DEVELOPMENT AND TESTING
OF A MIXER-EXTRUDER MACHINE FOR PROCESSING ANIMAL FEEDS

BY

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M. ENG/SEET/ 2004/1113

A THESIS SUBMITTED TO THE POST GRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS DEGREE (M.ENG) IN AGRICULTURAL AND BIORESOURCE ENGINEERING (FARM POWER AND MACHINERY)

DEPARTMENT OF AGRICULTURAL AND BIORESOURCE ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA

NOVEMBER, 2009

DECLARATION

I **Mu'azu Aliyu** do hereby declare that this research work has been conducted and written by me and is never presented elsewhere for the award of any degree. All the information derived from the works of others is duly acknowledged.

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CERTIFICATION

This thesis titled Development and Testing of a Mixer – Extruder Machine for Processing Animal Feeds by **Mu'azu Aliyu (M.Eng/SEET/2004/1113)** meets the regulations governing the award of the degree of M.Eng. of the Federal University of Technology, Minna and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This project is dedicated to my mother Hajiya Aishatu Mu'azu Haruna for her consistent words of prayers and encouragement throughout the entire period of my study.

ACKNOWLEDGEMENTS

All special praises are due to Allah for granting me the ability to undertake the course without much of a hitch.

I wish to acknowledge with thanks and high sense of appreciation the un-quantifiable, timely and valuable contributions of my supervisor Dr. Donald Adgidzi, for his constructive criticisms, valuable advice, thorough guidance and consistent words of encouragement, which led to the successful completion of this research within the time limit.

Although any attempt to express my deep appreciation to any single lecturer or group of lecturers for their genuine concern and support throughout the program's period runs the risk of offending those that were omitted, there are however lecturers who were of significant help to me notably among them are: Dr. A. A. Balami, Dr. Mrs Z. D. Osunde, Prof. M. G. Yisa, Prof A. Ajesegiri, Dr. N. Egrevba, Dr. B. A. Alabadan, Dr. O. Chukwu, and Prof. Sadiku of fisheries department to mention but a few.

Also deserving acknowledgement and a demonstrative gratitude are my superior officers, brothers, friends and colleagues such as: Engr. Atiku A. Maiyama (Provost, College of Agriculture, Zuru), Alhaji Muhammad Mu'azu Haruna (Bursar, CAZ), Engr. Muhmud Abubakar Manga, Mal. Yusuf Kaka Yauri, Umar Ahmad and Samira Muhammad.

May Allah's bounty continue to be yours always. Amen.

ABSTRACT

The absence of appropriate feed processing equipment at the disposal of our local farmers continue to make them rely on the expensive commercial feeds the safety and quality of which cannot always be guaranteed for their flocks of birds and livestock. In this work, an attempt was made to design and fabricate a machine capable of mixing feed ingredients and to compact them into pellets of different sizes and shapes. The machine consists of three main sections: the mixing section, an insulated cylindrical water boiler and the pelleting section capable of extruding 5 mm and 7 mm diameter pellets and cubes of 20 mm x 20 mm and 40 mm x 40 mm sizes. The mixer's performance evaluation in respect of four mixing durations of 5min, 10min, 15min and 20minutes, produces a corresponding performance of 78.15, 87.36, 95.16 and 95.31% level of mixing, indicating that the mixer's performance increases with increase in the duration of mixing and also that difficulty in mixing operation increases as the mixture approaches its equilibrium point. An average boiling time of 44.30min was recorded when the boiler was tested with 8 liters of water having an initial temperature of 25^0C. The pelleting section was evaluated at two feed-rate levels of 50kg/h and 60kg/h. In two experiments using two feed formulations per experiment, two circular dies (5mm and 7mm dia.) and two square dies (20mm x20mm and 40mm x 40mm). A 2^3 factorial design was used in the analysis. The capacity of the extruder was found to be affected by die size and material feed-rate. For the same feed formulation, the capacity of the extruder was found to increase with an increase in the size of the die and also increases at a rather decreasing rate with an increase in feed-rate.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The significance of proper feed formulation and its influence on the ability of cultured organisms to attain the desired genetic potential for growth, reproduction and longevity cannot be over emphasized. Feed production for livestock, poultry or aquatic life involves a range of activities, which include grinding, mixing, pelleting and drying operations. New (1987) gave a summary of the different types of machinery/equipment needed for the production of various types of feeds and they include grinders, mixers, elevators and conveyors, mixer/extruders, cooker/extruders, cooler/driers, fat sprayers and steam boilers.

The mixing operation in particular, is of great importance, since it is the means through which two or more ingredients to form the feed are interspersed in space with one another for the purpose of achieving a homogenous mixture capable of meeting the nutritional requirements of the target livestock, poultry or aquatic life being raised. Essentially, feed mixing can be done either manually or mechanically. The manual method of mixing feed entails the use of shovel to intersperse the feed's constituents into one another on open concrete floors. The manual method of mixing feed ingredients is generally characterized by low output, less efficient, labor intensive and may prove unsafe, hence, hazardous to the health of the intended animals, birds or fishes for which the feed is prepared.

The mechanical method of mixing is achieved by using mechanical mixers developed over the years to alleviate the shortcomings associated with the manual method. A wide variety of mixers are available for use in mixing components, the selection of which depends mainly on the phase or phases the components exists i.e. solid, liquid or gaseous phases. Brennan *et al* (1998) observed that regardless of the type of mixer, the ultimate aim of using a mixing device is to achieve a uniform distribution of the components by means of flow, which is generated by mechanical means.

With the components thoroughly mixed, the need to compact them into a stable form (i.e. pelleting) arises due to a number of reasons that include among others to: minimize the tendency of the mixed components to segregate, prevent the selection of particular ingredient within the mixture during feeding for example by birds or fishes and make the compounded feed easy to swallow. By and large, pelleting permits the conversion of homogeneous blend of ingredients into durable form having physical characteristics that make them suitable for feeding. Pellets differ in sizes, shapes and forms depending on the feeding requirements of the cultured organisms.

Many researchers observed that in most developing countries including Nigeria, the major headache common to farmers raising livestock, poultry and/or aquatic life is the lack of access to proper feeds that can meet the nutritional requirements of their flocks at the right time and in the right quality and price. Dogo (2001) for instance observed that the rate of poultry production in Nigeria is not commensurate with human population growth and demand. He therefore, opined that the major constraint is the high cost of feeds in the market. Similarly, Oyenuga (1973) citing the report of a committee on Food Crops set up by the

Nigerian Federal Ministry of Agriculture and Natural Resources, showed that protein from animal sources contribute about 17% of the total protein consumption to the average Nigerian diet compared to a contribution of approximately 68% of the total protein consumed in New Zealand, 71% in USA, 67% in Denmark and 60% in the UK. The reason for the low level intake of animal product in African countries he argued is due, partly, to the low population of cattle in some regions in relation to human population and requirements, but primarily due to low level of animal productivity in terms of slow growth, long calving intervals, slow reproductive cycle and low milk yield all occasioned by poor quality and or insufficient feeds.

Augusto *et al.* (1973), Fagbenro (1988) Kwari and Igwebuike (2001) Diarra *et al.* (2001) and many other researchers have indicated the feasibility of the utilization of various forms of farm and agro-industrial wastes and by-products in the formulation of complete feeds for livestock, poultry and aquatic life. Although the major essential raw materials required for the formulation of complete feeds from the results of such researches are within easy reach of the farmers and at low cost, the major limiting factor to taking the full advantages offered by the results of such researches has been the lack of available appropriate equipment to process the identified raw materials into the required feeds. This work is an attempt towards designing and fabricating a machine capable of mixing feed constituents and where the need be, pellet them into the desired shapes, sizes and forms. The design incorporates the used of local raw materials for the construction. Generally, the mixer-extruder machine as presented here is made compact, simple to operate and easy to maintain. Additionally the machine is cheap to own and comparable in performance with standard mixing-pelleting equipments of its kind.

1.2 Statement of the Problem

All living organisms ranging from the simplest unicellular prokaryote to the most advanced and complex multi-cellular mammals need nutrients to enable them synthesize the vast compounds they require for their maintenance, growth and reproduction. Farm animals including birds and aquatic life serve the function of converting feed into some form of animal product. Proper nutrition of farm animals is therefore of great importance to the nutrition of man, since they serve as the sources of essential proteins.

Competition for food between man and these animals particularly in the developing countries, often place them at great disadvantages in terms of proper nutrition. The results from many researches had shown the feasibility of formulating complete feeds from rough farm materials and/or agro industrial by-products. Such promising research findings appear difficult to exploit by our local stock raisers for a host of factors, chiefly among them being the lack of appropriate technology to process the identified raw materials into the required feeds.

Commercial feeds abound in the market, but apart from their exorbitant costs, they are susceptible to damage while in retail stores and in storage due to changes in temperature and humidity that impact quite significantly on the feed's moisture content, rate of chemical changes and attack and growth of moulds (fungi) and insects. Feeds are known to consist of perishable biological materials, which deteriorate with storage. It is therefore desirable to minimize storage time to the possible minimum with the view to getting the best from the feeds in terms of available nutrients they contain. One of the best ways to achieve same is when the average stock raiser (farmer) is able to compound desired feeds by taking into cognizance the daily feed requirements of his list of stocks.

Although some farmers own a private feed mill for processing feeds they need, most of the feed processing equipment used at farm level appears as stand alone units for executing only one feed processing operation. It is therefore not uncommon to find in such mills equipment the like of grinders, mixers, extruders, dryers, etc. Most farmers even if they can afford such equipment, consider it uneconomical to keep such machines particularly, that their services are not often needed at the same frequency. For instance, it is not all mixed feed ingredients that are pelletized let alone dry.

Economic consideration is not the only set back, performance wise, the farm level feed processing equipment particularly mixers and extruders surveyed, are not without problems. Most farm level feed mixers around often get clogged at the discharge port during evacuation of the mixed feed components due to poor flow property of ground materials and the design of the mixers. Pelleting equipment used at farm level in most cases lacks mechanism for regulating feed-rate. Thus leading to unwanted stoppages due to extrusion die blockages during operations. Such pelleting equipments also produce excessive noise and are generally characterized by rapid wear of bearings due to their constant contact with water or moist materials in the cause of operation and above all flaking of mixed ingredients, which cause a substantial reduction in the quality of the end product. All these pressing problems called for a research in the area of feed processing equipments.

1.3 Aims and Objectives of the Study

The aims and objectives of this work are to design and fabricate a single machine capable of mixing and producing pellets of different sizes.

1.4 Scope and Limitations of the Study

The scope of this work apart from designing and developing the machine is limited to performance evaluation in respect of the three principal units of the machine. These are namely the mixing, extruding and steam generating sections. In respect of the mixing section, its evaluation is limited to determining mixing ability, mixing duration and the time it takes to evacuate mixed components from the machine

Performance evaluation with respect to the extruding section is limited to only three processing parameters (i.e. feed-rate, feed formulation and die size) and their effects on machine capacity and quality (stability) of pellets. The steamer, which is thermostatically controlled, is evaluated for its capacity to heat water to the required temperature.

1.5 Significance of the Study

i. The project when fully developed will accord farmers the opportunity to prepare cylindrical and cubical pellets of required nutrients for their stocks (poultry, livestock and aquatic animals) at will.

ii. It will help farmers maximize their profits through cost savings, since most of the ingredients needed in the preparation of formulated feeds/pellets are within their reach and at low or no cost to them.

iii. The project will also assist in facilitating reduction in the environmental pollution caused by agricultural by-products the like of rice husks, the heaps of which are a common sight in most rice milling houses in our cities.

iv. The research apart from contributing to the body of knowledge already building in the area of feed mixing and feed extrusion, will thus facilitate in the development of cottage industries in the locality thereby help reduce unemployment among youths.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Feed Formulation

One of the most influencing factors governing the ability of cultured organisms to attain the much-desired genetic potential for growth, reproduction and longevity is proper nutrition. The nutritional requirements of animals differ throughout their life stages. Therefore before attempting to compound any feed, it is very vital that the growing stage of the target organisms is put into consideration. Feed formulation is the process in which appropriate feed ingredients are selected and blended in the right proportion to produce a diet with the nutrients capable of meeting the nutritional requirements of the organisms being raised. It is a fact of nature that no single feed ingredient can satisfy the nutritional requirements of any given cultured organisms. It is therefore, through careful selection of different feed ingredients, in the right quantity that a formulated ration which is nutritionally balanced, palatable, pelletable, and storable and above all ease to use, is produced. Komolafe *et al.* (1979) stressed that for the formulated feed to be of nutritional value, it must consist of ingredients that can be digested and absorbed by organisms in husbandry. Therefore certain basic information is very vital to the success of proper feed formulation and these are given by Sena and Trevor (1995) as:

a. Knowledge of nutrient requirements of the species of organisms in husbandry.

b. Feeding habit of the animal.

c. Composition of ingredients, their local availability and costs.

d. Ability of the cultured organisms to utilize nutrients from various sources (ingredients).

e. Rate of feed consumption of the specie in husbandry.

f. Feed additives required.

g. Type of feed processing desired.

In most instances, feed ingredients are sourced from rough farm products and or from agro-industrial by-products following extraction of high-value food item for human consumption. Such rough ingredients are generally regarded unsuitable for direct human consumption. New (1987), gave a list of ingredients commonly used in the formulation of feeds. The list of ingredients include: (a) grasses, (b) legumes, (c) miscellaneous fodder plants, (d) root crops, (e) cereals, (f) animal products, (g) miscellaneous feed stuffs, (h) oil bearing seed by-products, and (i) additives.

i. Grasses:

These can be utilized directly whether fresh or when they are completely dried. Grasses are generally characterized as feed ingredients with high fiber content.

ii. Legumes

With legumes, their leaves and stems are used as fodder for livestock. Leguminous seeds of crops such as locust beans, clover, groundnut, cowpeas and soybeans are rich in lysine but poor in methionine (Sena and Trevor, 1995). Lim and Akiyama (1992) reported that full-fat soybean has one of the best amino-acid profiles among vegetable proteins and is also a good source of linoleic and linolenic acids and phospholipids for fish. Similarly, Kwari and Igwebuike (2001) in a study on performance of broiler chickens fed graded levels of African locust bean (Parkia biglobosa), reported that parkia pulp can be used to replace up to 10% of the maize portion of broiler finisher diets without any depressive effects on the performance of the birds. They also reported that there is no depressive effect on the nutritive digestibility of the broilers even when the maize portion is replaced up to 20%.

iii. Miscellaneous fodder plants:

These covers part of plants used in feed formulation other than those specifically grown for fodder. Miscellaneous fodder plants are often used as leaf meal following a pre-heating treatment operation. Ng and Wee (1989) investigated the feasibility of using cassava leaf meal (***Manihot-esculenta***) in fish meal. The result of their study showed that cassava leaf meal can be used to replace up to 20% of fish meal protein in compounded diets for oreochromis niloticus without significant reduction in the performance of the organisms.

iv. Root crops

These are rich in carbohydrate as such they serve as an excellent source of energy. Although wastes from root crops can be included in small quantities in formulated feeds, a heat treatment is needed to destroy the toxin they contain. Potato and cassava starches are commonly used as binders, as such, they serve to increase the water stability of pellets. Vainionpa'a *et al.* (1989) reported that carrot can be mixed with wheat flour and starch based material to produce feed pellets for poultry birds and livestock.

v. Cereals

Cereals and their by-products are used in compounding feeds. They are generally high in carbohydrate content and significantly contribute to the protein and lipid content of formulated feeds. Corn, wheat bran, rice bran, rice husks, maize bran, millet bran, etc. are used in innumerable instances in formulated feeds. Many studies were conducted on the effects of substituting one product with another on the performance of cultured organisms. Diarra *et al.* (2001) reported that the substitution of wheat bran with millet bran has no adverse effect on the utilization of nutrients and the morphology of different intestinal segments of broiler chickens.

Cereal by-products have always been a cheap source of metabolisable energy for the poultry producer. While they may be lower in particular constituents, compared with the whole and ground feed grain, they are invariably easier to incorporate into feed and, sometimes, more palatable. According to Baksh (2003) hominy, the by-product of maize comprising of maize bran, maize germ and part kernels, has a high protein and fibre content. Maize bran, the outer covering of maize kernel, is useful, but is unsuitable for high-producing broilers and layers because of the very high fiber (15%) and low energy level. Wheat bran's high protein level, together with its high phosphorus content, makes it an essential and cheap component of poultry balanced diets. Wheat pollard (made up of ground wheat bran and wheat meal) is a useful mix, with high protein (15%)

content. Rice bran, a by-product of rice milling, is high in fiber and oil. Brewers dried grains, usually barley or sorghum with a protein level of around 20% looks attractive, even though its high fiber content of up to 15% limits its real value as a component of poultry diets. However, dried brewer's yeast – a superior brewery by-product, is rich in protein, minerals and vitamins, and has protein levels up to 45%.

vi. Animal products

Animal products normally originate either from terrestrial, avian or marine life. Sena and Trevor (1995) sees the inclusion of animal products in the preparation of feedstuff as significant in balancing up the amino-acid and vitamin deficiencies in cereals and other plant products. Some commonly used animal products in feed preparation are: blood meal, bone meal, meat meal, raw fish, feather meal, poultry by-product meal, fish silage and shrimp meal.

vii. Miscellaneous feedstuffs

These covers the non-conventional feed ingredients such as sugar cane molasses, leaf protein concentrate, seaweed, by-product of sugar and fermentation industries, microbial proteins, algae, manure and celluloses (New, 1987).

viii. Additives

The additives used in the formulation of feedstuffs cover: vitamins, binders, antioxidants, preservatives, prophylactic medicines, hormones and growth promoters. Most of these additives have specific uses in the feed, which may not be nutritional.

2.2 Feed Manufacture

Next after any successful feed formulation activity is its subsequent manufacture, which depend mainly on the type of feed the producer/farmer seek to make. Feed types are classified according to the stage of the life-cycle at which the target organisms are in. For fish, there are such groupings as contained in the works of Sena and Trevor (1995) as: starter feeds; fry feeds; fingerling feeds; grow-out feeds and broad stock feeds. Equally well in respect of poultry feeds there are starter feeds, layer feeds, layer finisher feeds, broiler feeds and broiler finisher feeds. Similar classifications exist for livestock feeds, for example pig starter feeds and swine grower feeds etc. are available. The ingredients used in the formulation of feeds may be the same with distinction only coming from the proportion of the ingredients within the blended components. For example pelletised starter and layers feeds manufactured by Grand Cereals and Oil Mills Limited a subsidiary of UAC Nigeria consists of the following nutrients as appeared in Tables 2.1 and 2.2 below.

Table 2.1: Pelletised starter feed

Nutrients	Proportion
Crude protein	21.00%
Fat	8.50%
Crude fiber	5.00%
Calcium	1.20%
Available phosphorus	0.30%

Source: Grand cereals and oil mills limited (2007)

Table 2.2: Pelletised layers feed

Nutrient	Proportion
Crude protein	16.5%
Fat	4.00%
Crude fiber	4.60%
Calcium	3.70%
Available phosphorus	0.41%

Source: Grand cereals and oil mills limited (2007)

Regardless of the feed type, all feeds fall into one of the two forms of feeds namely - the dry and non-dry feeds. Whereas dry feeds are made from dry ingredients or a combination of dry and moist ingredients with moisture content (wet basis) not exceeding 10%, non-dry feeds are however made from feed components that may be moist or wet. Thus non-dry feeds may be either wet (with moisture content ranging from 45% to 70%) or moist (if the moisture content of the ingredients is within the range of 18% to 40%). Wet feeds are generally made from wet materials such as: slaughterhouse waste, fish trash, fresh forage etc. Essentially the form of feed or its type notwithstanding, all feed manufacturing processes involves three major basic operations which are: grinding, mixing and pelleting operations. These three basic operations (steps) are discussed in some details below.

2.2.1 Grinding operation

Grinding is a size reduction operation, which is brought about by mechanical means without change in the chemical composition of the material. Through size reduction the surface area of the ground material become increased and this facilitate not only easy mixing and pelleting of the components, but as well digestibility of the feed so formed. Many attempts were made by various researchers to determine the value of grinding feeds ingredients using several feeding tests covering livestock and poultry feeds. Such tests according to Henderson and Perry (1976) revealed that coarse grinding is preferable in most cases to fine grinding. The scholars further gave the following specific recommendations:

(i). Under no circumstance should farm animals be fed with finely ground materials except small chicks, and even for them the ground material should not be powdery.

(ii). Forage should not be ground but chopped to minimize wastage by animals. Fine chopping or grinding does not improve the forage but may probably lower its quality through exposure to oxidation.

(iii). Forage crops for poultry should be ground fine to ensure consistency in feeding.

