree of filling of beans is 30–50 %. The recommended range rpm is 40-60 rpm.

The capacity of developed machine was calculated as 15 kg of soaked soybean / batch and the evaluation was done by using central composite rotating design. The response surface methodology was used to predict the satisfactory models for optimizing roasting time and temperature for the derived changes in colour, hardness and work done of soybean during roasting. The changes in colour attributes, hardness parameters and work done of roasted soybean were successfully described by the quadratic and interaction models. Successful optimization of the soybean roasting processes can be obtained by using the desirability functions of RSM. Based on these findings, it can be concluded that for soybean roasting, the recommended roasting time and outer temperature of drum is 11 min, 42 sec and 171.5°C, respectively.

The specific conclusions which have immersed from this investigation are as follows:

1. For roasting cascading type of motion mode is most suitable.
2. The optimized roasting time and outer temperature of drum in the developed roaster is 11min, 42 sec and 171.5^{o}C, respectively.
3. Developed soybean roaster is suitable for roasting soaked soybean.

ABSTRACT

ABSTRACT

Design and development of roaster for soaked soybean

This study was carried out to design and development of roaster for soaked soybean, for the design of roaster the effect of moisture content on some physical properties of soybean seed and split, transverse flow of soybean seed and split in rotating drum were studied. The performance of developed roaster and optimization of roasting time and temperature for soaked soybean was done by response surface methodology. The results showed that the sample size increased linearly in length, width, thickness, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, unit volume and surface area, where in sphericity, aspect ratio, and shape factor, were decreased linearly with the increase in moisture content from for soybean seed and splits. The cascading mode of motion was used to design rpm and degree of filling for roaster. The soybean roaster was designed and developed from locally available materials for roasting of soaked soybean. The design construction, calculations and fabrication at Central Institute of Agricultural Engineering (CIAE), Bhopal. The soybean roaster has capacity 15 kg/batch, the speed of rotating drum was 60 rpm obtained from of 1 hp electric motor with the help belt, pulley and gear arrangement. The machine was designed to power operated with overall dimensions 1831 mm x 600 mm x 910 mm. With the objective of optimizing the roasting of soybean, a central composite rotatable design (CCRD) was prepared to select variables level i.e. roasting time 9-12 min, roasting temperature 125-175^{o}C. The cascading type of motion mode is most suitable for roasting. The optimized roasting time and outer temperature of drum in the developed roaster is 11 min, 42 sec and 171.5^{o}C, respectively. The developed soybean roaster is suitable for roasting soaked soybean.

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APPENDICES

APPENDIX- I

Specification of instruments / equipments used in experimentation

(1) Texture analyzer

Model	:	TA.XT plus Texture Analyser
Force Capacity	:	50 kg.f (500N)
Force Resolution	:	0.1g
Load cells	:	0.5, 5, 30, 50kg.f
Speed Range	:	0.01 – 40mm/s
Range Setting	:	0.01 - 280mm
Data Channels	:	Filtered force at 20 bit, distance at 24bit,
External Instrument Channels	:	Four channels of RS485
Power supply	:	Universal mains input voltage
Net weight	:	16.2 kg

(2) Colourimeter

Model	:	Labscan XE Hunterlab
Measures reflected color using	:	0°/45° geometry
Wavelength range	:	400 nm-700 nm
Optical resolution and reporting interval	:	10 nm
Measurement diameter	:	50 mm
Measurement areas	:	50 mm to 5 mm
Operating temperature	:	10ºC to 40ºC
Storage temperature	:	-21ºC to 66ºC
Size	:	36 x 19 x 30 mm

(3) Thermocouple

Thermocouple	:	Type-K Model
Range	:	328 to 2498 °F / –200 to 1370 °C
Resolution	:	0.1° from -328 to 990°F/-200 to 640°C, 1° from 990 to 2498°F / 640 to 1370°C
Accuracy	:	±1° C