Brennan *et al.* (1998) listed three types of forces used to achieve communition of feed materials. These forces are: the compressive, shearing and impact forces. Some commonly used size reduction equipment that utilizes these forces either singly or in combinations are: the hammer mills, crushing rolls and burr mills. The type of force most likely to effect disintegration of feed material depends on the mechanical structure of the material. Whereas crystalline materials require compressive forces to cause communition, fibrous materials require shearing forces to effect their disintegration.

The size of ground material may fall into one of three groups viz: dimension range, sieve range and microscopic range. Sieve range particles are classified by screening through a series of Tyler sieves as indicated in Table 2.3

Table 2.3: Tyler standard screen sieves.

Mesh no. Openings to 25 mm.		Diameter of wire, mm.	Actual size of opening, mm.
3	Coarse size grain	0.1178	6.7640
4		1.6510	4.6990
6		9.1440	3.3274
8		0.8128	2.3622
14	Medium size grain	0.6350	1.1684
28		0.3175	0.5893
48	Fine size grain	0.2337	0.2946
100		0.1067	0.4420

Source: Henderson and Perry (1976).

2.2.2 Mixing operation

Mixing as the dispersing of components one throughout the other has been defined by Brennan *et al.* (1998) from two perspectives as: (i) an operation in which two or more components are interspersed in space with one another and (ii) an operation which tends to remove non-uniformities in the properties of materials in bulk, e.g. color, temperature, composition etc. The blending of components also referred to as mixing operation occurs in innumerable instances in both the feed and food industries. The process of mixing begins with the components grouped together in some container but still as separate as pure components. Thus, if small samples are taken throughout the container, they will almost all consist of one pure component. As mixing proceeds, samples will increasingly contain more of the ingredients (components) in proportion approximating the overall proportions of the components in the whole container.

The attainment of a homogenous blend of ingredients though highly desirable in the manufacture of feeds, is seldom if not impossible to achieve. The major hindrance as outlined by Brennan *et al.* (1998) is the flow properties of the components as influenced by their specific physical properties (e.g. size and shape) and the design of the mixer. Henderson and Perry (1976) also identified difficulty in mixing as arising where solids are of the same size and shape but having different specific gravity, or if they have different shape or size. The dual authors further stressed that satisfactory mixing process is one that produces a uniform mixture, accomplished in a minimum time and achieved with minimum overhead cost for power and labor. Sena and Trevor (1995) however argued that provided the particle sizes are uniform, segregation (un-mixing) of ingredients is minimized and the blend should consist of ingredients of similar formulation. Segregation of particles is most likely to occur where group of particles within a mass are free to change their positions. This readily occurs with smaller particles within the mass than with larger particles. Nienow *et al.* (1985) reported that materials with size below 10 μm do not segregate while those with size above 75 μm segregate quite readily. Brennan *et al.* (1998) pointed out the significance of detecting any tendency for segregation to occur when selecting solid-mixing equipment through the use of heap test.

Williams (1988) classified solid mixers into two groups viz:

(i). Segregating mixers with diffusive mixing mechanism, examples are the non-impeller types of mixers such as tumbler mixers and (ii). The less segregating mixers with convective mixing mechanism, examples are the impeller types of mixers such as screw mixers.

Some commonly used solid mixers as discussed by Brennan *et al.* (1998) includes:

a. Tumbler mixers:

A tumbler mixer has a revolving vessel through which the mass of solids is tumbled. The vessel is usually made to rotate at a speed of 100 rpm i.e. half the critical speed of the mixer. Some tumbler mixers are provided with baffles for restricting and directing flow of materials. The working capacity of a tumbler mixer ranges from 50% to 60% of the volume of the vessel. Equilibrium mixing is normally attained in 10 - 15 minutes. Essentially tumbler mixers are diffusive in operation as such are best suited to blending components with similar physical properties for the avoidance of segregation of components.

b. Horizontal trough mixers:

A classical example of a horizontal trough mixer is the ribbon mixer having a horizontal trough which may either be open or closed. Typical ribbon mixer consists of two counter rotating ribbons that rotate at differential speeds. In operation while one of the ribbons attempts to move the material towards the right, the other ribbon will attempt to move it towards the left. The resultant movement is in one direction, this system can be use as a continuous mixer. The mechanism of operation of this type of mixer is convective as such it is best suited to mixing components that are likely to segregate during blending.

c. Vertical screw mixers:

These are quite quick and efficient particularly in mixing small quantities of additives into large masses of materials. A typical vertical screw mixer consists of a vertical acting auger conveyor that rotates inside a cylindrical or cone shaped mixing chamber. The auger may be made fixed at the center of the mixing chamber or it may be made to orbit around the central axis of the mixing chamber so as to take care of stagnant layer of materials lying near the wall of the mixing chamber.

2.2.3 Pelleting operation

With the components thoroughly mixed the need to compact them into a stable form arises due to a number of reasons as outlined by Adgidzi *et al* (2006) and they include: (i) to minimize the tendency of the mixed components to segregate, (ii) to prevent the selection of particular ingredient within the mixture during feeding particularly by birds, (iii) to make the compounded feed easy to swallow and (iv) to avoid waste of feeds, as the pellets can be collected and re-used after every feeding period. Pelleting according to Sena and Trevor (1995) allows for the conversion of homogenous blend of ingredients into durable forms having physical characteristics that make them suitable for feeding. It is further seen as the compacting of feeds by extruding individual ingredients or mixtures of ingredients into durable forms (Brennan *et al,* 1998).

Pelleting is the process whereby a marsh of feed material is forced through a restricted orifice (die) to form a stable strand, which may either be circular, square or slot-like in shape depending on the cross-sectional profile of the die. It is also seen as a thermodynamic operation in which materials are conveyed and pressed with screw inside a barrel resulting in high-rise in temperature of the material (Sahay and Singh, 2001). Although in pelleting operation maximum compaction is needed for good quality pellets, Sena and Trevor (1995) pointed out that compaction and extruder capacity are antagonistic, as such an economic balance has to be reached in the operation of the machine. Pellet making involves exposing the mixture of dry feed ingredients to steam for a period of 5 – 20 seconds, raising the temperature to 85 – 200^{0}C and attaining a moisture of 16 – 24% (Sena and Trevor, 1995) or 15 – 45% (Bonie, 1985) depending on the type of pellet we seek to produce (i.e. whether compressed pellets or dry extruded pellets). Sena and Trevor (1995) stated that pellets quality is influenced by the fat level, moisture content and humidity. The authors further stressed that low fat levels (< 2%) make pellet unduly hard and high fat levels (> 10%) make pelleting difficult. Excessive moisture results in soft pellets and insufficient moisture results in crumbly pellets. Similarly, Oguntimein (1988) in his own assertion sees material composition (e.g. protein, starch, fiber and fat content) as the major factor affecting the quality of pellets. He submitted that protein – rich materials plasticize when heated and acts as a binder to produce strong pellets. Starches gelatinize when heated in the presence of water and also act as a binder to produce strong pellets. Fibers are difficult to compress but when they are present in sufficiently fine strands in the pellets, they give toughness to the products. Fat acts as lubricants, resulting in ease pressing and therefore high capacity extrusion and lower power consumption.

Hennie (2003) classified extruders into two groups based on: (i) the amount of shear they can generate and (ii) the manner in which they generate heat energy. To this end there are extruders of high shear design, medium shear design and those of low shear design. A knowledge concerning the amount of shear an extruder can generate is important in the selection of the right extruder for the attainment of desired result. For example whereas oil bearing seeds contains high levels of fats which cause more lubrication inside the extrusion barrel, thus requiring an extrusion process of high shear design in order to generate enough friction energy for proper processing. Products such as animal feeds, poultry feeds and fish feeds are starchier in composition and therefore require medium shear extrusion processing to be successful.

Brennan *et al.* (1998) outlined three ways by which heating is effected inside an extrusion barrel viz:

(i) Through energy dissipated as a result of shearing of the viscous – like dough food or feed material within the barrel.

(ii) By conductive transfer of heat from electric heaters or steam – heated jackets surrounding the barrel, or

(iii) By injecting steam into the barrel.

During pelleting the temperature in the barrel may rise to as much as 200^0C and the pressure built in may be as high as 60 atm. As the feed marsh is forced through the die, the sudden drop in pressure causes rapid expansion of the extrudate and moisture loss which leads to the cooling of the product evaporatively (Harper, 1981).

Van Zuilichem *et al.* (1983), Sahay and Singh (2001) and Jowitt (1984) classified extruders according to the number of screws operating inside an extrusion barrel, along this line of classification there is the single – screw and double – screw extruders. The double screw extruder comprises two intermeshing screws which can either be co – rotating or contra – rotating. The single screw extruder has only one screw in that it differs from the double – screw extruder both in design and in operation. Although single – screw extruders are less complex and less expensive than the double – screw extruders, they however involve larger shear forces, higher power consumption and can cause large temperature differences within the material being processed. Extruders may have barrels that are parallel sided or tapered for increased shear and compression forces. Extruders are also available in different makes and sizes. For example whereas Clextral B. C. 45 extruder is provided with an extrusion barrel length of 600 mm, length/diameter (L/D) ratio of 9:1 and a die size of 22.25 x 1.5 mm, the Warner and Pfeiderer ZSK – 57 comes with an extrusion barrel length of 1000 mm, length/diameter (L/D) ratio of 16:1 and die size (thickness) of 3.2 – 7.9 mm.

Sahay and Singh (2001) pointed out that the performance of an extruder is best understood by knowing the types of flows which occurs within its screw and the barrel arrangement. These flows as outlined by the authors are:

i. Drag flow: This form of flow results from the relative motion between the screw and the barrel. It represents the positive forward movement of material from the feed end to the discharge end. A high drag flow entails high extruder output.

ii. Pressure flow: This occurs by virtue of pressure difference between the inlet (feed end) and outlet (discharge end) of the extrusion barrel. Pressure flow is continuous via the helices created by the screw flights and screw root and the barrel. The direction of material flow is as to oppose drag flow (i.e. from discharge to feed end).

iii. Leakage flow: This is similar in nature to the pressure flow as such it is also caused by pressure gradient. The flow in itself however, occurs in the tolerance between the screw flights and the barrel wall. This flow is particularly of negative consequence to the capacity of the extruder.

Hennie (2003) looks at the factors affecting the success and efficiency of an extrusion plant and explains that its design, quality and management must be properly established. It is therefore essential to know that pelleting machines differ in design because the application they are designed for differs. Thus variation in raw materials and end product characteristics are the main driving force behind all types of extruders available to the food and feed industries. A study conducted on the effect of processing parameters on the water stability of standard catfish feed by Hastings and Higgs (1980) clearly showed that certain processing parameters (i.e. die size, nature of material and steam utilization or its absence) have a significant influence on water stability of pellets. The influence of barrel valve on the degree of fill of a screw extruder was investigated by Van Zuilichem *et al.* (1989) who reported that with high temperature profile the degree of fill increased when the rotational speed of the screws decreased. An increase in the mass flow rate reduced the degree of fill when the rotational speed of the screws was low (218 rpm). Altomare and Ghossi (1986) have calculated degrees of fill of screw extruders and found a maximum of 46%. At increasing feed rates, the measurements of Jager *et al.* (1988) show an increase in the degree of fill.

CHAPTER THREE

3.0 DESIGN METHODOLOGY

3.1 Design Considerations

Considering the multiple functions the machine is meant to perform (i.e. thorough mixing of feed ingredients and where the need be, pellet them into the required sizes, shapes and forms), the following were considered in the cause of the design:

a. Poor flowability property of ground materials is strongly recognized as an impediment to the operation of the machine and is used as a guide in the design of hopper, stirrer and discharge and transfer channels.

b. Unitization in design so that the mixing unit can be operated independent of the pelleting and steam generating sections of the machine when our need is only limited to mixing feed ingredients. This helps in reducing costs due to energy use.

c. Because extruders are highly sensitive to feed-rate, the use of a flap to allow for variation in material feed-rate going into the extrusion barrel is regarded significant to avoid blockage of extrusion openings during operation.

d. The need for designing different set of dies to cater for the various feeding requirements of the stock being considered.

e. Simplicity and ease in construction so as to facilitate easy maintenance.

f. Made from locally available raw materials so as to be cheap to own and use by the small, medium and large-scale stock raisers. This should serve as a guide in material selection.

g. Since the density of feed varies not only with the number of ingredients forming the feed and their moisture content but as well with the proportion of ingredients used, in this work for the purpose of computations, all feeds are assumed to have an average density of 800 kg/m^3. Similarly it is also assumed that the extruder has the capacity to extrude 1.2m length of pellets per minute. This serves as a guide in the selection of a slider – crank mechanism that drives the cutting mechanism and also in determining the speed, which it must run, to allow for the production of pellets with average length of 20 mm. Generally, the entire length, height and width of the machine are assumed.

3.2 Design Calculations

3.2.1 Determination of the volumes of mixing chamber and extruder

(a) Volume of mixing chamber

The mixing chamber consists of two unequal cylinders (upper and lower cylinders) that are connected by a frustum as shown in fig. 3.1 below.

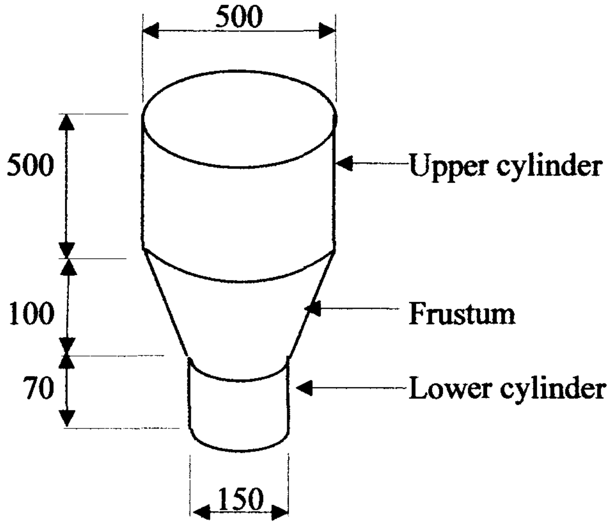


Fig. 3.1 Mixing chamber

The total volume of this chamber is computed using the relationship:

$$V_T = V_U + V_F + V_L \tag{3.1}$$

Where,

V_T = total volume of mixing chamber

V_U = volume of upper cylinder

V_L = volume of lower cylinder

V_F = volume of frustum

The equations for finding the volume of a cylinder and that of a frustum are given by Garlick and Barnes (1981) as:

$$V = \pi r^2 h \tag{3.2}$$

$$V_f = \frac{1}{3} h_f (A + \sqrt{AB} + B) \tag{3.3}$$

Where,

V = volume of cylinder, m^3

V_f = volume of frustum, m^3

r = radius of cylinder, m

h = height of cylinder, m

h_f = height of frustum, m

A = area of bigger end of frustum, m^2

B = area of smaller end of frustum, m^2

From equation 3.2, the volume of upper cylinder (V_U) is computed thus:

$$V_U = \pi r^2 h_U$$

For: r = 0.25 m, h_U = 0.50 m and π = 3.142, then:

$$V_U = 3.142 \times 0.25^2 \times 0.50$$

$$\therefore V_U = 0.098\ m^3$$

From equation 3.3, the volume of frustum (V_F) is calculated thus:

$$V_F = \frac{1}{3} h_F (A + \sqrt{AB} + B)$$

but, A = 3.142 x 0.25^2

$$\therefore A = 0.196 m^2$$

and B = 3.142 x 0.075^2

$$\therefore B = 0.018 m^2$$

h_F (height of frustum) = 0.100m, substituting for A,B and h_F in the above equation gives:

$$V_F = \frac{1}{3} \times 0.1 \times (0.196 + \sqrt{0.196 \times 0.018} + 0.018)$$

$$\therefore V_F = 0.007 m^3$$

Volume of lower cylinder is computed using equation 3.2 as:

$$V_L = \pi r^2 h$$

For r = 0.075 m and h = 0.070 m then:

$$V_L = 3.142 \times 0.075^2 \times 0.070$$

$$V_L = 0.001\ m^3$$

Since $V_T = V_U + V_F + V_L$, substituting for V_U, V_F, and V_L with their computed values gives:

$$V = 0.098 + 0.007 + 0.001$$
$$\therefore V = 0.106 m^3$$

This means that the mixing chamber has the theoretical capacity to hold and mix 0.106 m^3 of feed ingredients at a time.

(b) Volume of extruder

The extrusion barrel is represented in fig. 3.2, the volume of this barrel (V_{EX}) is computed using equation 3.3 given as

$$V_{EX} = \frac{1}{3}h(A + \sqrt{AB} + B)$$

$$Where:$$

$$A = \frac{\pi D^2}{4} = \frac{3.142 \times (0.15)^2}{4} = 0.018 m^2$$

$$B = \frac{\pi D^2}{4} = \frac{3.142 \times (0.01)^2}{4} = 0.008 m^2$$

$$h(length of extruder) = 0.6 m$$

$$\Rightarrow V = \frac{1}{3} \times 0.6 \times (0.018 + \sqrt{0.018 \times 0.008} + 0.008) = 0.008 m^3$$

$$\therefore Volume\ of\ extruder = 0.008 m^3$$

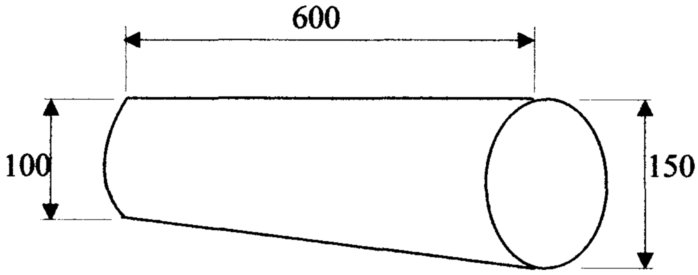


Fig. 3.2 Extrusion barrel

3.2.2 Capacities of conveyors

Two auger conveyors were designed for the machine. The conveyors are: (i) a vertical acting auger conveyor (fig. 3.3), which operates inside a close fitted tube to effect blending of feed components and (ii) a horizontal acting auger conveyor (fig. 3.4) that operates inside a close fitted tapered extrusion barrel used to achieve feed conditioning and its subsequent extrusion through the dies.

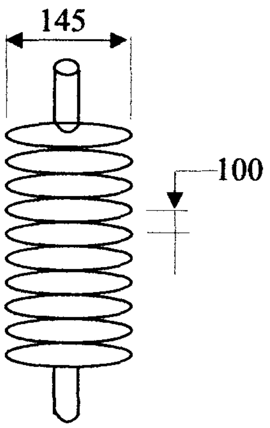


Fig. 3.3 Vertical acting auger conveyor

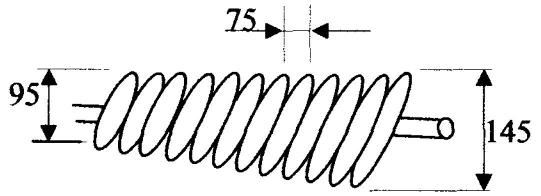


Fig. 3.4 Horizontal acting auger conveyor

The auger in the mixing section (fig. 3.3) is designed with helices of uniform diameter of 145 mm and a pitch of 100 mm. Its capacity is computed using equation 3.4 given by Kubota (1995) as:

$$Q = 60n\phi p\gamma(D^2 - d^2)\frac{\pi}{4} \tag{3.4}$$

Where,

Q = capacity of conveyor, t/h

γ = bulk density of conveyed material, 800 kg/m^3

n = number of screw rotations, 800 rpm

p = conveyor pitch, 0.1 m

D= pitch diameter of conveyor, 0.145 m

d = diameter of shaft, 0.02 m

π = constant, 3.142

ϕ = factor introduced for inclined conveyor, 0.33 (note Lucia and Assennato, 1994 reported that a tube auger operating at 90^0 to the horizontal has its output reduced by two-third, i.e. $\phi = 0.33$)

Substituting these values in the above auger capacity equation yields:

$$Q = 60 \times 800 \times 0.33 \times 0.1 \times 800 \times (0.145^2 - 0.02^2) \times \frac{3.142}{4}$$
$$\therefore Q = 20.53 t/h$$

The pelleting auger (fig 3.4) is designed tapered with major and minor diameters of 145 mm and 95 mm respectively (i.e. its pitch diameter is the average of the two diameters and this is equal to 120 mm). Its helices are designed with uniform pitch of 75 mm. The capacity of this conveyor is computed using the following values for the equation variables: n = 500 rpm, $\phi = 1$, p = 0.075 m, $\gamma = 800$ kg/m^3, D_{av} = 0.12 m, d = 0.02 m and π =3.142. Therefore by substitution we have:

$$Q = 60 \times 500 \times 1 \times 0.075 \times 800 \times (0.12^2 - 0.02^2) \times \frac{3.142}{4}$$
$$\therefore Q = 19.795 t/h$$

3.2.3 Power required by the conveyors

The power required by the two conveyors, are computed separately, because the conveyors are designed to be powered by two separate motors. The power (L) required to operate the mixing auger was computed using equation 3.5 as expressed by Kubota (1995) viz:

$$L = 0.7355 ClQ \tag{3.5}$$

Where,

L = power required by the conveyor, kW

C = coefficient, constant for conveyed material, 0.3

l = length of conveyor, 0.5

Q= 20.53 t/h

$$\Rightarrow L = 0.7355 \times C \times l \times Q$$
$$L = 0.7355 \times 0.3 \times 0.5 \times 20.53$$
$$\therefore\ L = 2.26 kW$$

An electric motor of 5 HP (3.729 kW) with a speed of 1450 rpm is selected to power the mixer. For the pelleting auger, its power requirement is calculated using the following values for the power equation variables: C = 0.3, l = 0.5 m and Q = 19.795 t/h. Thus:

$$L = 0.7355 \times 0.3 \times 0.5 \times 19.795$$
$$\therefore\ L = 2.184 kW$$

An electric motor of 5 HP (3.729 kW) with speed of 1450 rpm is also selected to power the pelleting auger.