(4) Multimeter

Model	:	Sanwa P-3 Students Model
Pin Jack Range selection	:	Entirely eliminates mechanical switching trouble.
Ranges	:	DC V 0.25/10/50/250/1000V
AC V	:	10/50/250/500/1000V
DCA	:	0.25/10/250mA
OHMs	:	0-10K/1M
Size	:	122 x 92 x 43 mm Weight 400 gms
Batteries	:	2 x 1.5 V Pencil Cells (AA Size)

(5) Clampmeter

Model	:	Clampmeter
Maximum voltage	:	1000V DC or 700V AC RMS.
Altitude	:	<2000 m
Display	:	LCD 3999 counts Updates 2-3/sec
Ranging method	:	Auto range mode
Jaw capability	:	40mm,Max conductor size
Power	:	3 x 1.5 V Pencil Cells (AAA Size)
Size:	:	255 mm × 86 mm × 32 mm
Operating	:	5ºCto 35ºC
Storage temperature	:	-10ºCto 50ºC

6) Digital vernier caliper

Model	:	CD-15CPX, Mitutoyo Corp Made in japan.
Resolution	:	0.01mm 1-150mm
Power	:	one 1.5 volt bottle seal
Temperature	:	0 ± 40^0c
RH	:	≤ 80%
Measuring speed	:	≤1.5 m/sec

7) Tachometer

Model	:	Digital photo (non contact) type Tachometer (HTM-560)
Range	:	60 – 1,00,000 rpm
Resolution	:	0.1rpm up to 1000 rpm
Accuracy	:	±0.05% + 1 digit
Sampling Rate	:	1 sec.
Measuring distance	:	75 mm to 300 mm
Size	:	200 x 75 x 40 mm
Battery	:	4 x 1.5 V Pencil Cells (AAA Size)

8) Stopwatch

Model	:	Digital Stop Watch-Racer
Electronic Reading	:	1/100th of second with larm/timer/calendar display
Mechanical Reading	:	1/5th or 1/10th of second with 1/2/3button
Accuracy	:	±1.0% full scale range in use
Battery	:	Lithium battery

9) Hot air oven

Model	:	Hot air oven- Laboratory type, Rivotek
Mode of heating	:	Installed with forced air circulation, digital temperature controller, electrical.
Temperature range	:	5 oC above ambient (room temperature) to 250 oC
Voltage	:	230 Volts AC.

10) Weighing balance

Model	:	Precisa 310 M, Adair Dutt & Co. Pvt. India
Weighing Range	:	320 g
Readability	:	1 mg
Voltage	:	230V+-15%,50Hz
Operating temperature	:	10ºC to 50 ºC

APPENDIX – II

GEOMETRICAL PROPERTIES OF SOYBEAN SEED

Time (min)	L (mm)	W (mm)	T (mm)	AMD (mm)	GMD (mm)	SMD (mm)	EQD (mm)	Sp	AR	SA (mm^2)	a	b	SF(λ)	VT (mm^3)
0	7.63	6.72	5.09	6.48	6.39	11.15	8.01	0.84	0.88	131.78	7.07	991.80	1.05	140.35
15	7.72	6.83	5.13	6.56	6.47	11.29	8.10	0.84	0.88	134.95	7.21	1049.22	1.06	145.46
30	7.81	6.94	5.18	6.64	6.55	11.43	8.21	0.84	0.89	138.31	7.36	1110.28	1.06	150.95
45	8.06	7.08	5.28	6.81	6.70	11.70	8.41	0.83	0.88	145.31	7.48	1213.96	1.06	162.36
60	8.31	7.23	5.39	6.98	6.87	11.99	8.61	0.83	0.87	152.76	7.61	1330.83	1.05	174.83
75	8.61	7.36	5.46	7.14	7.02	12.27	8.81	0.82	0.85	160.30	7.72	1447.21	1.05	187.56
90	8.95	7.46	5.50	7.30	7.16	12.53	9.00	0.80	0.83	167.81	7.77	1556.45	1.04	200.28
105	9.03	7.46	5.83	7.44	7.32	12.79	9.18	0.81	0.83	174.72	7.60	1620.59	1.02	213.25
120	9.09	7.46	6.17	7.57	7.48	13.04	9.36	0.82	0.82	181.44	7.44	1682.89	1.00	226.17
135	9.10	7.57	6.33	7.67	7.58	13.21	9.49	0.83	0.83	185.82	7.56	1774.69	1.00	234.84
150	9.14	7.65	6.47	7.75	7.68	13.36	9.60	0.84	0.84	190.01	7.62	1853.28	1.00	243.10
165	9.66	7.65	6.47	7.93	7.82	13.63	9.79	0.81	0.79	199.33	7.48	1944.20	0.98	259.78
180	10.23	7.65	6.47	8.12	7.97	13.93	10.00	0.78	0.75	209.81	7.34	2046.47	0.96	278.72
195	10.49	7.68	6.47	8.21	8.05	14.08	10.11	0.77	0.73	215.13	7.33	2114.86	0.95	288.56
210	10.78	7.71	6.47	8.32	8.13	14.24	10.23	0.75	0.72	221.09	7.31	2190.40	0.95	299.64
225	10.80	7.74	6.47	8.34	8.15	14.27	10.25	0.75	0.72	221.93	7.35	2215.89	0.95	301.36
240	10.81	7.77	6.47	8.35	8.16	14.29	10.27	0.75	0.72	222.58	7.40	2239.65	0.95	302.73

APPENDIX-III

GEOMETRICAL PROPERTIES OF SOYBEAN SPLITS

Time (min)	L (mm)	W (mm)	T (mm)	AMD (mm)	GMD (mm)	SMD (mm)	EQD (mm)	Sp	AR	SA (mm^2)	a	b	SF (λ)	VT (mm^3)
0	5.98	4.28	2.36	4.21	3.92	7.06	5.06	0.66	0.72	54.85	153.52	167.46	1.09	35.87
15	6.65	4.77	2.59	4.67	4.35	7.83	5.62	0.65	0.72	67.46	233.15	255.82	1.10	48.88
30	7.39	5.18	2.77	5.11	4.73	8.55	6.13	0.64	0.70	80.83	330.29	361.47	1.09	63.76
45	7.93	5.40	2.85	5.39	4.96	8.99	6.45	0.63	0.68	89.90	401.36	436.94	1.09	74.33
60	8.36	5.66	2.90	5.64	5.16	9.38	6.73	0.62	0.68	97.95	476.58	522.98	1.10	84.20
75	9.88	5.73	2.96	6.19	5.51	10.14	7.28	0.56	0.58	118.67	624.81	649.39	1.04	109.04
90	10.34	5.79	3.10	6.41	5.70	10.48	7.53	0.55	0.56	127.93	704.21	714.81	1.02	121.62
105	10.63	5.99	3.10	6.57	5.82	10.73	7.71	0.55	0.56	133.89	778.27	800.66	1.03	129.93
120	11.01	6.07	3.10	6.73	5.92	10.94	7.86	0.54	0.55	139.94	837.69	859.33	1.03	138.01
135	11.27	6.13	3.38	6.93	6.16	11.31	8.13	0.55	0.54	149.99	943.64	939.36	1.00	153.94
150	11.36	6.18	3.44	6.99	6.23	11.43	8.22	0.55	0.54	153.08	981.91	974.43	0.99	158.89
165	11.37	6.25	3.51	7.04	6.29	11.53	8.29	0.55	0.55	155.46	1019.36	1012.10	0.99	163.10
180	11.41	6.28	3.56	7.08	6.34	11.60	8.34	0.56	0.55	157.42	1044.94	1034.71	0.99	166.39
195	11.41	6.30	3.62	7.11	6.38	11.66	8.39	0.56	0.55	158.87	1064.99	1050.93	0.99	169.05
210	11.41	6.30	3.62	7.11	6.38	11.66	8.39	0.56	0.55	158.87	1064.99	1050.93	0.99	169.05
225	11.42	6.30	3.62	7.11	6.39	11.67	8.39	0.56	0.55	159.02	1066.30	1051.92	0.99	169.25
240	11.42	6.30	3.62	7.11	6.39	11.67	8.39	0.56	0.55	159.02	1066.30	1051.92	0.99	169.25