3.2.4 Determination of operating pressure in the extrusion barrel

The pressure in the extrusion barrel is computed using equation 3.6.

$$P = \frac{L}{Q_f} \tag{3.6}$$

Where,

P = pressure inside the extrusion barrel, N/m^2

L = power available to the conveyor, 2,184 W

Q_f = volumetric flow rate of material, m^3/s. For this case where Q = 19,794.6 kg/h. In terms of volumetric equivalent, Q = 0.007 m^3/s obtained using equation 3.7.

$$V_f = \frac{Q}{\rho} \tag{3.7}$$

Where,

$V_f = \textit{volumetric flow rate}, m^3/s$

$Q = \textit{mass flow rate}, 19{,}794.6\, kg/h\,(5.50\, kg/s)$

$\rho = \textit{density of feed}, 800\, kg/m^3$

$$\Rightarrow V_f = \frac{5.50}{800}$$

$$\therefore V_f = 0.007\, m^3/s$$

Therefore by substitution we get:

$$P = \frac{2184}{0.007}$$

$$\therefore\ P = 312\, kPa$$

3.2.5 Determination of thrust force (W)

The thrust force (W) moving the material inside the extrusion barrel of cross sectional area (A) is computed using equation 3.8 expressed by Walker (1981) as:

$$W = PA \tag{3.8}$$

Where,

P = pressure in the barrel, 312 kPa (see section 3.2.4).

A = area of extruder = $\pi\frac{(D^2-d^2)}{4} = 3.142\times\frac{(0.145^2-0.095^2)}{4} = 0.009\, m^2$

Substituting for P and A in the above expression gives:

$$W = 312 \times 0.009$$
$$\therefore W = 2.941\,kN$$

3.2.6 Determination of tangential force (F)

The force which lifts the feed material as it moves inside an extrusion barrel (i.e. tangential force) is computed using equation 3.8 given by Walker (1981) as:

$$F = W \tan \vartheta \tag{3.9}$$

Where,

F = tangential force lifting the body, N/m^2

W = thrust force, 2.941 kN (see section 3.2.5)

$$\tan \vartheta = \frac{Lead}{\pi \times pitch\,diameter} \tag{3.10}$$

Where,

$$Lead = Number\ of\ start \times pitch = 1 \times 0.075 = 0.075\,m$$

$$thus\ \tan \vartheta = \frac{0.075}{3.142 \times 0.12} = 0.199$$

By substitution,

$$\Rightarrow F = 2.941 \times 0.199$$
$$\therefore F = 0.585\,kN (585\,N)$$

3.2.7. Determination of extrusion pressure

For a constant feed-rate, speed of extrusion, feed formulation and material density, extrusion pressure then only varies with die size. In this work, four dies are designed to extrude pellets. The dies are:

a. Two square die holes of 20 mm x 20 mm

b. One square die hole of 40 mm x 40 mm

c. A 5 mm diameter die with 24 holes

d. A 7 mm diameter die with 24 holes

The pressures of extrusion in respect of the dies are computed using equation 3.8 in the form:

$$P = \frac{W}{A}$$

Where,

P = extrusion pressure

W = thrust force

A = total area of extrusion holes.

From section 3.2.5, thrust force (W) was found to be 2.941 kN. The area of the holes on the four dies needs to be computed and they are obtained thus:

Die 1, $A_1 = 2lb = 2 \times 0.02 \times 0.02 = 8 \times 10^{-4} m^2$

Die 2, $A_2 = lb = 0.04 \times 0.04 = 1.6 \times 10^{-3} m^2$

Die 3, $A_3 = \dfrac{24\pi D_3{}^2}{4} = \dfrac{24 \times 3.142 \times (0.005)^2}{4} = 4.472 \times 10^{-4} m^2$

Die 4, $A_4 = \dfrac{24\pi D_4{}^2}{4} = \dfrac{24 \times 3.142 \times (0.007)^2}{4} = 9.236 \times 10^{=4} m^2$

Their corresponding extrusion pressures are obtained thus:

Die 1, $P_1 = \dfrac{W}{A_1} = \dfrac{2.941}{8 \times 10^{-4}} = 3.676 mPa.$

Die 2, $P_2 = \dfrac{W}{A_2} = \dfrac{2.941}{1.6 \times 10^{-3}} = 1.838 mPa$

Die 3, $P_3 = \dfrac{W}{A_3} = \dfrac{2.941}{4.472 \times 10^{-4}} = 6.576 mPa.$

$$\text{Die 4, } P_4 = \frac{W}{A_4} = \frac{2.941}{9.236 \times 10^{-4}} = 3.184\, mPa.$$

3.2.8 Determination of material hold-up (H) in the extrusion barrel

This is computed using the equation below as expressed by Van Zuilichem *et al.* (1989).

$$H = DV_{Tot} \qquad (3.11)$$

Where,

$H = material\ hold\ up, m^3$

$D = \deg ree\ of\ fill\ obtained\ as\ 46\%\ by\ Altomare\ and\ Ghossi\ (1986).$

$V_{Tot} = reaction\ volume\ of\ the\ extruder = vol.of\ barrel - vol\ of\ screw$

$From\ \sec tions\ 3.2.1(b)\ and\ 3.2.1.5(b), the\ volumes\ of\ extrusion\ barrel\ and\ the$

$screw\ were\ computed\ as\ 0.008\, m^3\ and\ 1.59 \times 10^{-4}\, m^3\ respective ly.$

Thus,

$$V_{Tot} = 0.008 - 1.59 \times 10^{-4}$$

$$\therefore V_{Tot} = 0.007841\, m^3$$

$Substituti ng\ for\ D\ and\ V_{Tot}\ in\ above\ equation\ gives:$

$$H = 0.46 \times 0.007841$$

$$\therefore H = 0.0036\, m^3 .Or\ in\ terms\ of\ mass\ assu \min g\ a\ feed\ density\ of\ 800 kg / m^3, then:$$

$$H = 0.0036 \times 800$$

$$\therefore H = 2.88\, kg$$

3.2.9 Determination of the volume of steamer

The main tank of the steamer is designed cylindrical with the following dimensions: height (h) = 300 mm and diameter (d) = 220 mm as shown in fig. 3.5 below. Its volume (V) is computed using equation 3.2 given as:

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

$$V = 3.142 \times (0.11)^2 \times 0.3$$

$$V = 0.011\, m^3 (i.e\ it\ has\ the\ capacity\ to\ hold\ 11\, kg\ of\ water)$$

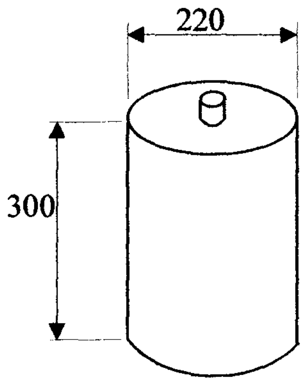


Fig. 3.5: The steamer

3.2.10 Determination of heating duration

The time required to heat a given quantity of water from known temperature to the required temperature is computed using equation 3.12 as expressed by Donnelly (1980).

$$t = \frac{\Delta T m c_p}{L\eta} \qquad (3.12)$$

Where,

t = heating time, s

ΔT = change in temperature, ^{0}C

m = mass of water in the heater, kg

c_p= specific heat capacity of water, J/kg^{0}C

L = power rating of the heating element, W

η= efficiency of the heating element, %

In this case where m = 8 kg, c_p = 4,180 J/kg^{0}C, L = 3,000 W, η= 85 % T_1 = 25^{0}C and T_2 = 100^{0}C using the said equation 3.12 above gives:

$$t = \frac{(100-25)\times 8\times 4180}{3000\times 0.85}$$

$$\therefore t = 983.53s\,(16.39\,\text{min})$$

3.2.11 Determination of energy required to heat water

The total energy required to raise the temperature of water from 25^0C to 100^0C is computed using equation 3.13 below as given by Ozumba and Obiakor (2004).

$$q = \frac{\Delta T m c_p}{\Delta t} \qquad (3.13)$$

Where,

q = quantity of heat energy required, J

ΔT = change in temperature, ^{0}C

m = mass of water in the boiler, kg

c_p = specific heat capacity of water, J/kg ^{0}C

dt = time required for heating, s

For our case where m = 8 kg, c_p = 4180 J/kg^{0}C, ΔT = 75^0C and Δt is as obtained in section 3.3.9 i.e. 983.53 seconds. Thus:

$$q = \frac{75 \times 8 \times 4180}{983.53}$$
$$\therefore q = 2550\,J\,(2.55\,kJ)$$

3.2.12 Determination of heat loss from the steamer through conduction

The rate of heat loss through conduction from the steamer insulated wall to the surrounding is computed using Fourier's law of heat conduction as expressed by Henderson and Perry (1976) in equation 3.14.

$$q = \frac{\Delta T}{R} \qquad (3.14)$$

Where,

q = rate of heat loss per area, W/m^2

ΔT = temperature change, ^{0}C

R = total resistance to heat flow, m^{2}K/W

$$for: T_1 = 100^0 C, T_2 = 25^0 C,$$

and R (i.e. total resistance to heat flow across cylindrical objects) is expressed by Brennan et. al (1998) as:

$$R = R_1 + R_2 + R_3 \qquad (3.15)$$

Where: R_1, R_2, R_3.....are the individual resistances to heat flow across cylinder walls.

r_x = cylinder radius, l = length of cylinder and k_x = thermal conductivity of material from which the cylinder is made.

$$R_1 = \frac{\ln\frac{r_2}{r_1}}{2\pi l k_1} = \frac{\ln\frac{0.111}{0.110}}{2\times 3.142\times 0.32\times 48.5} = 9.28\times 10^{-5} m^2 K/W$$

$$R_2 = \frac{\ln\frac{r_3}{r_2}}{2\pi l k_2} = \frac{\ln\frac{0.151}{0.111}}{2\times 3.142\times 0.32\times 0.65} = 2.35\times 10^{-1} m^2 K/W$$

$$R_3 = \frac{\ln\frac{r_4}{r_3}}{2\pi l k_3} = \frac{\ln\frac{0.1525}{0.151}}{2\times 3.142\times 0.32\times 48.5} = 1.01\times 10^{-4} m^2 K/W$$

$$\Rightarrow R = 9.28\times 10^{-5} + 2.35\times 10^{-1} + 1.01\times 10^{-4} m^2 K/W$$

$$\therefore R = 0.235 m^2 K/W$$

Thus:

$$q = \frac{100-25}{0.235}$$

$$\therefore q = 319.149 W/m^2$$

3.2.13 Determination of rate of water and steam discharge from the boiler.

(a). Rate of water discharge

Water discharge Q_w from the boiler is calculated using equation 3.16 given by Victor and Benjamin (1975) thus:

$$Q_w = Av \tag{3.16}$$

Where,

$Q_w = water\ discharge,\ m^3/s$

$A = cross-sectional\ area\ of\ pipe$

$$A = \frac{\pi D^2}{4}$$

$$= \frac{3.142 \times 0.0071^2}{4}$$

$$\therefore A = 3.96 \times 10^{-5} m^2$$

$v =$ *velocity of water flow obtained from equation* 3.17 *as given by Victor and Benjamin* (1975).

$$v = \sqrt{2gh} \tag{3.17}$$

Where,

$v = velocity\ of\ water\ flow,\ m/s$

$g = acceleration\ due\ to\ gravity,\ 9.81 m/s^2$

$h = length\ of\ pipe\ over\ which\ pressure\ drops\ occur, 0.3 m$

Substituting these values in the above equation yields

$$v = \sqrt{2 \times 9.81 \times 0.3}$$

$$\therefore v = 2.43 m/s$$

Since, $A = 3.96 \times 10^{-5} m^2$ *and* $v = 2.43 m/s$ *as computed above then,*

$$\Rightarrow Qw = 3.96 \times 10^{-5} \times 2.43$$

$$\therefore\ Qw = 9.62 \times 10^{-5} m^3/s (0.35 m^3/h)$$

The maximum discharge as computed above can be varied through the use of a stop valve included in the flow line as reflected in the orthographic projection of the machine.

(b) Rate of steam discharge

The rate of steam flow from the boiler is also calculated using equation 3.18 as expressed by Victor and Benjamin (1975):

$$Q_S = Av \tag{3.18}$$

Where,

$A = \textit{cross-sectional area of the pipe expressed as:}$

$$A = \frac{\pi D^2}{4}$$

$$A = \frac{3.142 \times (0.01835)^2}{4}$$

$$\therefore A = 0.00026 m^2$$

$v = \textit{average velocity of steam flow expressed by Ozumba and Obiakor (2004) as:}$

$$v = \left[\frac{P_1 - P_2}{4 f L}\right]\left[\frac{D^2 - r^2}{4}\right] \tag{3.19}$$

Where:

$P_1 = \textit{steam pressure at } 105^0 C\,(1.208 \times 10^5 N/m^2, \textit{Spalding and Cole}, 1974)$

$P_2 = \textit{atmospheric pressure}\,(1.01396 \times 10^5 N/m^2)$

$D = \textit{inside diameter of pipe}\,(18.35 mm)$

$r = \textit{inside radius of pipe}\,(9.175 mm)$

$L = \textit{length of pipe over which pressure drops occur}\,(750 mm)$

$f = \textit{frictional factor}, (\textit{assuming a laminar flow}, f = \frac{64}{2000} = 0.032)$

$$\Rightarrow v = \left[\frac{120800 - 101396}{4 \times 0.032 \times 1.1}\right]\left[\frac{0.01835^2 - 0.009175^2}{4}\right]$$

$$= 137812.5 \times 0.000063135$$

$$\therefore v = 8.70 m/s$$

$$\Rightarrow Q_s = 0.00026 \times 8.70$$

$$\therefore Q_s = 2.3 \times 10^{-3} m^3/s\,(8.14 m^3/h)$$

3.2.14 The drive

V-belt and pulley arrangements were adopted in this work to transmit power from the two electric motors to the shafts of the mixing and pelleting units. The main reasons for adopting the v-belt drive are its flexibility, simplicity, and low maintenance costs. Additionally, the v-belt has the ability to absorb shocks thereby mitigating the effects of vibratory forces (Gary *et al.*, 1984). Under this section the following computations were made:

(a) Pulley diameters

The diameter of the pulley for the mixing auger is calculated using equation 3.20 expressed by Champion and Arnold (1976) as:

$$D_2 = \frac{N_1 D_1}{N_2} \tag{3.20}$$

$Where:$

$N_1 = speed\ of\ motor, 1450\, rpm$

$D_1 = diameter\ of\ motor\ pulley, 80\, mm$

$D_2 = diameter\ of\ mixing\ auger\ pulley,\ mm$

$N_2 = speed\ of\ mixing\ auger, 800\, rpm$

$$\Rightarrow D_2 = \frac{1450 \times 80}{800}$$

$$\therefore D_2 = 145\, mm$$

In similar manner the diameter of the pulley for the shaft of the pelleting auger is obtained using equation 3.20 with the following values for the equation's variables:

$N_1 = speed\ of\ motor, 1450\, rpm$

$D_1 = diameter\ of\ motor\ pulley, 80\, mm$

$N_2 = speed\ of\ pelleting\ auger, 500\, rpm$

$D_2 = diameter\ of\ pelleting\ auger\ pulley,\ mm$

$$\Rightarrow D_2 = \frac{1450 \times 80}{500}$$

$$\therefore D_2 = 232\, mm$$

A compound belt drive consisting of four pulleys and two v-belts are used to command the operation of the slider-crank cutting mechanism. The drive permits the blade to run at a designed speed of 60 rpm with the extruder shaft running at a speed of 500 rpm. The layout for the arrangement of shafts and pulleys used for the drive is as shown in fig. 3.6 below.

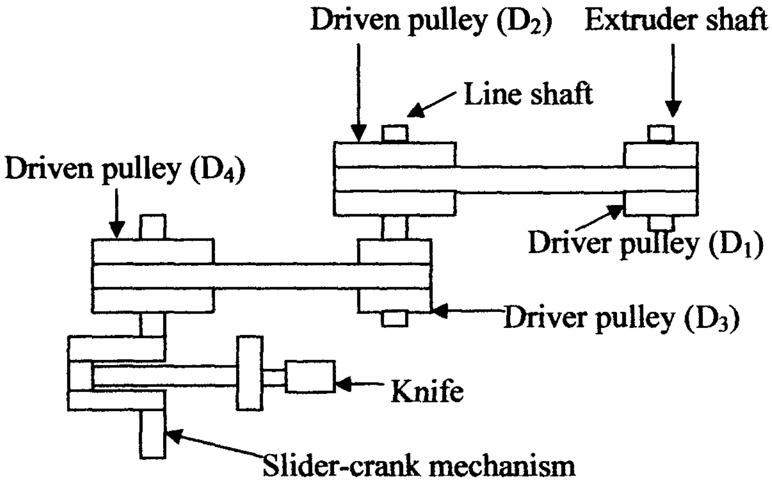


Fig. 3.6: Cutting mechanism and its drive

From the above fig, the diameter of the pulley on the crankshaft (D_4) used to give the required blade speed of 60 rpm is obtained using equation 3.20 expressed as:

$$N_1 D_1 = N_2 D_2$$

Where,

N_1 = *speed of driver pulley*, 500 *rpm*

D_1 = *diameter of driver pulley*, 50 *mm*

N_2 = *speed of driven pulley, rpm*

D_2 = *diameter of driven pulley*, 140 *mm*

This means that:

$$N_2 = N_1 \frac{D_1}{D_2}$$

$$N_2 = \frac{50 \times 500}{140}$$

$$\therefore N_2 = 178.57\,rpm\,(i.e.\,speed\ of\ line\ shaft\ is\ 178.57\,rpm)$$

From the fig. above, $N_2 = N_3$ by using the concept of equation 3.20 we have:

$$D_4 = D_3 \frac{N_3}{N_4}$$

$$\begin{aligned} &Where: \\ &\quad D_4 = diameter\ of\ pulley\ on\ crankshaft,\ mm \\ &\quad N_3 = speed\ of\ blade, 178.57\,rpm \\ &\quad D_3 = diameter\ of\ driver\ pulley\ on\ line\ shaft, 50\,mm \end{aligned}$$

$$\begin{aligned} &N_4 = speed\ of\ blade, 60\,rpm \\ &This\ implies\ that: \\ &D_4 = \frac{50 \times 178.57}{60} \\ &\therefore D_4 = 148.81\,mm \end{aligned}$$

b. Belt speed

The belt speed for the mixer drive is calculated using equation 3.21 as expressed by Shigley and Mischike (2001).

$$v = \frac{\pi DN}{60000} \tag{3.21}$$

Where,

$$\begin{aligned} &v = belt\ speed, m/s \\ &D = diameter\ of\ motor\ pulley, 80\,mm \\ &N = speed\ of\ motor, 1450\,rpm \\ &\pi = cons\tan t, 3.142 \\ &Substituting\ these\ values\ in\ the\ above\ equation\ gives: \\ &\quad v = \frac{3.142 \times 80 \times 1450}{60000} \\ &\quad \therefore v = 6.07\,m/s \end{aligned}$$

The belt speed for the drive of the pelleting auger is also similarly calculated using the following values for variables:

$$N = speed\ of\ motor, 1450\ rpm$$
$$D = diameter\ of\ motor\ pulley, 80\ mm$$
$$\pi = 3.142$$

$Thus:$

$$v = \frac{3.142 \times 80 \times 1450}{60000}$$
$$\therefore v = 6.07\ m/s$$

Both of these speeds falls within the acceptable v-belt speed for agricultural machines drives, which ranges from 5 – 20 m/s as reported by Gary *et al.* (1984).The belt speeds for the two belts used to drive the cutting mechanism are obtained separately. The speed of the first belt i.e. one operating between the extruder shaft and line shaft is found using the following values for the variables in the equation:

$$N = speed\ of\ extruder\ shaft, 500\ rpm$$
$$D = diameter\ of\ pulley, on\ the\ extruder\ shaft, 50\ mm$$
$$\pi = 3.142$$

$Thus:$

$$v = \frac{3.142 \times 50 \times 500}{60000}$$
$$\therefore v = 1.31\ m/s$$

As for the belt operating between the line shaft and crankshaft, its speed was computed using the following values for the variables in the belt speed equation:

$$N = speed\ of\ line\ shaft, 178.57\ rpm$$
$$D = diameter\ of\ pulley\ on\ line\ shaft, 50\ mm$$
$$\pi = 3.142$$

$Thus:$

$$v = \frac{3.142 \times 50 \times 178.57}{60000}$$
$$\therefore v = 0.47\ m/s$$

c. Belt length

Equation 3.22 given below as expressed by Shigley and Mischike (2001) was used in determining the belt length for both the mixing, pelleting and cutting mechanism drives.

$$X = 2C + 1.57(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4C} \tag{3.22}$$

Where,

X = belt length, m

C = center distance between pulleys, m

D_1= pitch diameter of driver pulley, m

D_2=pitch diameter of driven pulley, m

The belt length for the mixer's drive is computed using the following values for the variables:

$$C = center\ distance, 400\,mm$$
$$D = diameter\ of\ driver\ pulley, 80\,mm$$
$$D = diameter\ of\ driven\ pulley, 145\,mm$$

Since,

$$X = 2C + 1.57(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4C}$$

$$\Rightarrow X = 2 \times 400 + 1.57(80 + 145) + \frac{(80 - 145)^2}{4 \times 400}$$

$$\therefore X = 1156\,mm (1.156\,m)$$

The belt length for the drive of the pelleting section of the machine is obtained by using the following values for the variables in equation 3.22:

C = center distance, 300 mm;

D_1= diameter of driver pulley, 80 mm

D_2= diameter of driven pulley, 232 mm.

Thus:

$$X = 2 \times 300 + 1.57(80 + 232) + \frac{(80 - 232)^2}{4 \times 300}$$
$$\therefore X = 1109.09\,mm(1.109\,m)$$

A B-50 V-belt is selected. It has a top width (b) of 17mm and thickness (t) of 11 mm with weight per meter of 1.89 N (Khurmi and Gupta, 2004).

The belt lengths for the drive to the cutting mechanism are found using the following values for the variables in the equation: For the belt operating between the pulleys on the extruder shaft and line shaft the following values applies:

C = center distance, 350 mm;

D_1 = diameter of driver pulley, 50 mm

D_2 = diameter of driven pulley, 140 mm.

This implies that:

$$X = 2 \times 350 + 1.57(50 + 140) + \frac{(50 - 140)^2}{4 \times 350}$$
$$\therefore X = 1004.09\,mm(1.004\,m)$$

For the shaft operating between the pulleys on line shaft and crankshaft, its length was found using the following values for the variables:

C = center distance, 345 mm

D_1= diameter of driver pulley, 50 mm

D_2= diameter of driven pulley, 148.81 mm.

Therefore by substitution:

$$\Rightarrow X = 2\times 345 + 1.57(50 + 148.81) + \frac{(50 - 148.81)^2}{4\times 345}$$

$$\therefore X = 1009.02\,mm\,(1.009\,m)$$

d. Number of belts required

The number of belt required to transmit the designed power from electric motor to the shaft of the mixing auger is computed using equation 3.23 expressed by Khurmi and Gupta (2004) as:

$$N_B = \frac{L}{(T_1 - T_2)v} \tag{3.23}$$

Where,

N_B = *number of belts,* (?)

L = *designed power,* 2260 W (*see section* 3.3.3)

T_1 = *tension on the tight side of the belt,* 474.26 N (*see section* 3.3.15*a*)

T_2 = *tension on the slack side of the belt,* 101.43 N (*see section* 3.3.15*a*)

v = *belt speed,* 6.07 m/s (*see section* 3.3.14*b*)

By substitution we have:

$$N_B = \frac{2260}{(474.28 - 101.43)\times 6.07}$$

$$\therefore N_B = 0.998 \approx 1\,belt$$

Similarly for the extruder drive, its required number of belts is calculated using the same equation 3.23 with the following values for the variables:

L = *designed power,* 2184 W (*see scetion* 3.3.3)

T_1 = *tension on the tight side of the belt,* 317.20 N (*see section* 3.3.15*b*)

T_2 = *tension on the slack side of the belt,* 92.46 N (*see section* 3.3.15*b*)

v = *belt speed,* 6.07 m/s (*see section* 3.3.14*b*)

$$\Rightarrow N_B = \frac{2184}{(317.20 - 92.46)\times 6.07}$$

$$\therefore N_B = 1.60 \approx 2\,belts$$

3.2.15 Determination of shaft diameter

Two shafts were designed for the machine i.e. one each for the mixing and pelleting sections. Their design is as follows:

(a) Mixer shaft design

The expression for finding centrifugal tension (T_c) is given by Khurmi and Gupta (2004) as:

$$T_C = mv^2 \tag{3.24}$$

$Since\ m = 1.89\,N\,(mass\ of\ selected\ belt, see\ section\ 3.3.14c)\ and$
$v = 6.07\,m/s\,(velocity\ of\ belt, see\ section\ 3.3.14b,$
$then,$

$$T_C = 1.89 \times (6.07)^2$$
$$T_C = 69.64\,N$$

Walker (1981) gave the following equations in respect of power, velocity and tension on the slack and tight sides of v-belt drive:

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\vartheta \operatorname{cosec}\beta} \tag{3.25}$$

$$L = (T_1 - T_2)v \tag{3.26}$$

$$T = (T_1 - T_2)r \tag{3.27}$$

Where,

T_1 = tension on tight side, N

T_2 = tension on slack side, N

T_c = centrifugal tension, N

μ = coefficient, 0.25

θ = angle of lap = 180 – 2 sinα, rads

$\alpha = \frac{d_2 - d_1}{2C}$, deg

β = semi angle of groove of pulley, deg.

L = power, W

v = velocity of pulley, m/s

T = maximum torque, Nm

r = radius of pulley, m

From equation 3.25 given as:

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu \vartheta \operatorname{cosec}\beta}$$

Knowing that:

$T_c = 69.64\,N$

$\mu = 0.25$

$\beta = 16^0$

$\vartheta = 180^0 \pm 2\sin^{-1}\frac{145-80}{2\times400} = 170.68^0\ (2.98 rads)$

$$\frac{T_1 - 69.64}{T_2 - 69.64} = e^{0.25\times2.98\operatorname{cosec}16^0}$$

$T_1 - 69.64 = 14.92T_2 - 1039.03$

$$T_1 = 14.92T_2 - 969.39 \qquad (3.28)$$

Knowing that maximum torque (T) is expressed as:

$$T = \frac{60L}{2\pi N} \qquad (3.29)$$

From sections 3.2.2 *and* 3.2.3, $L = 2265\ W$ *and* $N = 800$ *rpm thus* :

$$T = \frac{60 \times 2265}{2 \times 3.142 \times 800}$$

$$T = 27.03\ Nm$$

Considering equation 3.27 i.e.:

$$T = (T_1 - T_2)r$$

Since:

$$T = 27.03\,Nm \text{ and } r\ (\text{radius of pulley}) = 0.0725\,m, \text{then}:$$

$$T_1 = \frac{27.03}{0.0725} + T_2$$

$$T_1 = 372.83 + T_2 \qquad (3.30)$$

Combining equations (3.28) and (3.30) yields

$$14.94T_2 - 969.39 = 372.83 + T_2$$

$$\therefore T_2 = 96.29\,N$$

Substituting for T_2 *in equation* (3.30) *gives*

$$T_1 = 372.83 + 96.29$$

$$\therefore T_1 = 469.12N$$

Weight of auger (W_a) on shaft is computed using the relationship:

$$W_a = mg \qquad (3.31)$$

where,

$$m\ (\text{mass of auger}) = \text{density of mild steel} \times \text{total volume of rods used}$$

$$\text{Density of mild steel} = 7800\,kg/m^3$$

$$\text{Volume of rods} = \frac{\pi D^2 l}{4} = \frac{3.142 \times 0.006^2 \times 9}{4}$$

$$\therefore \text{Volume of rods} = 2.54 \times 10^{-4}\,m^3$$

By substitution,

$$m\ (\text{mass of auger}) = 7800 \times 2.54 \times 10^{-4} = 1.98\,kg$$

$$\text{Since } g\ (\text{acceleration due to gravity}) = 9.81\,m/s^2$$

Substituting for m and g in the equation above gives,

$$W_a = 1.98 \times 9.81$$

$$\therefore W_a = 19.42\,N$$

The approximate weight of pulley (Wp) on shaft is also computed using the expression:

$$W_p = mg \tag{3.32}$$

$where,$

$m\,(mass\ of\ pulley) = density\ of\ mild\ steel \times approximate\ volume\ of\ material\ used$

$Density\ of\ mild\ steel = 7800\ kg/m^3$

$$Approximate\ volume\ of\ material\ used = \frac{\pi D^2 w}{4}$$

$$= \frac{3.142 \times 0.145^2 \times 0.02125}{4}$$

$\therefore Approximate\ volume\ of\ material\ used = 3.51 \times 10^{-4}\ m^3$

$By\ substitution,$

$$\Rightarrow m = 7800 \times 3.51 \times 10^{-4}$$

$$\therefore m = 2.737\ kg$$

$Since\ g\,(acceleration\ due\ to\ gravity) = 9.81\ m/s^2$

$Substituting\ for\ m\ and\ g\ in\ equation\ (3.32)\ above\ gives:$

$$W_p = 2.737 \times 9.81$$

$$\therefore W_p = 26.85\ N$$

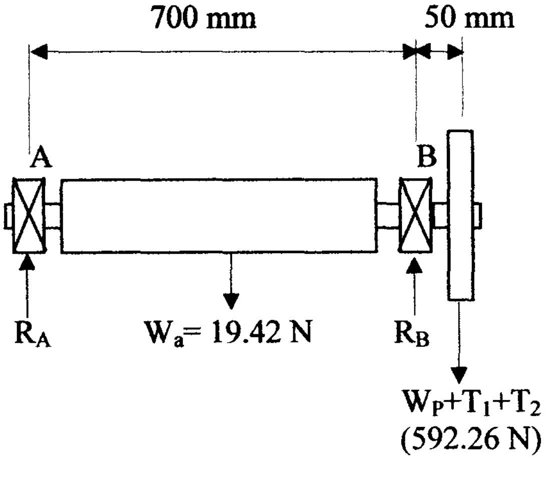


Fig. 3.7 Shaft assembly for the mixer

Fig. 3.7 shows the mixer shaft assembly being supported by two ball bearings A and B with reactions R_A and R_B. By taking moment about A gives:

$$\sum M_A = 0$$
$$(592.26 \times 0.75) + R_B(0.75 - 0.05) + 19.42(0.75 - 0.05 - 0.35) = 0$$
$$444.195 + 0.7R_B + 6.797 = 0$$
$$\therefore R_B = -644.27\,N$$

For the shaft assembly in fig. 3.7,

$$R_A + R_B = 19.42 + 592.26$$
$$\Rightarrow R_A + R_B = 611.68$$

Substituting of R_B with computed value yields:

$$R_A = 611.68 - (-644.27)$$
$$\therefore R_A = 1277.40\,N$$

From the vertical load diagram in fig. 3.8, total vertical reaction at the bearings is given by:

$$R_{AV} + R_{BV} = 611.68\,N. \mathit{Taking\ moment\ about\ A\ gives:}$$
$$R_{BV} \times 0.7 = 592.26 \times 0.75 + 19.42 \times 0.35$$
$$\therefore R_{BV} = 644.27\,N$$
$$\mathit{Since,} R_{AV} + R_{BV} = 611.68\,N, \mathit{subustituting\ for}\ R_{BV}\ \mathit{yields}$$
$$R_{AV} = 611.68 - 644.27$$
$$\therefore R_{AV} = -32.59\,N$$
$$\mathit{Bending\ moment\ at}\ A\,(M_{AV})$$
$$M_{AV} = R_{AV} \times 0.35$$
$$\therefore M_{AV} = 11.41\,Nm$$
$$\mathit{Bending\ moment\ at}\ B\,(M_{BV})$$
$$M_{BV} = R_{BV} \times 0.05$$
$$\therefore M_{BV} = 32.21\,Nm$$

From the horizontal load diagram in figure 3, the total reaction at the bearings is obtained as:

$R_{AH} + R_{BH} = 19.42\,N. \textit{Taking moment about A yields:}$

$R_{BH} \times 0.7 = 19.42 \times 0.35$

$\therefore R_{BH} = 9.71\,N$

$\textit{Since, } R_{AH} + R_{BH} = 19.42\,N, \textit{substituting for } R_{BH} \textit{ with computed value gives:}$

$R_{AH} = 19.42 - 9.71$

$\therefore R_{AH} = 9.71\,N$

Horizontal bending moment at $A\,(M_{AH})$.

$M_{AH} = R_{AH} \times 0.35 = 3.40\,N$

Horizontal bending moment at $B\,(M_{BH})$

$M_{BH} = R_{BH} \times 0.35 = 3.40\,N$

The resul tan t bending moment at $A\,(M_A)$

$M_A = \sqrt{(M_{AV})^2 + (M_{AH})^2} = \sqrt{(11.41)^2 + (3.4)^2} = 11.91\,Nm$

The resultant bending moment at B (M_B) is:

$$MB = \sqrt{(M_{BV})^2 + (M_{BH})^2} = \sqrt{(32.21)^2 + (3.4)^2} = 32.39\,Nm$$

We see that maximum bending moment is at B. therefore maximum bending moment M = M_B = 32.39 Nm.

Equations for computing equivalent twisting moment (T_e) and that of a shaft diameter (d) are given by Khurmi and Gupta (2004) as:

$$T_e = \sqrt{(MK_b)^2 + (TK_t)^2} \tag{3.33}$$

$$d^3 = \frac{16T_e}{\pi\tau} \tag{3.34}$$

Where,

T_e = equivalent twisting moment, Nm

M = maximum bending moment, Nm

T = torsional moment, Nm

K_b = fatigue factor due to bending, 2.0

K_t = fatigue factor due to torsion, 1.5

τ = maximum allowable shear stress, N/mm^2

d = diameter of shaft, m

Using equation 3.33 equivalent twisting moment (T_e) is computed using the following values for the variables:

$$
\begin{aligned}
M &= 32.39\,Nm \\
T &= 27.03\,Nm \\
K_b &= 2.0 \\
K_t &= 1.5
\end{aligned}
$$

By substitution,

$$\Rightarrow T_e = \sqrt{(32.39 \times 2.0)^2 + (27.03 \times 1.5)^2}$$

$$\therefore T_e = 76.42\,Nm$$

Ryder (2001) outlined two conditions which a shaft must satisfy for it to be able to transmit power with least danger of failure. The conditions are (a) that the shaft must not twist more than 1^0 on a length of 15 diameters (i.e. $\vartheta = \pi/15D$), and (b) the shear stress must not exceed 55 N/mm^2. The equation for determining working stress in shaft is expressed by Ryder (2001) as:

$$\tau_w = \left(\frac{G\vartheta}{l}\right)\xi \qquad (3.35)$$

Where,

τ_w = working stress, N/mm^2

G = moment of rigidity for mild steel shaft, 80,000 N/mm^2 (Khurmi and Gupta, 2004)

ϑ = angle of twist, $\pi/15D$ (Ryder, 2001)

ξ = polar moment of inertia, $\pi D^4/32$ (Ryder, 2001)

l = length of shaft, 800 mm

By substitution we have:

$$\tau_w = \frac{80{,}000 \times \pi \times \pi D^4}{15D \times 800 \times 32}$$
$$\therefore \tau_w = 2.06 D^3 \ N/mm^2$$

The equation for finding permissible stress in shaft is given by Ryder (2001) as:

$$\tau_p = \left(\frac{2\tau}{D}\right)\xi \tag{3.36}$$

Where,

τ_p = permissible stress, N/mm^2

τ = maximum allowable shear stress, 55 N/mm^2 (Ryder, 2001)

ξ = polar moment of inertia, $\pi D^4/32$ (Ryder, 2001)

By substitution the following is obtained:

$$\tau_p = \frac{2 \times 55 \times \pi D^4}{D \times 32}$$
$$\therefore \tau_p = 10.80 D^3 \; N/mm^2$$

Comparing the value of τ_w with τ_p above, it follows that the working stress (τ_w) is less than the permissible stress (τ_p). In fact the actual working stress (τ_a) is obtained using equation 3.37 as expressed by Ryder (2001).

$$\tau_a = \left(\frac{\tau_w}{\tau_p} \right) \tau \tag{3.37}$$

Where,

τ_a = actual working stress, N/mm^2

τ_w = working stress, obtained above as 2.06D^3 N/mm^2

τ_p = permissible stress, obtained above as 10.80D^3 N/mm^2

τ = maximum allowable shear stress, 55 N/mm^2

Substituting for τ_w, τ_p *and* τ with their values in equation 3.37 yields:

$$\tau_a = \left(\frac{2.06 D^3}{10.80 D^3} \right) \times 55$$
$$\therefore \tau_a = 10.49 \, N/mm^2$$

This means that the actual working stress (τ_a) is less than the maximum allowable shear stress (τ). Therefore, the diameter of the shaft is computed using equation 3.34 with the following values for the variables:

$$T_e = 76.42\,Nm,$$
$$\tau \;= 55\,MPa$$

By substitution,

$$\Rightarrow d^3 = \frac{16 \times 76.42}{3.142 \times 55 \times 10^6}$$
$$\therefore d = 0.01913\,m\,(19.13\,mm)$$

A shaft of 20 *mm is selected.*

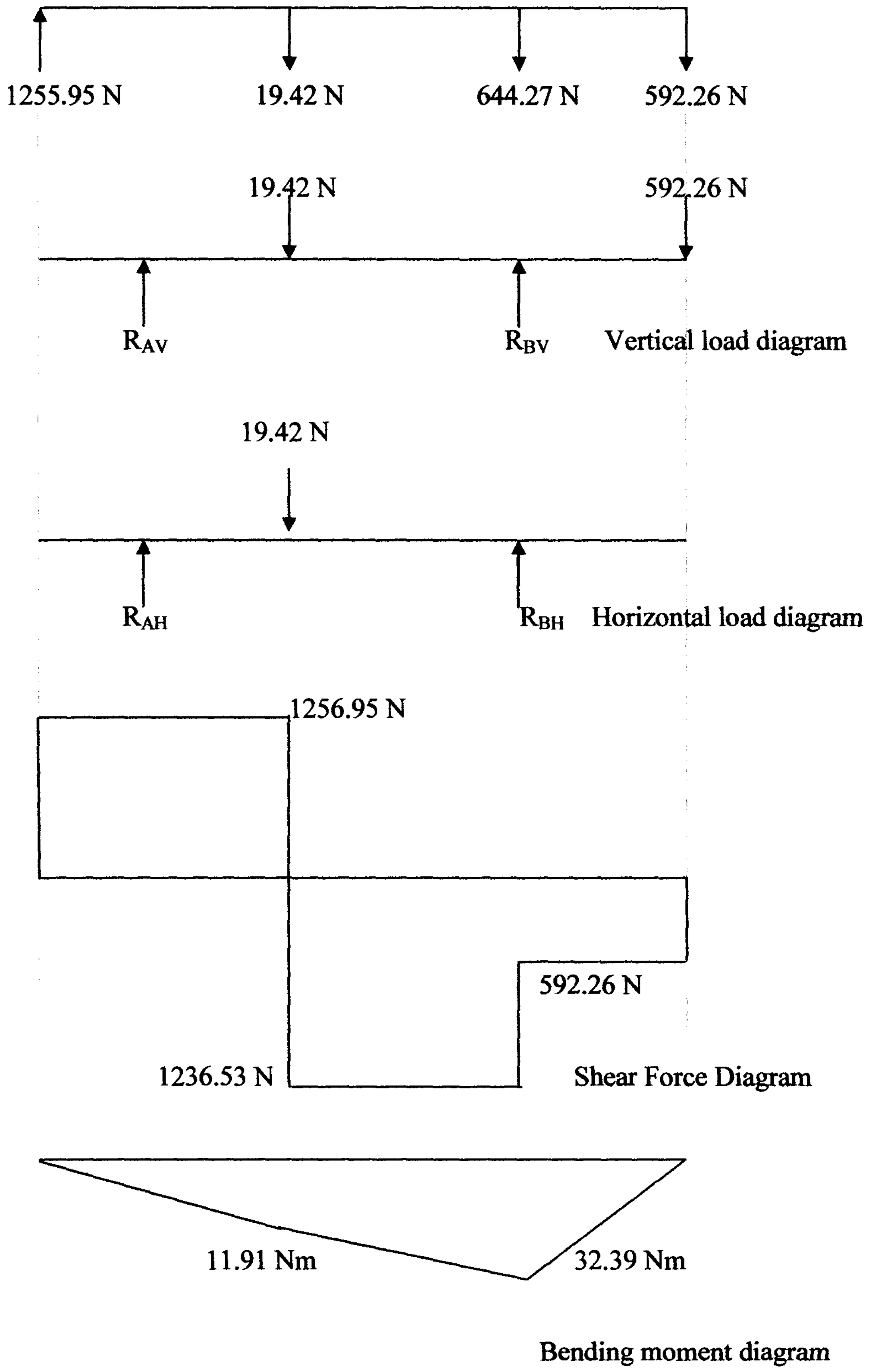


Fig 3.8: Bending moment and shear force diagrams for mixer's shaft

(b) Extruder shaft design

The diameter of the extruder's shaft is also determined using the same approach as in (A) of this section. The computations were made thus:

From equation 3.24, centrifugal tension ($T_{c)}$ is given by:

$$T_c = mv^2$$
$$Where:$$
$$m = weight\,/\,meter\ length\ of\ belt, 1.89\,N$$
$$v = belt\ speed, 6.07\,m\,/\,s$$
$$Thus:$$
$$T_c = 1.89 \times 6.07$$
$$T_c = 69.64\,N$$

Using equation 3.25 i.e.:

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\vartheta \operatorname{cosec}\beta}$$
$$Since:$$
$$T_c = 69.64N, \mu = 0.25, \beta = 16^0\ and$$
$$\vartheta = 180 - 2\sin^{-1}\tfrac{232-80}{2\times300} = 150.65^0\ (2.63\,rads)$$

Substituting these values in the above equation gives:

$$\frac{T_1 - 69.64}{T_2 - 69.64} = e^{0.25\times2.63\times\operatorname{cosec}16^0}$$
$$T_1 - 69.64 = 10.86T_2 - 756.51$$
$$T_1 = 10.86T_2 - 686.87 \tag{3.38}$$

Maximum torque is expressed in equation 3.29 as:

$$T = \frac{60L}{2\pi N}$$
$$Since: L = 2184\,W\ and\ N = 800\,rpm,$$
$$\Rightarrow T = \frac{60\times2184}{2\times3.142\times800}$$
$$\therefore T = 26.07\,N$$

From equation 3.27 we have:

$$T_1 = \frac{T}{r} + T_2$$

$$Since : T = 26.07\,N\; and\; r = 0.116\,m$$

$$\Rightarrow T_1 = \frac{26.07}{0.116} + T_2$$

$$\therefore T_1 = 224.74 + T_2 \qquad (3.39)$$

Combining equations (3.38) and (3.39) produce:

$$10.86T_2 - 686.87 = 224.74 + T_2$$
$$9.86T_2 = 911.61$$
$$\therefore T_2 = 92.46\,N$$

Substituting for T$_2$ in equation (3.36) produce:

$$T_1 = 224.74 + 92.46$$
$$\therefore T_1 = 317.20\,N$$

Weight of auger (W$_a$) on shaft is calculated using the equation below.

$$W_a = mg \qquad (3.40)$$

$$Where:$$
$$m\,(mass\ of\ auger) = density(\rho) \times volume(V)$$
$$\rho = 7800\,kg / m^3\ for\ mild\ steel$$
$$V = \frac{n\pi D^2 h}{4}$$
$$Diameter\ of\ rod\,(D) = 6\,mm$$
$$Length\ of\ rod\,(h) = 0.7\,mm$$
$$Number\ of\ rods\,(n) = 7.5$$
$$By\ substitution,$$
$$V = \frac{3.142 \times (0.006)^2 \times 0.7 \times 7.5}{4} = 1.59 \times 10^{-4} m^3$$

$$Since\ g\ (acceleration\ due\ to\ gravity) = 9.81\,m/s^2$$
$$\Rightarrow W_a = 7800 \times 1.59 \times 10^{-4} \times 9.81$$
$$\therefore W_a = 12.17\,N$$

Weights of pulleys on shaft: Two pulleys (P_A and P_B) are used i.e. one on each side of the shaft as shown in figure 3.9. The individual weights for the pulleys are computed thus:

$Weight\ of\ pulley\ A\ (W_A),$

$$W_A = m_A g \qquad (3.41)$$

$Where,$

$m_A\ (mass\ of\ pulley\ A) = density\ of\ material \times Volume\ of\ pulley\ A$

$Density\ of\ material = 7800\,kg/m^3$

$$Volume\ of\ pulley = \frac{\pi D^2 w}{4} = \frac{3.142 \times (0.232)^2 \times 0.02125}{4} = 3.594 \times 10^{-3}\,m^3$$
$$\Rightarrow m_A = 7800 \times 3.594 \times 10^{-3}$$
$$\therefore m_A = 7.01\,kg$$

$Since\ g\ (acceleration\ due\ to\ gravity) = 9.81\,m/s^2, by\ substitution$

$$\Rightarrow W_A = 7.01 \times 9.81$$
$$\therefore W_A = 68.77\,N$$

$Weight\ of\ pulley\ B\ (W_B),$

$$W_B = m_B g \qquad (3.42)$$

$Where,$

$g = 9.81\,m/s^2\ and$

$m_B\ (mass\ of\ pulley\ B) = density\ of\ material\ used \times Volume\ of\ pulley\ B$

$But,\ density\ of\ material\ used\ (i.e\ mild\ steel) = 7800\,kg/m^3\ and$

$$Volume\ of\ pulley = \frac{\pi D^2 w}{4} = \frac{3.142 \times (0.1)^2 \times 0.02125}{4} = 1.669 \times 10^{-4}\,m^3$$
$$\Rightarrow m_B = 7800 \times 1.699 \times 10^{-4}$$
$$\therefore m_B = 1.30\,kg$$

$Since\ g\ (acceleration\ due\ to\ gravity) = 9.81\,m/s^2, by\ substitution,$

$$\Rightarrow W_B = 1.30 \times 9.81$$
$$\therefore W_B = 12.75\,N$$

Belt speed (v) of pulley B (P_B) is computed using equation 3.21 expressed as:

$$v = \frac{\pi DN}{60000}$$

Where,

$\pi = 3.142,$

$D(diameter\ of\ pulley\ B) = 100\,mm\ and$

$N(speed\ of\ pulley\ B) = 800\,rpm$

By substitution,

$$\Rightarrow v = \frac{3.142 \times 100 \times 800}{60000}$$

$$\therefore v = 4.19\,m/s$$

Centrifugal tension (T_c) is obtained from equation 3.24 i.e.

$$T_c = mv^2$$

Where,

$m(mass/unit\ length\ of\ belt = 1.89\,N$

$v(belt\ speed) = 4.19\,m/s$

$$\Rightarrow T_c = 1.89 \times (4.19)^2$$

$$\therefore T_c = 33.18\,N$$

$Since\ T_c = 33.18\,N, \mu = 0.25,\ \beta = 16^0\ and$

$\vartheta = 180 - 2\sin^{-1}\frac{100-250}{2\times250} = 214.92^0\ (3.75\ rads)$

Using equation 3.25 produce:

$$\frac{T_1 - 33.18}{T_2 - 33.18} = e^{0.25 \times 3.75 \times \cos ec16^0}$$

$$T_1 - 33.18 = 30.00T_2 - 995.41$$

$$T_1 = 30.00T_2 - 962.23 \qquad (3.43)$$

Maximum torque (T) is computed using the expression:

$$T = \frac{60L}{2\pi N}$$
$$\text{Where,}$$
$$L = 2184W$$
$$N = 800\,rpm$$

$$\Rightarrow T = \frac{60 \times 2184}{2 \times 3.142 \times 800}$$
$$\therefore T = 26.07\,Nm$$
$$By\,applying\,equation\,3.27,$$
$$\Rightarrow T_1 = \frac{26.07}{0.05} + T_2$$
$$\therefore T_1 = 521.4 + T_2 \qquad (3.44)$$

Combining equation (3.43) and (3.44) produce:

$$30.00T_2 - 962.23 = 521.40 + T_2$$
$$29T_2 = 521.40 + 962.23$$
$$\therefore T_2 = 51.16\,N$$
$$Substituting\,for\,T_2\,in\,equation\,(3.44)$$
$$T_1 = 521.40 + 51.16$$
$$\therefore T_1 = 572.56\,N$$

The shaft assembly for the extruder and the reactions (R_C and R_D) at the bearings (C and D) is shown in fig. 3.9. Considering the mass center of a cone as $\frac{3}{4}l$. Where *l is the length of cone,* taking moment about C produce:

$$636.47 \times 0.1 + 478.43(0.65) + R_D(0.6) + 12.17(0.65 - 0.05 - {}^3\!/_4 \times 0.6) = 0$$
$$310.98 + 0.6R_D + 1.83 + 6.36$$
$$\Rightarrow -R_D = \frac{319.17}{0.6}$$
$$\therefore R_D = -531.95\,N. \textit{The negative sign account for the direction of } R_D.$$

For the equilibrum of the shaft,

$$R_C + 478.43 = R_D + 636.47 + 12.17$$

Substituting for R_D with computed value above gives :

$$R_C = 531.95 + 636.47 + 12.17 - 478.43$$

$$\therefore R_C = 702.16N$$

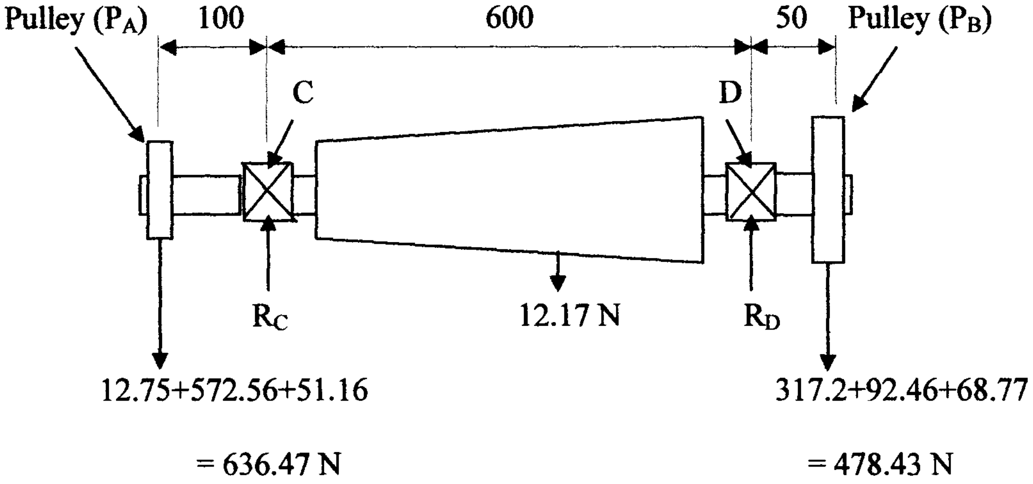
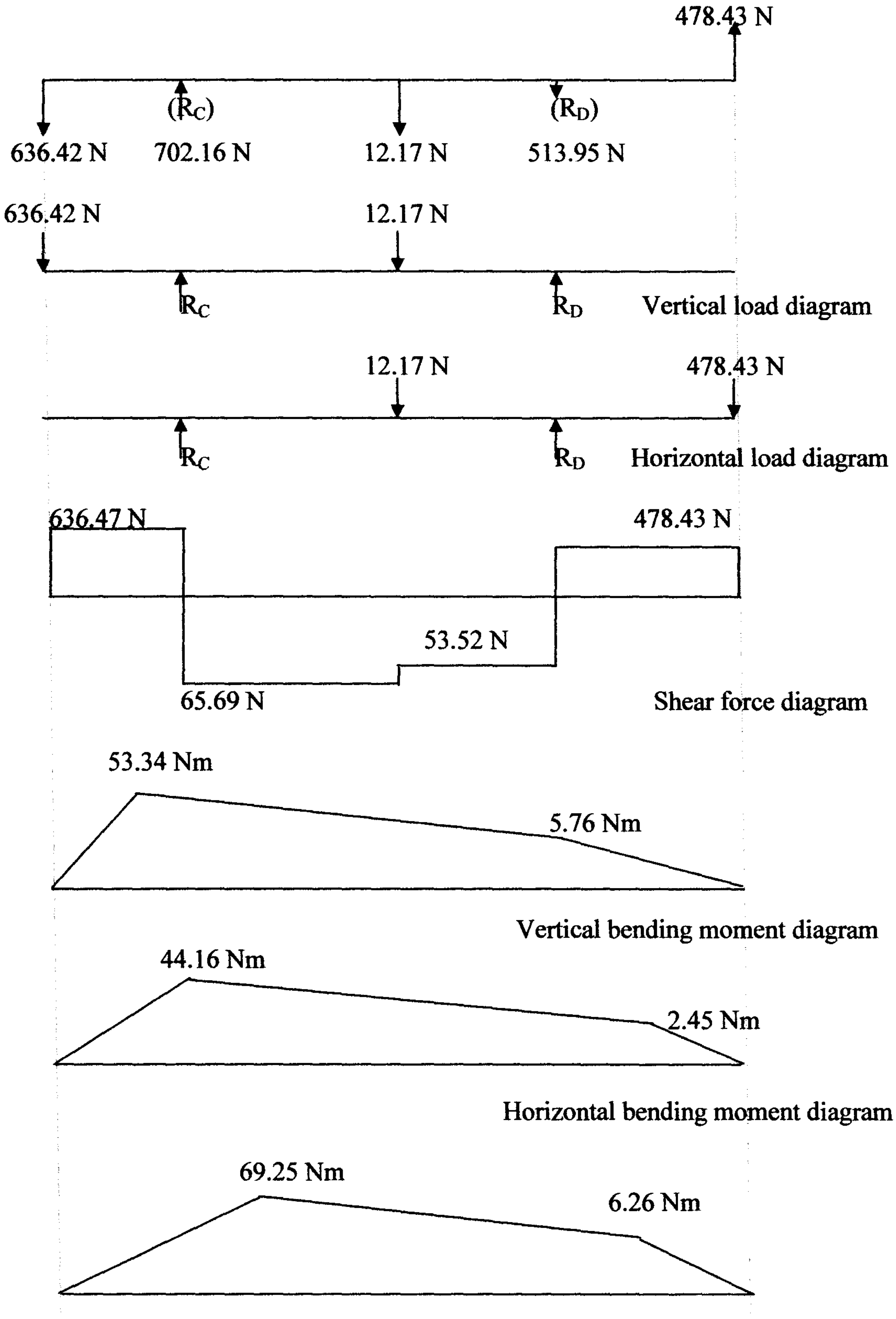


Fig. 3.9: Shaft assembly for the extruder



Resultant bending moment diagram

Fig. 3.10: Bending moment and shear force diagrams for the extruder shaft.

Referring to fig. 3.10, the maximum bending moment is at C. That is to say:

$$M = M_c$$
$$\therefore M = 69.25\,Nm$$

Since M = 69.25 Nm, K_m= 2.0, K_t = 1.5 and T = 26.07 Nm, by applying equation 3.33 the equivalent twisting moment (T_e) is calculated thus:

$$T_e = \sqrt{(MK_m)^2 + (TK_t)^2}$$
$$\Rightarrow T_e = \sqrt{(69.25 \times 2)^2 + (26.07 \times 1.5)^2}$$
$$\therefore T_e = 143.91\,Nm$$

Working stress for the extruder shaft is computed using equation 3.35 expressed as:

$$\tau_w = \left(\frac{G\vartheta}{l}\right)\xi$$

Where,

τ_w = working stress, N/mm^2

G = moment of rigidity for mild steel shaft, 80,000 N/mm^2 (Khurmi and Gupta, 2004)

ϑ = angle of twist, $\pi/15D$ (Ryder, 2001)

ξ = polar moment of inertia, $\pi D^4/32$ (Ryder, 2001)

l = length of shaft, 750 mm

By substitution we have:

$$\tau_w = \frac{80{,}000 \times \pi \times \pi D^4}{15D \times 750 \times 32}$$
$$\therefore \tau_w = 2.19D^3\ N/mm^2$$

The permissible stress in the shaft is obtained using equation 3.36 as:

$$\tau_p = \left(\frac{2\tau}{D}\right)\xi$$

Where,

τ_p = permissible stress, N/mm^2.

τ = maximum allowable shear stress, 55 N/mm^2 (Ryder, 2001)

ξ = polar moment of inertia, $\pi D^4/32$ (Ryder, 2001)

Substituting the above values in the equation, the following is obtained:

$$\tau_p = \frac{2 \times 55 \times \pi D^4}{D \times 32}$$
$$\therefore \tau_p = 10.80D^3\ N/mm^2$$

Comparing the value of τ_w with τ_p above, it follows that the working stress (τ_w) is smaller than the permissible stress (τ_p). Actual working stress (τ_a) is obtained using equation 3.37 expressed as:

$$\tau_a = \left(\frac{\tau_w}{\tau_p}\right)\tau$$

Where,

τ_a = actual working stress, N/mm^2

τ_w = working stress, obtained above as 2.19D^3 N/mm^2

τ_p = permissible stress, obtained above as 10.80D^3 N/mm^2

τ = maximum allowable shear stress, 55 N/mm^2

Substituting for τ_w, τ_p *and* τ with their values in equation 3.37 yields:

$$\tau_a = \left(\frac{2.19D^3}{10.80D^3}\right) \times 55$$
$$\therefore \tau_a = 11.15\,N/mm^2$$

The maximum allowable shear stress (τ) is greater than the computed actual working stress (τ_a), as such by employing equation 3.34, the extruder's shaft diameter is obtained thus:

$$d^3 = \frac{16T_e}{\pi\tau}$$
$$For: T_e = 144.74\,Nm, \pi = 3.142\, and\, \tau = 55\,MPa, then:$$
$$\Rightarrow d^3 = \frac{16 \times 143.91}{3.142 \times 55 \times 10^6}$$
$$\therefore d = 0.023\,m\,(23\,mm)$$

A shaft of 25 mm is selected for this design.

3.2.16 Bearing selection

The basic parameters for selecting bearing size as outlined by Gary *et al.* (1984) are radial load (W_R), the thrust or axial load (W_A), speed (N), required life (L_R) and shock or vibration conditions. The basic dynamic equivalent radial load for the bearings on the mixer shaft is calculated using equation 3.45 expressed by Khurmi and Gupta (2004) as:

:

$$W_E = X.VW_R + YW_A \tag{3.45}$$

Where,

$$\begin{aligned}
W_R(\textit{radial load}) &= \frac{L}{2\pi Nr} \\
&= \frac{2265}{2\times 3.142\times 800\times 0.0725} \\
\therefore W_R &= 6.21N
\end{aligned}$$

$$\begin{aligned}
W_A(\textit{thrust or axial load}) &= \textit{Weight of shaft} + \textit{load on shaft} \\
&= \left(\frac{7800\times 3.142\times 0.02^2\times 0.8\times 9.81}{4}\right) + 26.85 + 19.52 \\
\therefore W_A &= 65.6N
\end{aligned}$$

The values of X and Y are obtained from the standard table using the ratio $\frac{W_A}{W_R}$ *as a guide. In our case* $\frac{W_A}{W_R} = \frac{65.6}{6.21} = 10.56 > e$ *From the standard table as contained in the works of Khurmi and Gupta* (2004) $X = 0.56$ *and* $Y = 1$

$V = 1$

Substituting for the computed values in the above equation yields:

$$\begin{aligned}
W_E &= 0.56\times 1\times 6.21 + 1\times 65.6 \\
\therefore W_E &= 69.08N
\end{aligned}$$

This means that the bearing should be selected for $W_E = 69.08N$*. A 6304 ball bearing with dynamic load rating (C) of 12500 N, bore diameter of 20 mm, outer diameter 47 mm and width of 14 mm was choosen for this design.*

The life rating of the bearing was calculated using equation 3.46 given by Khurmi and Gupta (2004) as:

$$L_R = \left(\frac{C}{W_E}\right)^k \times 10^6 \qquad (3.46)$$

Where,

$C\ (basic\ dynamic\ load) = 12{,}500\, N$

$W_E\ (equivalent\ radial\ load) = 69.08\, N$

$k = 3\ for\ ball\ bearing$

$$\Rightarrow L_R = \left(\frac{12{,}500}{69.08}\right)^3 \times 10^6$$

$$\therefore L_R = 5.92 \times 10^{12}\, revs.$$

$$In\ hours\ L_R = \frac{5.92 \times 10^{12}}{60 \times 800}$$

$$\therefore L_R = 1.23 \times 10^8\, hours$$

In like manner, the basic dynamic equivalent radial load for the bearings on the extruder shaft is calculated using equation 3.45 given as:

$$W_E = X.VW_R + YW_A$$

Where,

$$W_R (radial\ load) = \frac{L}{2\pi Nr}$$

$$= \frac{2265}{2 \times 3.142 \times 500 \times 0.0725}$$

$$\therefore W_R = 9.94\, N$$

$$W_A (thrust\ or\ axial\ load) = Weight\ of\ shaft + load\ on\ shaft$$

$$= \left(\frac{7800 \times 3.142 \times 0.02^2 \times 0.75 \times 9.81}{4}\right) + 68.77 + 12.75 + 12.17$$

$$\therefore W_A = 111.72\, N$$

$The\ values\ of\ X\ and\ Y\ are\ obtained\ from\ the\ s\tan dard\ table\ u\sin g\ the\ ratio\ \frac{W_A}{W_R}\ as\ a$

guide. In our case $\frac{W_A}{W_R} = \frac{111.72}{9.94} = 11.24 \geq e$ *From the standard table as contained in the works of Khurmi and Gupta* (2004) $X = 0.56$ *and* $Y = 1$

$V = 1$

Substituting for the computed values in the above equation yields:

$$W_E = 0.56 \times 1 \times 9.94 + 1 \times 111.72$$

$$\therefore W_E = 117.29\,N$$

This means that the bearing should be selected for $W_E = 117.29\,N$. *A* 6305 *ball bearing with dynamic load rating* (*C*) *of* 16,600 *N, bore diameter of* 25 *mm, outer diameter* 62 *mm and width of* 17 *mm was choosen for this design.*

The life rating of the bearings (L_R) was calculated using equation 3.46 with the following values for the variables:

C (*basic dynamic load*) $= 16{,}600\,N$

W_E (*equivalent radial load*) $= 117.29\,N$

$k = 3$ *for ball bearing*

By substitution,

$$\Rightarrow L_R = \left(\frac{16{,}600}{117.29}\right)^3 \times 10^6$$

$$\therefore L_R = 2.83 \times 10^{12}\,revs.$$

$$In\ hours\ L_R = \frac{2.83 \times 10^{12}}{60 \times 500}$$

$$\therefore L_R = 9.43 \times 10^7\ hours$$

3.3 Description of Various Parts of the Machine

The mixer-pelleting machine consists of three main sections, which are:

i. The mixing section

ii. Pelleting/Extruding section and

iii. Steam generating section.

Apart from the above main sections, the machine has some other parts that operate with or facilitate the operations of the three main sections. These parts include: the hopper, frame, cutting mechanism, feed transfer channel and electrical control point. The orthographic views of the machine are given in fig II.13 of appendix II. A detailed discussion is offered below regarding the general construction of the parts that make up the machine.

3.3.1 Mixing section

The mixing section consists of two cylindrical bodies (upper and lower) of different diameters that are connected by a frustum. The upper cylinder is made with a diameter of 500 mm and height of 500 mm. The lower cylinder has a height of 70 mm and a diameter of 150 mm. The height of the frustum, which connects the two cylinders, is 100 mm. Both the cylinders and the frustum were constructed using a mild steel sheet metal of 1.5 mm thickness. Two openings of 100 mm and 80 mm diameter were provided at the foot end of the frustum. These openings connect respectively to the discharge and transfer channels.

The mixing chamber is provided with a centrally based, vertical acting auger conveyor that operates inside a close fitting tube of 150 mm diameter and length of 500 mm. The auger is constructed on a mild steel rod of 20 mm diameter shaft using a mild steel rod of 6 mm diameter. Its helices were made with a uniform diameter of 145 mm and pitch of 100 mm. The lower end of the auger carries a ring of 145 mm diameter. This ring bear three blades spaced 120^0 apart. Both the blades and the ring are constructed using a mild steel flat bar of 12.5 x 3 mm. The working drawings for the development of mixing chamber are shown in appendix II figs. II.1 – II.3. The feed ingredients to be mixed are introduced into the mixing chamber via a trapezoidal hopper constructed also from a mild steel sheet metal of 1.0 mm thickness. The hopper is constructed with the following dimensions: major width, 300 mm; minor width, 150 mm; length, 300 mm and a height of 100 mm. The hopper is made to stand at an inclined angle of 60^0 with respect to the mixing chamber when fixed in place. The working drawings for the development of hopper are given in appendix II fig. II.12.

3.3.2 Pelleting/extruding section

The pelleting/extruding section comprises of an extrusion barrel, a horizontal acting auger conveyor and extrusion dies. The extrusion barrel is made tapered and constructed from a mild steel sheet of 1.5 mm in thickness. The barrel is made with the following dimension: 150 mm major diameter, 100 mm minor diameter and 600 mm in length. The working drawing of the development of extrusion barrel is given in appendix II fig. II.5. The auger conveyor is made to work inside the barrel in a close fitting association. It is constructed on a 20 mm diameter mild steel rod with a major pitch diameter of 145 mm and a minor pitch diameter of 95 mm. Further more the extrusion auger is constructed with a uniform pitch of 75 mm using a 6 mm diameter mild steel rod. The length of the auger on the shaft is 500 mm (see fig. 3.3).

Four extrusion dies are constructed for use in conjunction with the extrusion barrel depending on the size and shape of pellets required. Two of the dies are meant to produce cylindrical pellets and the other two for producing cubes. Dies one and two were respectively made from mild steel square pipes of 20 mm x 20 mm x 20 mm and 400 mm x 400 mm x 20 mm. Dies three and four (i.e. the last two dies) were however made using a mild steel plate of 3 mm thickness with each having the following dimensions: 80 mm length and 30 mm width. 24 holes of 5 mm and 7 mm diameter were drilled respectively on the two plates. The drawings for the development of extrusion dies are given in fig. II.6.

3.3.3 Steaming section

This section consists of two insulated cylinders of 220 mm diameter x 320 mm height and 300 mm diameter x 400 mm height respectively. The cylinders were made from a mild steel sheet of 1.5 mm thickness. The insulating material used to separate the two cylinders is sawdust. The steamer is equipped with an electric heating plate of 3 kW, a temperature-regulating thermostat, a steam and water delivery pipes along with their corresponding control valves of 1" and ½" respectively. The delivery pipes used are galvanized steel pipes of ¾" for conveying steam from the topmost part of the steamer to the lowermost part of the feed transfer channel and a ½" pipe for transferring hot water from the lower end of the steamer to a t-junction that connect with the steam delivery pipe. A side indicator lamp that will enable the operator to monitor the operation of the electric plate is provided and located at lower end of the outer wall of the steamer. Equally well, a water gauge for enabling the operator to monitor correctly, the level of water in the steamer is provided. It is made from a transparent rubberized hose of 5 mm diameter with a length of 350 mm. For more details, see figs. II.7 and II.8 i.e. the working drawings for the development of steamer in appendix II.

3.3.4 Cutting mechanism

A slider-crank mechanism of CG-125 motorcycle is adopted in the design. The slider-crank mechanism has a stroke length of 60 mm with crank throws of 10 mm thickness and diameter of 110 mm. Two blade sections (A and B) constructed from a mild steel sheet metal of 1.5 mm thick are made to work with this mechanism in order to effect slicing of strands of pellets. Whereas on the one hand blade section A is meant to slice cubical strand of pellets and is made with the following dimensions: length, 100 mm and width, 80 mm. Blade section B, on the other hand is meant to cut cylindrical strand of pellets. This blade section has the following dimensions: length, 100 mm and width, 5 mm. The drive for the cutting mechanism assembly is as shown in fig. 3.6.

3.3.5 Channels and flaps

Two ports (i.e. transfer and discharge ports) are constructed to convey mixed components out of the mixing chamber on completion of a blending operation. Whereas the transfer port is meant to allow material transfer from the mixing chamber to the extrusion barrel for further processing (pelleting), the discharge port however permit us to evacuate blended materials out of the mixing section when our needs for using the machine stops short of pellet making. Both ports are provided with flaps that allows for the opening and closing of their ports. The discharge port is made cylindrical from a mild steel sheet metal of 1.5 mm with the following dimensions: 100 mm diameter and a length of 100 mm. The transfer port is also constructed using a 1.5 mm mild steel sheet metal with the following dimensions: diameter, 800 mm and a height of 100 mm. The transfer port is made to connect with the material transfer channel also constructed using a mild steel sheet metal of 1.5 mm thickness. This channel is fabricated in a frustum shape to ensure continuous movement of materials without danger of blockage. The dimensions of this channel are: major diameter, 100 mm; minor diameter, 80 mm and height, 400 mm. The major diameter end of the frustum like channel is connected to the extrusion barrel, while its minor diameter end is made to connect with the transfer port on the mixing chamber. The drawing schedules for the development of ports and flaps appears in appendix II fig. II.4.

3.3.6 The frame

All the parts that make up the machine are mounted on or supported by a rectangular frame robustly built with detachable stands. An angle iron of 50 mm x 50 mm x 5 mm is used in the construction of the frame, for its rated strength and stability in service. The frame is constructed with the following dimensions: 1250 mm height, 1000 mm length and 600 mm width. The complete working drawings for the development of the frame assembly are as shown in fig. II.9 of appendix II.

3.3.7 Electrical control point

A central electrical control point is provided for convenience and issue of safety during operation. The control point consists of three socket outlets of 15A each. Three (3) connecting plugs one each from the two electric motors (i.e. mixer's and extruder's motors) and that of the heating element are attached to the sockets. A 2.5 mm PVC cable is used in connecting the three socket outlets and the connection is in parallel. A 4.0 mm PVC cable is used as the supply lead for the outlets.

3.3.8 Protective guards

Two protective guards for the drives of the mixer and that of the cutting mechanism are constructed using a mild steel sheet metal of 1.0 mm. The two guards are constructed to offer protection to the operator against the danger posed by rotating parts of the machine in the cause of operation. The details concerning the two guards constructed are as shown in figs. II.10 and II.11 of appendix II.

3.4 Description and Operation of the Machine

During operation with the switch of the mixer's electric motor set at the "ON" position, the feed ingredients are introduced into the mixer via a trapezoidal shaped hopper located at the upper part of the mixing compartment. Material introduction into the mixer is in order of quantity, with the bulky among the components introduced into the machine first. With the material inside the mixing chamber, the rotating action of the centrally based vertical acting auger, lifts it up from the lower cylinder through the close fitting tube and drops it high up at the end of the tube. After thorough mixing is achieved as assessed through a look-in window located at the side of the mixing chamber, the flap of the discharge channel is open to allow the mixed components out of the mixer where our need for using the machine is only to blend feed constituents. Complete evacuation of the material is facilitated by the rotating action of the stirrer, which work close to the surface of the frustum section of the mixing chamber. At the end of evacuation operation, the motor switch is put off. Alternatively, if our need for using the machine include pellet making after blending of components, then on completion of the mixing process, the electric motor switch for the extruder is activated i.e. set "ON" and the flap of the transfer channel is open to allow for the passage of mixed components from the mixing section into the pelleting section. Prior to the opening of the material transfer flap, either the water control valve or the steam control valve is opened to allow hot water or steam to pass through the steam/water delivery pipe to the foot end of the feed material transfer channel, depending on the form of pellet we seek to produce i.e. whether compressed pellets or extruded dry pellets.

The feed component while in the extruder is not only condition with steam or mix with hot water coming from the steamer, but it is further mixed as it is moved by the pelleting auger towards the extrusion die. As the material moves uniformly towards the die, the pressure acting on it increases sufficiently to force it through the die hole(s). The pellets coming out from the die takes the shape of the die hole. A reciprocating blade located underneath the die cut off strands of pellets into the required length. By manipulating the material feed-rate, quantity of steam or water passed into the extrusion barrel, the number and proportion of ingredients, pellets of varying properties can be formed. At the end of pelleting operation, the extrusion barrel should be thoroughly flushed with plenty supply of water from the boiler while the pelleting auger is still running. After cleaning exercise, the switch of the motor for the extruder is put off.

3.5 Material Selection

Materials used in the fabrication of the machine were generally selected based on intended functions by taking into cognizance their strength, durability, machinability and availability in the market.

3.6 Cost of Construction of the Machine

The cost of constructing the mixer-pelleting machine covers cost of materials used for the construction and those paid for labor. A summary of the list of materials used in constructing the machine along with their associated costs is given in Table 3.1. Table 3.2 gives the labor cost of construction.

Table 3.1: Material cost estimate.

No.	Item	Qty	Rate (N)	Amount (N)
1	5Hp electric motor	2	20,000	40,000
2	1.5mm sheet metal	1	7,500	7,500
3	5mm x 5mm angle iron	3	3,000	9,000
4	½ " Flat bar	3	400	1,200
5	¼ " Mild steel rod	2	300	600
6	13mm bolt and nuts	52	10	520
7	17mm bolt and nuts	11	20	220
8	6304 ball bearings	3	250	750
9	6305 ball bearings	2	250	500
10	3,000W heating element	1	3,000	3,000
11	3mm plate	scrap	500	500
12	1.0mm mild steel sheet	1 length	2,000	2,000
13	CG-125 crank shaft	scrap	500	500
14	Pulley (150mm dia.)	2	750	1,500
15	Pulley 2-groove (250mm diameter.)	1	2,000	2,000
16	Pulley (75mm diameter)	2	500	1,000
17	Pulley (50mm diameter)	2	400	800
18	Adhesive (glue)	1 tin	500	500
19	13A socket outlets	3	100	300
20	13A plugs	3	100	300
21	Conduit boxes	3	50	150
22	1" stop valve	1	600	600
23	½" stop valve	1	400	400
24	½" nipples	2	100	200
25	1" union connector	2	150	300
26	1" elbow connector	2	50	100
27	T-connector	1	50	50
28	1" galvanized pipe	Scrap	300	300
29	½" galvanized pipe	Scrap	200	200
30	Arc welding electrode	1 Packet	2,500	2,500
31	Paint (Auto base)	1 liter	1,200	1,200
32	Body filler	¼ tin	300	300

Sub total == 79,590

Table 3.2: Labor cost of construction.

No.	Description	Amount (N)
1	General metal work	10,000
2	Plumbing work	1,000
3	Electrical work	500
4	Body finishing and painting work	1,200
	Sub-total =	12,700

The total cost of constructing the machine is thus the summation of sub-total material cost (N79,590) and sub-total labor cost (N12,700). Therefore the total cost of construction is **N92,290.00**

3.7 Machine Evaluation/Testing

Two main tests (the preliminary and the actual) were conducted. Prior to the actual testing of the machine as a single entity (i.e. integrated system), two of the three principal sections of the machine (the mixing and steam generating sections) were tested individually for their independent roles in the operation of the machine. Both the mixing and pelleting sections of the machine were first test run under the no-load condition using two electric motors of 5 Hp with speed rating of 1450 rpm. One electric motor was couple to each of the sections as shown in fig. 3.11.

Whereas, the mixing auger was run at a speed of 800 rpm under the no-load condition, the pelleting auger was driven at a speed of 500 rpm. Essentially, the no-load test was carried out to ascertain the smoothness of operation for the machine's rotating parts. Details regarding the procedure followed in conducting the two tests (preliminary and actual) are as discussed below:

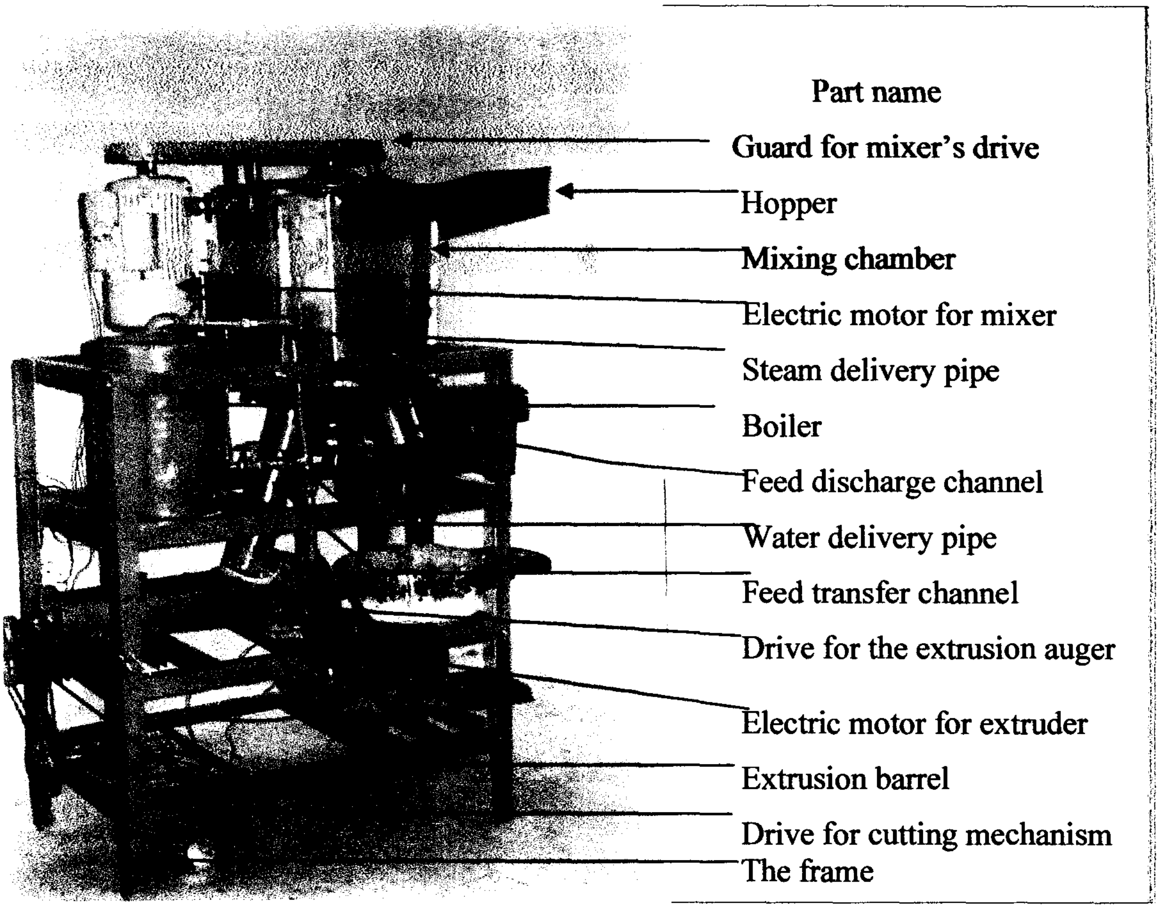


Fig. 3.11 Pictorial view of the mixer-pelleting machine

3.8 Preliminary Testing of the Machine

3.8.1 Mixer testing

Preliminary testing of the mixer was targeted at evaluating its ability to blend feed components, duration of mixing and rate of discharge both through the discharge and the transfer channels. At the onset of the experiment, 150 kg of ground corn, 0.795 kg of cassava flour and 7.95 kg of shelled corn were obtained from the market and the test materials were divided into three equal measures of 50 kg for ground corn, 0.265 kg for cassava flour and 2.65 kg for shelled corn, and the mixer's performance test was conducted and replicated thrice according to the standard test procedure for farm batch feed mixers developed by ASAE, 1978 as cited in the work of Ibrahim and Fasasi (2004). Four mixing durations of 5 min, 10 min, 15 min and 20 min where considered in the cause of conducting the tests. At the end of each test run, ten samples of 500 g were drawn from the mixed components and the coefficient of variation among blended samples and mixing levels, were computed using the expressions below as given by Ibrahim and Fasasi (2004):

$$CV = \frac{S}{x} \tag{3.47}$$

$$\%D_M = (1 - CV) \times 100 \tag{3.48}$$

$$and\ S = \sqrt{\frac{\Sigma(X - x)^2}{(n-1)}} \tag{3.49}$$

Where,

$CV =$ *Coefficient of variability*

$\%D_M =$ *Percent mixing level*

$S =$ *Standard deviation*

$X =$ *Weight of shelled corn in each sample*

$x =$ *Mean value of shelled corn in the samples*

$n =$ *Number of samples*

Discharge of mixed feed components through the transfer channel, was determined through three flap positions (i.e. one is when the flap is fully opened and the other two positions where established through manipulation of the flap position until a feed discharge rate of 50 kg/h and 60 kg/h were obtained). This is important, since it enable us to evaluate pelleting section of the machine at two feed-rate levels. Three of such tests were made at each setting and the average values were used as the feed-rate variables. The rate of evacuation of blended components via the discharge port was also determined in three separate tests. The tests data obtained from preliminary testing of the mixer for the four mixing durations of 5 min, 10 min, 15 min and 20 min are respectively presented in Tables 3.3 to 3.6. This data was used in computing the coefficient of variation in the compositions of the samples hence, the level of mixing attained.

Table 3.3: Weight of ungrounded corn recovered from samples tested in a 5 minutes mixing operation.

Sample Number	Replicates					
	I		II		III	
	X (g)	$(X-x)^2$	X (g)	$(X-x)^2$	X (g)	$(X-x)^2$
1	16	14.44	28	20.25	20	2.25
2	17	7.84	24	0.25	15	42.25
3	25	27.04	30	42.25	23	2.25
4	15	23.04	22	2.25	30	72.25
5	22	4.84	26	6.25	21	0.25
6	27	51.84	18	30.25	17	20.25
7	18	3.24	15	72.25	26	20.25
8	14	33.64	27	12.25	16	30.25
9	20	0.04	19	20.25	22	0.25
10	24	17.64	26	6.25	25	12.25
Total	198	183.60	235	212.50	210	202.50
Mean (x)	19.8		23.5		21.0	

Table 3.4: Weight of ungrounded corn recovered from samples tested in a 10 minutes mixing operation.

Sample Number	Replicates I X (g)	I $(X-x)^2$	II X (g)	II $(X-x)^2$	III X (g)	III $(X-x)^2$
1	22	0.25	21	3.24	24	0.64
2	25	6.25	26	10.24	20	10.24
3	19	12.25	25	4.84	23	0.04
4	23	0.25	19	14.44	21	4.84
5	20	6.25	27	17.64	25	3.24
6	26	12.25	23	0.04	26	7.84
7	28	30.25	20	7.84	25	3.24
8	23	0.25	24	1.44	23	0.04
9	21	2.25	21	3.24	27	14.44
10	18	20.25	22	0.64	18	27.04
Total	225	90.50	228	63.60	232	71.60
Mean (x)	22.5		22.8		23.2	

Table 3.5: Weight of ungrounded corn recovered from samples tested in a 15 minutes mixing operation.

Sample Number	Replicates I X (g)	I $(X-x)^2$	II X (g)	II $(X-x)^2$	III X (g)	III $(X-x)^2$
1	25	0.01	23	4.41	26	1.44
2	24	0.81	27	3.61	25	0.04
3	25	0.01	25	0.01	23	3.24
4	23	3.61	25	0.01	24	0.64
5	24	0.81	26	0.81	25	0.04
6	26	1.21	27	3.61	26	1.44
7	24	0.81	24	1.21	26	1.44
8	27	4.41	24	1.21	23	3.24
9	26	1.21	25	0.01	25	0.04
10	25	0.01	25	0.01	25	0.04
Total	249	12.90	251	14.90	248	11.60
Mean (x)	24.9		25.1		24.8	

Table 3.6: Weight of ungrounded corn recovered from samples tested in a 20 minutes mixing operation.

Sample Number	Replicates I		II		III	
	X (g)	$(X-x)^2$	X (g)	$(X-x)^2$	X (g)	$(X-x)^2$
1	27	4.41	24	0.64	25	0.36
2	23	3.61	26	1.44	23	1.96
3	26	1.21	23	3.24	25	0.36
4	25	0.01	25	0.04	26	2.56
5	25	0.01	24	0.64	23	1.96
6	26	1.21	26	1.44	24	0.16
7	24	0.81	25	0.04	24	0.16
8	24	0.81	25	0.04	25	0.36
9	25	1.01	23	3.24	24	0.16
10	24	0.81	27	4.84	25	0.36
Total	249	13.90	248	15.60	244	8.40
Mean (x)	24.9		24.8		24.4	

3.8.2 Steamer testing

The steamer was evaluated for its capacity to heat 8 liters of water initially at 25^0C to boiling point temperature. The test was repeated thrice and for each test, eight liters of water was introduced into the steamer and a stop-watch was used to record the time it takes to boil the water. Prior to the tests the thermostat knob was set at the maximum level.

Essentially, the preliminary testing of the machine helped in the actual testing since it facilitates knowledge gain, regarding the time frame needed to achieve the required mixing level by the mixer and boiling of water by the steamer. In this way, the two unit operations become better synchronized hence efficient pelleting operation.

3.9 Actual Testing of the Machine

Actual testing of the machine was made with all the three main sections of the machine in operation. It was conducted not only to determine the ability of the extruder to produce pellets of different sizes and shapes but as well, the effect of die size, feed rate and feed formulation on the capacity of the extruder. During the actual testing of the machine, two experiments were conducted covering a total number of sixteen (16) experimental runs i.e. eight runs far experiment. Each of the runs was ran for five minutes and replicated thrice.

3.9.1 Experiment I (Cubical pellets production)

The experiment was conducted at 2 levels of feed formulations, 2 levels of die sizes and 2 levels of feed rates. The two feed formulation levels used for this experiment are (a) formulation I made from 45.7 kg g/corn meal, 5.5 kg cassava meal, 5.6 kg rice husk and 3.2 kg blood meal; and (b) formulation II made from 45.7 kg g/corn meal, 5.5 kg cassava meal, 5.6 kg rice husk, 3.2 kg blood meal and 3.2 kg ground nut cake meal. The two levels of dies used are 20 x 20 mm and 40 x 40 mm square shape. Two feed rate levels of 50 kg/h and 60 kg/h were considered in this experiment. Thus, a 2^3 factorial experimental design was employed. The layout for the experiment is shown in Table 3.7.

Table 3.7: Design layout for experiment I

Run Number	A (1×10^{-4} m^2)	B (kg)	C (kg/h)
1	4	0	50
2	16	0	50
3	4	3.2	50
4	16	3.2	50
5	4	0	60
6	16	0	60
7	4	3.2	60
8	16	3.2	60

A = Die size
B = Feed formulation (Groundnut cake meal inclusion)
C = Feed rate

3.9.2 Experiment II (Cylindrical pellets production)

Experiment II was also conducted using two sizes of dies (5 mm and 7 mm diameter circular dies), two feed rate levels (50 kg/h and 60 kg/h) and two levels of feed formulations (17.25 % crude protein feed formulation made from 30.5 kg corn meal, 6 kg wheat bran, 7.2 kg cotton seed meal, 4.5 kg soybean meal, 5.1 kg groundnut cake meal, 4.5 kg limestone meal, 1.8 kg bone meal, 0.21 kg salt and 0.15 kg vitamin premix; and 18.00 % crude protein feed formulation made from 16.62 kg corn meal, 14.4 kg soybean meal, 24 kg rice offal, 3 kg beniseed meal, 1.8 kg bone meal, 0.18 kg salt and 0.18 kg vitamin premix). The 2^3 factorial design layout for experiment II is given in Table 3.8

Table 3.8: Design layout for experiment II

Run Number	A (Ø mm)	B (%)	C (kg/h)
1	5	17.25	50
2	7	17.25	50
3	5	18.00	50
4	7	18.00	50
5	5	17.25	60
6	7	17.25	60
7	5	18.00	60
8	7	18.00	60

A = Die size
B = Feed formulation (Protein content)
C = Feed rate

All the pellets produced in the cause of the experiments were formed at average moisture content of 35% wet basis by the addition of correct amount of hot water of 95^0C (i.e. 0.45 lt/min at feed-rate of 50 kg/h and 0.54 lt/min at feed-rate of 60 kg/h) to the mixed ingredients. Prior to extrusion, all the constituents for the four feed formulations were oven dried. At the end of each test run, extrudates produced were weighed using a digital compact scale CS 2000 and a sample of 5 g was collected and oven dried to determine its moisture content as described by Henderson and Perry (1976).

In the cause of the experiments, two processing parameters (die size and feed-rate) and material composition and their effects on the capacity of the extruder were investigated. All the three parameters considered were investigated at two levels each as such a 2^3 factorial design was used in the analysis as discussed by Montgomery (1991). The deviation data used in the calculation of sum of squares for the analysis of variance is given in appendix I.

Eight samples of 50 g each were randomly selected, one from each of the eight extrudate groups made from the two feed formulations in experiment II. The samples were then place into containers of standing water separately and allowed to stay there for 5 minutes, thereafter, the un-crumbled pellets were recovered, oven dried and reweighed so as to obtain the per cent dried matter retained in the test samples as described by Sena and Trevor (1995). This test was conducted to determine the water stability of sampled pellets. Some of the sample pellets produced in the cause of the experiments is illustrated in Plate I.

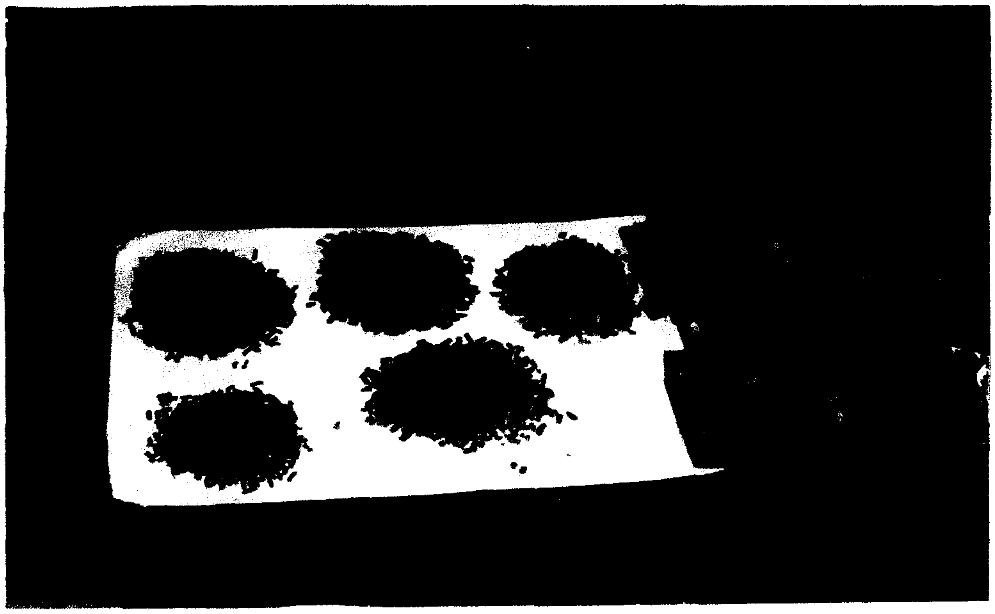


Plate I: Sample pellets produced with the machine

CHAPTER FOUR

4.0 RESULTS

The results obtained from the preliminary and actual testing of the machine are as presented in the below sub-headings.

4.1 Preliminary Test Results

4.1.1 Mixer test results:

The result of the performance test on the mixer's ability to blend feed components in respect of the four mixing durations of 5 min, 10 min, 15 min and 20 min. are as presented in Tables 4.1, 4.2, 4.3 and 4.4 respectively. Table 4.5 gives a summary of the results for the four mixing durations considered on the performance of the mixer.

Table 4.1 Mixer's performance in a 5 minutes mixing operation.

Replicate	Mean value of x (g)	Coefficient of variation (%)	Degree of mixing (%)
1	19.80	22.81	77.19
2	23.50	20.68	79.32
3	21.50	22.06	77.94
Total	64.80	65.55	234.45
Mean	**21.60**	**21.85**	**78.15**

Table 4.2 Mixer's performance in a 10 minutes mixing operation.

Replicate	Mean value of x	Coefficient of variation	Degree of mixing
	(g)	(%)	(%)
1	22.50	14.09	85.91
2	22.80	11.66	88.34
3	23.20	12.16	87.84
Total	68.50	37.91	262.09
Mean	**22.83**	**12.64**	**87.36**

Table 4.3 Mixer's performance in a 15 minutes mixing operation.

Replicate	Mean value of x (g)	Coefficient of variation (%)	Degree of mixing (%)
1	24.90	4.81	95.19
2	25.10	5.13	94.87
3	24.80	4.58	95.42
Total	74.80	14.52	285.48
Mean	**24.93**	**4.84**	**95.16**

Table 4.4 Result of mixer's performance in a 20 minutes mixing operation.

Replicate	Mean value of x (g)	Coefficient of variation (%)	Degree of mixing (%)
1	24.90	4.81	95.19
2	24.80	5.31	94.69
3	24.40	3.96	96.04
Total	74.10	14.08	285.92
Mean	**24.70**	**4.69**	**95.31**

Table 4.5 Summary of results for the mixer's performance.

Mixing duration (min.)	**Replicates/Coefficient of variation (%)**			**Average CV**	**Degree of mixing (%)**
	I	**II**	**III**		
5	22.81	20.68	22.06	21.85	78.15
10	14.09	11.66	12.16	12.64	87.36
15	4.81	5.13	4.58	4.84	95.16
20	4.81	5.31	3.96	4.96	95.31
Total	46.52	42.78	42.76	44.29	355.98
Mean	**11.63**	**10.70**	**10.69**	**11.07**	**89.00**

4.1.2 Steamer test results

The result for the steamer's performance test is given in Table 4.6.

Table 4.6 Performance test result for the steamer

Test Number	Quantity of water used (lt)	Boiling time (min)	Initial water (°C)	Final water (°C)
1	8	45.10	25	100
2	8	43.50	25	100
3	8	44.30	25	100
Total	24	132.90	75	300
Mean	**8**	**44.30**	**25**	**100**

4.2 Actual Test Results

4.2.1 The effect of die size, feed formulation and feed rate on the extruder capacity

Table 4.7 gives the result of the extruder performance in pelleting feed formulation I of experiment I. While Table 4.8 gives the performance of the extruder in pelleting feed formulation II of experiment I. Table 4.9 represents the result for the analysis of variance on the effect of die size, feed formulation and feed rate on the capacity of the extruder in producing cubical pellets. In Tables 4.10 and 4.11 the results of the extruder performance in respectively extruding feed formulations I and II of experiment II are presented. The result for the analysis of variance for the effect of die size, feed formulation and feed rate on the capacity of the extruder in producing cylindrical pellets is given in Table 4.12.

Table 4.7 Effect of die size and feed-rate on extruder capacity using feed formulation I of experiment I

Die Size	Replicates	Feed rate/Extruder capacity		Total	Mean
		50 kg/h	60 kg/h		
D_1	1	43.50	49.00	92.60	46.30
	2	44.50	49.50	94.00	47.00
	3	45.00	50.75	95.75	47.88
	Total	133.00	149.25	282.25	47.04
	Mean	**44.33**	**49.75**	**94.08**	**47.04**
	MH	5.67	10.25	15.92	7.96
D_2	1	45.75	51.75	97.50	48.75
	2	46.50	52.50	99.00	49.50
	3	46.50	53.25	99.75	49.88
	Total	138.75	157.50	296.25	49.38
	Mean	**46.25**	**52.50**	**98.75**	**49.38**
	MH	3.75	7.50	11.25	5.63

D_1 = Square die 20 x 20 mm
D_2 = Square die 40 x 40 mm
MH = Material hold up

Table 4.8 Effect of die size and feed-rate on extruder capacity using feed formulation II of experiment I

Die Size	Replicates	Feed rate/Extruder capacity		Total	Mean
		50 kg/h	60 kg/h		
D_1	1	46.25	51.00	97.25	48.63
	2	46.50	52.00	98.50	49.25
	3	47.00	52.25	99.25	49.63
	Total	139.75	155.25	295.00	49.17
	Mean	**46.58**	**51.75**	**98.33**	**48.17**
	MH	3.42	10.25	13.67	6.84
D_2	1	47.00	54.00	101.00	50.50
	2	47.50	54.50	102.00	51.00
	3	47.50	55.50	103.00	51.50
	Total	142.00	164.00	306.00	51.00
	Mean	**47.33**	**54.67**	**102.00**	**51.00**
	MH	2.77	5.33	8.10	4.05

D_1 = Square die 20 x 20 mm
D_2 = Square die 40 x 40 mm
MH = Material hold up

Table 4.9 ANOVA for the effect of die size, feed formulation and feed-rate on extruder capacity in producing cubical pellets.

Source of Variations	Sum of squares	Degrees of freedom	Mean squares	Computed F
Die size (A)	26.042	2	13.021	17.246*
Feed formulation (B)	21.094	2	10.547	13.970*
Feed-rate (C)	94.010	2	47.005	62.258*
AB	0.375	2	0.188	0.249
AC	3.375	2	1.688	2.236
BC	0.260	2	0.130	0.172
ABC	0.667	2	0.334	0.442
Error	6.792	9	0.755	
Total	152.615	23		

*Significant at 5% probability level.

Table 4.10 Effect of die size and feed-rate on extruder capacity using feed formulation I of experiment II.

Die		Feed rate/Extruder capacity			
Size	Replicates	50 kg/h	60 kg/h	Total	Mean
	1	46.75	55.25	102.00	51.00
	2	47.00	56.00	103.00	51.50
D_3	3	47.10	56.20	103.30	51.50
	Total	140.85	167.45	308.30	51.38
	Mean	**46.95**	**55.82**	**102.77**	**51.38**
	MH	3.05	4.18	7.23	3.62
	1	48.00	56.75	104.75	52.38
	2	48.30	57.10	105.40	52.70
D_4	3	48.45	57.40	105.85	52.93
	Total	144.75	171.25	316.00	52.67
	Mean	**48.25**	**57.08**	**105.33**	**52.67**
	MH	1.75	2.92	4.67	2.34

D_3 = Circular die Ø 5 mm
D_4 = Circular die Ø 7 mm
MH = Material hold up

Table 4.11: Effect of die size and feed-rate on extruder capacity using feed formulation II of experiment II

Die Size	Replicates	Feed rate/Extruder capacity 50 kg/h	60 kg/h	Total	Mean
	1	47.10	55.80	102.90	51.45
	2	47.50	56.20	103.70	51.85
D_3	3	47.90	56.75	104.65	52.33
	Total	142.50	168.75	311.25	51.88
	Mean	**47.50**	**56.25**	**103.75**	**51.88**
	MH	2.50	3.75	6.25	3.13
	1	47.90	57.50	105.40	52.70
	2	48.30	58.18	106.48	53.24
D_4	3	48.60	58.56	107.16	53.58
	Total	144.80	174.24	319.04	53.17
	Mean	**48.27**	**58.08**	**106.35**	**53.17**
	MH	1.73	1.92	3.65	1.83

D_3 = Circular die Ø 5 mm
D_4 = Circular die Ø 7 mm
MH = Material hold up

Table 4.12 ANOVA for the effect of die size, feed formulation and feed-rate on extruder capacity in producing cylindrical pellets.

Source of Variations	Sum of squares	Degrees of freedom	Mean squares	Computed F
Die size (Factor A)	10.010	2	5.005	18.401*
Feed formulation (Factor B)	1.500	2	0.750	2.757
Feed-rate (Factor C)	5.227	2	2.614	9.610*
AB	0.000	2	0.000	0.000
AC	0.400	2	0.200	0.735
BC	0.282	2	0.141	0.518
ABC	0.454	2	0.227	0.835
Error	2.447	9	0.272	
Total	20.320	23		

*Significant at 5% probability level.

4.2.2 The effect of die size, feed formulation and feed rate on the pellets water stability

Table 4.13 gives the result of water stability of sample pellets from experiment II in respect of die size (A), feed formulation (B) and feed-rate (C).

Table 4.13 Effect of die size, feed-rate and feed formulation on water stability of pellets.

Die	% Dry material retained after 5min in standing water			
Size	BI/CI	BI/CII	BII/CI	BII/CII
D_3	54	60	79	83
D_4	64	77	88	95

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

Table 4.1 gives the average weight of ungrounded corn recovered from each of the 10 samples drawn from the mass of mixed components after a mixing period of 5 min in respect of the three replicated tests. The average weights of corn (x) recovered from the three replicates are 19.80 g, 23.50 g and 21.50 g with corresponding coefficient of variability (CV) of 22.81%, 20.68% and 22.06% respectively. The result showed that variation in composition of ingredients among samples tested ranges from 20.68% to 22.81% with an average CV of 21.85% i.e. the degree of mixing achieved is 78.15%.

In Table 4.2, the average weight of recovered ungrounded corn of 22.50 g, 22.80 g and 23.20 g with their corresponding computed coefficient of variation of 14.09%, 11.66% and 12.16% for the three replicates are obtained when the mixing duration was doubled from 5 min to 10 min. The result shows a significant reduction in variation of feed components among samples. That is to say non-uniformity among sample's composition decreases on the average by about 9.21% resulting from doubling mixing duration from 5 min to 10 min. This is in conformity with the findings of Brennan *et al.* (1998), who reported that in a mixing operation, non-uniformity among components in the mixture decreases with time of mixing until equilibrium mixing is attained. The average CV of 12.64% shows that the mixer's performance rose from 78.15% (Table 4.1) to 87.36% (Table 4.2) due to increased mixing time from 5 min to 10 min.

Table 4.3 gives the performance of the mixer during a mixing duration of 15 min. From the table the average weight of shelled corn recovered from the three replicates were 24.9 g, 25.1 g and 24.8 g with respective computed coefficient of variations of 4.81%, 5.31% and 4.58%. The average coefficient of variation is therefore 4.84%. This result shows a significant reduction in the coefficient of variations in feed components for the samples tested. The degree of mixing attained is as high as 95.16% as indicated in Table 4.3, which portrays an impressive improvement of about 7.8% reduction in non-uniformity of components among samples from what obtains when the mixing duration was 10 min. The result further indicate an increase in the level of difficulty associated with intimate blending of feed components as the mixture approaches its equilibrium level (i.e. from 78.15% at 5 minutes increase by 9.21% at 10 minutes and by 7.8% at 15 minutes).

Table 4.4 gives the weight of ungrounded corn recovered from each of the ten samples with mean values of 24.90 g, 24.80 g and 24.40 g from the three replicates and corresponding coefficient of variations of 4.81%, 5.31% and 3.96% respectively during a 20 minutes mixing process. The average value of coefficient of variation for the three replicates being 4.69% indicating that, the mixer's performance pegged at 95.31% as given in Table 4.4. Comparison of this result with what obtained during a 15 minutes mixing operation shows a marginal difference of 0.15%. The result corroborates the findings of Brennan *et al.* (1998) that after equilibrium mixing is attained, further mixing will not produce a better result.

A summary of result for the mixer's performance in respect of the four mixing durations of 5 min, 10 min, 15 min and 20 min is given in Table 4.5. From the result in Table 4.5, the average mixing level in respect of the four mixing durations considered stood at 89% attained in 12.5 min (i.e. the average of the four mixing durations of 5, 10, 15 and 20 min).

Table 4.6 gives the result of the performance test conducted on the steamer. For the three tests conducted, it took the boiler 45.1 min, 43.5 min and 44.3 min respectively to boil 8 liters of water initially at 25^0C to 100^0C. The average boiling time stood at 44.3 min, which is greater than the theoretical boiling time of 16.39 min as computed in section 3.2.10 of this work. The reason for the large time difference between the actual and theoretical may be attributed to heat loss through the cylinder wall, the use of less efficient heating element than was supposed and perhaps the operation of the thermostat which interrupt at intermittent intervals, the flow of electric current through the heating element whenever the set temperature for the plate is reached.

From the result presented in Table 4.7, it is seen that machine capacity increases with an increase in the size of the die. Whereas an average extruder capacity of 44.33 kg/h (i.e. about 88.66% extrusion) was obtained with a die D_1 of size 20 mm x 20 mm, the capacity rose by about 1.92 kg/h to reach 46.25 kg/h (i.e. 92.50% extrusion) when die D_2 of size 40 mm x 40 mm was used for the same feed formulation I and feed-rate of 50 kg/h. In terms of material hold up in the extrusion barrel, it decreases from 5.67 kg/h (11.34% retention) to 3.75 kg/h (7.50% retention) for dies D_1 and D_2 respectively. This means that the chances of die blockage in the cause of pellet making, is more likely to occur while using smaller size die (D_1) than with a bigger size die (D_2). Similar trend is recorded at feed rate of 60 kg/h, where the average extruder capacity stood at 49.75 kg/h (82.92% extrusion) with die D_1 and 52.50 kg/h (87.50% extrusion) with die D_2. Comparison between the average capacity values in respect of feed-rate of 50 kg/h and feed-rate of 60 kg/h from the two dies shows that the capacity of the extruder increases at a decreasing rate from 44.33 kg/h (88.66% extrusion) at feed-rate of 50 kg/h to 49.75 kg/h (82.92% extrusion) at feed-rate of 60 kg/h for die D_1 and from 46.25 kg/h (92.50 extrusion) at feed-rate of 50 kg/h to 52.50 kg/h (87.50 extrusion) at feed-rate of 60 kg/h for die D_2.

In terms of material hold up (Table 4.7) as influenced by material feed-rate, with respect to die D_1 it rose from 5.67 kg/h (11.34% retention) at feed-rate of 50 kg/h to 10.25 kg/h (17.08% retention) at feed-rate of 60 kg/h and from 3.75 kg/h (7.50% retention) at feed-rate of 50 kg/h to 7.50 kg/h (12.50% retention) at feed-rate of 60 kg/h for die D_2. Implying that regardless of the size of the die, material blockage is more likely to occur at higher feed-rate than at lower feed-rate levels. This confirms the findings of Brennan *et al.* (1998) who stressed that in an extrusion process, material compaction and machine capacity are antagonistic i.e. increase in one leads to a decrease in the other. This is so because with increased feed-rate after certain level, the speed of the screw becomes lowered as more materials are compacted and this cause a drop in the extrusion pressure, hence rate of extrusion. This stand is further supported by the findings of Van Zuilichem *et al.* (1989) who reported that an increase in the mass flow rate of material into an extruder causes a reduction in the degree of fill of the extrusion barrel with accompanying reduction in the speed of the screw, hence a reduction in the capacity of the extruder.

Table 4.8 gives the capacities of the extruder from the two dies (D_1 and D_2) used in extruding feed formulation II used in experiment I that have 5% (3.2 kg) groundnut cake meal added to the constituents of feed formulation I. From the result presented in Table 4.8, it is observed that the average capacities of the extruder when compared with those in Table 4.7, increases from 44.33 kg/h (88.66% extrusion) to 46.58 kg/h (93.16% extrusion) for die D_1 and from 46.25 kg/h (92.50% extrusion) to 47.33 kg/h (94.66% extrusion) for die D_2 at feed-rate of 50 kg/h. At feed-rate of 60 kg/h, the average extruder capacities rose from 49.75 kg/h (82.92% extrusion) to 51.75 kg/h (86.25% extrusion) for die D_1 and from 52.50 kg/h (87.50% extrusion) to 54.67 kg/h (91.12% extrusion) for die D_2. Regarding material hold up, at feed-rate of 50 kg/h, it drops from 5.67 kg/h (11.34% retention) and 3.75 kg/h (7.50% retention) to 3.42 kg/h (6.84% retention) and 2.77 kg/h (5.54% retention) for dies D_1 and D_2 respectively. At feed –rate of 60 kg/h, the material hold up in the extrusion barrel drops from 10.25 kg/h (17.08% retention) to 8.25 kg/h (13.75% retention) for die D_1 and for die D_2 the material hold up drops from 7.50 kg/h (12.50% retention) to 5.33 kg/h (8.88% retention), all in favor of feed formulation II. The observed increase in the capacity of the extruder resulting from using feed formulation II having an oil bearing ingredient tallies with the findings of Oguntimein (1988) who reported that during pelleting fat acts as lubricant, which facilitate easy pressing and therefore high capacity extrusion and lower power consumption.

The ANOVA for the effect of die size, feed formulation and feed-rate and their interactions on the capacity of the extruder is given in Table 4.9. The result of the analysis confirms that die size (factor A), feed formulation (factor B) and feed-rate (factor C) are significant processing parameters that affect extruder capacity.

Table 4.10 gives the performance of the machine in pelleting feed formulation I (17.25% crude protein content) of experiment II using two cylindrical dies D_3 and D_4 of sizes 5 mm and 7 mm diameter respectively. The extrusion was done at two feed-rate levels of 50 kg/h and 60 kg/h. The result shows that for die D_3 the average capacity of the machine rose from 46.95 kg/h (93.90% extrusion) at feed-rate of 50 kg/h to 55.82 kg/h (93.03% extrusion) at feed-rate of 60 kg/h, while the average material hold up rose from 3.05 kg/h (6.10% retention) to 4.18 kg/h (6.97% retention). For die D_4 the average capacity of the extruder increases from 48.25 kg/h (96.50% extrusion) with corresponding average material hold up of 1.75 kg/h (3.50% retention) at feed-rate of 50 kg/h to 58.08 kg/h (96.80% extrusion) with corresponding material hold up of 1.92 kg/h (3.20% retention) at feed-rate of 60 kg/h. Comparison of material hold up at both feed-rate levels among the two dies clearly reveals that greater materials are held in the extrusion barrel at the end of operation with smaller dies than with bigger dies. This means that regardless of feed-rate, the possibility of unnecessary stoppages occasioned by die blockage is higher with die D_3 than with die D_4.

In Table 4.11, the performance of the extruder in the cause of pelleting feed formulation II (18% crude protein content) of experiment II while using two circular dies of 5 mm and 7 mm diameter is presented. The result shows that whereas the average capacity of the extruder increases with an increase in the size of the die, material hold up in the extruder however decreases with an increase in the size of the die. For instance at feed rate of 50 kg/h, the capacity of the extruder increases by 0.77 kg/h when it rose from 47.50 kg/h (95.00% extrusion) with die D_3 to 48.27 kg/h (96.54% extrusion) with die D_4. Similarly, at feed-rate of 60 kg/h there is an observed rise in the average capacity of the extruder, to the tune of about 1.83 kg/h when the average capacity jumps from 56.25 kg/h (93.75% extrusion) with die D_3 to 58.08 kg/h (96.80% extrusion) with die D_4. The result further revealed that greater compaction of material is achieved at feed-rate of 60 kg/h with die D_3 than with die D_4 at the same feed-rate of 60 kg/h or than with dies D_3 and D_4 at feed-rate of 50 kg/h.

Comparison between the average capacity values in Table 4.10 with those in Table 4.11 shows no significant change in the extruder performance resulting from using feed formulation II (18% crude protein level) in place of feed formulation I (17.25% crude protein level). Perhaps texture wise, the two formulations (i.e. I and II) might be the same, hence the reason for similar extruder performance. The analysis of variance given in Table 4.12 confirms die size (factor A) and feed-rate (factor C) as factors that significantly affect the capacity of the extruder in the cause of pelleting poultry feed formulations I and II used in experiment II.

From the result presented in Table 4.13 on the water stability of pellets, the stability of sample pellets tested, is seen to vary with die size, feed-rate and feed formulation. With respect to die size, the stability of sample pellets investigated increases with the size of the die. It can be observed from the table that extrudates from die D_4 (7 mm diameter) are more stable in water than those from die D_3 (5 mm diameter). Similarly, feed formulation has a significant influence on the water stability of pellets as shown in Table 4.13. From the table, it is seen that irrespective of die size and feed-rate, pellets made from feed formulation II returned better stabilized. The reason may be attributed to the used of smaller amount of salt (Sena and Trevor, 1995) and richer protein and fat bearing ingredients in feed formulation II (BII) than what obtains in feed formulation I (BI). Oguntimein (1988) reported that protein-rich materials plasticize when heated and act as a binder to produce strong pellets.

Feed-rate also impact positively on the water stability of sample pellets tested. In which increase in feed-rate from CI (50 kg/h) to CII (60 kg/h) leads to percentage increase in water stability of 6 % and 13 % in respect of dies D_3 and D_4 for extrudates made from feed formulation BI. And for pellets produced from feed formulation BII, the percentage increase in material retained resulting from increasing feed-rate stood at 4 % and 7 % respectively for pellets extruded from dies D_3 and D_4. Perhaps this may be due to the fact that better compaction of mash ingredients is achieved at high feed-rate level than at low feed-rate level.

5.1 Conclusions and Recommendations

5.1.1 Conclusions

The mixer-pelleting machine has been designed, fabricated and tested. From the result of the tests, the following conclusions are drawn:

i. A mixing performance of up to 95.31% was attained in 20minutes of operation and evacuation of mixed materials from the mixer was observed to be almost complete and was accomplished in a time frame of 9 minutes with the mixer at full capacity (i.e. 60 kg of feed ingredients or two-third of the mixing chamber filled).

ii. The capacity of the extruder was found to be a function of die size, feed-rate and material composition. For the same material composition, the capacity of the extruder increases with an increase in the size of the die and also increases at a rather decreasing rate with an increase in feed-rate.

iii. Regardless of the type of feed formulation used, the possibility of die clogging is affected by material feed-rate and die size. Increase in feed-rate and use of small size die raises the probability of die blockage and by implication causes a reduction in the capacity of the extruder.

iv. The water stability of pellets is also affected by material composition, die size and feed-rate.

v. The machine has the ability to mix feed ingredients and then extrude pellets of different shapes (i.e. circular and bars) and sizes (5mm, 7mm, 20mm x 20mm and 40mm x 40mm) depending on the need of the farmer.

5.1.2 Recommendations

Sequel to the testing of the machine and the results obtained thereof, the below recommendations are dimmed necessary:

i. There is the need for further study on the machine with the view to making improvements on it. The problem of the ineffectiveness of the cutting mechanism should be looked into and where possible it is hereby suggested that a separate variable speed running electric motor should be provided to exclusively power the cutting mechanism. Similarly in order to safeguard the operator from inhaling dusty feed ingredients in the cause of mixing operation, it is hereby strongly recommended that a flap be provided for the closing of the hopper opening immediately after the introduction of feed ingredients into the mixer. This will stop fine feed particles from flying out of the mixer during operation.

ii. It has been observed in the cause of test operations, that the production of adequate amount of steam by the boiler on a sustainable ground to facilitate effective feed conditioning during the entire extrusion process appears to be difficult due to the intermittent operation of the bimetallic strip type of thermostat adopted in the design. A better type of thermostat should be adopted so as to guarantee efficient supply of steam and hence production of steam pellets.

iii. To effectively guard against the production of unwholesome pellets and the possibility of die blockage resulting from left-over feed marsh in the extrusion barrel, the extruder should be thoroughly flushed with plenty supply of cleaned water immediately after completion of any given pelleting operation.

Similarly, both the mixer and the steamer should be emptied off their content after operation so as to avoid undue rusting and or clogging of components.

iv. Since no attempt was made to relate the quantity of water used in the tests with the capacity of the extruder and also that the machine has the ability to produce steam pellets particularly with the recommended improvements on the steamer effected, study in this area is also advocated.

v. To eliminate the danger of die blockage at the beginning of a pellet making operation, it is strongly recommended that the extrusion barrel should first be irrigated liberally by passing hot water to it before the flap of the material transfer port is opened. The opening of this flap should be gradual and stopped when extrudates of sufficient strength are observed beginning to be formed.

vi. The volume of the steamer as designed (i.e. with 11 liters water holding capacity) appear to be small, this should be increase to at least 40 liters water holding capacity to permits one complete hour of pelleting operation before suspending operation for the purpose of water refill. In similar manner, the number of holes on the dies should be increase so as to increase the extruder's output and lowers the tendency of die blockage particularly at high feed-rate levels.

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APPENDICES

APPENDIX I

CALCULATION OF SUM OF SQUARES USED IN ANOVA

Table A : Deviation data for the extruder capacity with respect to pellet production for experiment I

	Feed formulation			
	I		II	
Die	Feed-rate		Feed-rate	
Size	50kg/h	60kg/h	50kg/h	60kg/h
D_1	-6.50	-11.00	-3.75	-9.00
	-5.50	-10.50	-3.50	-8.00
	-5.00	-9.25	-3.00	-7.75
	-17.00 (1)	-30.75 (c)	-10.25 (b)	-24.75 (bc)
D_2	-4.25	-8.25	-3.00	-6.00
	-3.50	-7.50	-2.50	-5.50
	-3.50	-6.75	-2.50	-4.50
	-11.25 (a)	- 22.50 (ac)	-8.00 (ab)	-16.00 (abc)

Sum of Squares for Feed Formulations I and II of Experiment I

$$A = \frac{1}{4n}\left(a + ab + ac + abc - (1) - b - c - bc\right)$$

$$= \frac{1}{12}\left(-11.25 - 8 - 22.5 - 16 + 17 + 10.25 + 30.75 + 24.75\right)$$

$$= \frac{25}{12}$$

$$\therefore A = 2.08$$

$$SS_A = \frac{(25)^2}{24}$$

$$\therefore SS_A = \underline{\underline{26.042}}$$

$$B = \frac{1}{4n}\left(b + ab + bc + abc - (1) - a - c - ac\right)$$

$$= \frac{1}{12}\left(-10.25 - 8 - 24.75 - 16 + 17 + 11.25 + 30.75 + 22.50\right)$$

$$= \frac{22.5}{12}$$

$$\therefore B = 1.875$$

$$SS_B = \frac{(22.5)^2}{24}$$

$$\therefore SS_B = \underline{\underline{21.094}}$$

$$C = \frac{1}{4n}\left(c + ac + bc + abc - (1) - a - b - ab\right)$$

$$= \frac{1}{12}\left(-30.75 - 22.5 - 24.75 - 16 + 17 + 11.25 + 10.25 + 8\right)$$

$$= \frac{-47.5}{12}$$

$$\therefore C = -3.96$$

$$SS_C = \frac{(-47.5)^2}{24}$$

$$\therefore SS_C = \underline{\underline{94.010}}$$

$$AB = \frac{1}{4n}\left((1) + ab + c + abc - a - b - ac - bc\right)$$

$$= \frac{1}{12}\left(-17 - 8 - 30.75 - 16 + 11.25 + 10.25 + 22.50 + 24.75\right)$$

$$= \frac{-3}{12}$$

$$\therefore AB = -0.25$$

$$SS_{AB} = \frac{(-3)^2}{24}$$

$$\therefore SS_{AB} = \underline{\underline{0.375}}$$

$$AC = \frac{1}{4n}\left((1) + ac + b + abc - a - ab - c - bc\right)$$

$$= \frac{1}{12}\left(-17 - 22.50 - 10.25 - 16 + 11.25 + 8 + 30.75 + 24.75\right)$$

$$= \frac{9}{12}$$

$$\therefore AC = 0.75$$

$$SS_{AC} = \frac{(9)^2}{24}$$

$$\therefore SS_{AC} = 3.\underline{\underline{375}}$$

$$BC = \frac{1}{4n}\left((1) + a + bc + abc - b - ab - c - ac\right)$$

$$= \frac{1}{12}\left(-17 - 11.25 - 24.75 - 16 + 10.25 + 8 + 30.75 + 22.50\right)$$

$$= \frac{2.5}{12}$$

$$\therefore BC = 0.208$$

$$SS_{BC} = \frac{(2.5)^2}{24}$$

$$\therefore SS_{BC} = \underline{\underline{0.260}}$$

$$ABC = \frac{1}{4n}\left(a + b + c + abc - (1) - ab - ac - bc\right)$$

$$= \frac{1}{12}\left(-11.25 - 10.25 - 30.75 - 16 + 17 + 8 + 22.50 + 24.75\right)$$

$$= \frac{4}{12}$$

$$\therefore ABC = 0.333$$

$$SS_{ABC} = \frac{(4)^2}{24}$$

$$\therefore SS_{ABC} = \underline{\underline{0.666}}$$

$$\Rightarrow SS_{Sub-total} = 145.823$$

$$SS_T = \sum_i \sum_j \sum_k y^2 - \frac{y_{...}^{\,2}}{abcn}$$

$$= 975.125 - \frac{(140.5)^2}{24}$$

$$\therefore SS_T = 152.615$$

$$SS_E = SS_T - SS_{Sub-total}$$

$$= 152.615 - 145.823$$

$$\therefore SS_E = 6.792$$

Table B : Deviation data for the extruder capacity with respect to pellet production for experiment II.

	Feed formulation			
	I		II	
Die	Feed-rate		Feed-rate	
Size	50kg/h	60kg/h	50kg/h	60kg/h
D_3	-3.25	-4.75	-2.90	-4.20
	-3.00	-4.00	-2.50	-3.80
	-2.90	-3.80	-2.10	-3.25
	-9.15 (1)	-12.55 (c)	-7.50 (b)	-11.25 (bc)
D_4	-2.00	-3.25	-2.10	-2.50
	-1.70	-2.90	-1.70	-1.75
	-1.55	-2.60	-1.40	-1.50
	-5.25 (a)	-8.75 (ac)	-5.20 (ab)	-5.75 (abc)

Sum of Squares for Feed Formulations I and II of Experiment II

$$A = \frac{1}{4n}\left(a + ab + ac + abc - (1) - b - c - bc\right)$$

$$= \frac{1}{12}\left(-5.25 - 5.2 - 8.75 - 5.75 + 9.15 + 7.5 + 12.55 + 11.25\right)$$

$$= \frac{15.5}{12}$$

$$\therefore A = 1.292$$

$$SS_A = \frac{(15.5)^2}{24}$$

$$\therefore SS_A = \underline{\underline{10.010}}$$

$$B = \frac{1}{4n}\left(b + ab + bc + abc - (1) - a - c - ac\right)$$

$$= \frac{1}{12}\left(-7.5 - 5.2 - 11.25 - 5.75 + 9.15 + 5.25 + 12.55 + 8.75\right)$$

$$= \frac{6}{12}$$

$$\therefore B = 0.5$$

$$SS_B = \frac{(6)^2}{24}$$

$$\therefore SS_B = \underline{\underline{1.5}}$$

$$C = \frac{1}{4n}\left(c + ac + bc + abc - (1) - a - b - ab\right)$$

$$= \frac{1}{12}\left(-12.55 - 8.75 - 11.25 - 5.75 + 9.15 + 5.25 + 7.5 + 5.2\right)$$

$$= \frac{-11.2}{12}$$

$$\therefore C = -0.933$$

$$SS_C = \frac{(-11.2)^2}{24}$$

$$\therefore SS_C = \underline{\underline{5.227}}$$

$$AB = \frac{1}{4n}\left((1) + ab + c + abc - a - b - ac - bc\right)$$

$$= \frac{1}{12}\left(-9.15 - 5.2 - 12.55 - 5.75 + 5.25 + 7.5 + 8.75 + 11.25\right)$$

$$= \frac{0.1}{12}$$

$$\therefore AB = 0.008$$

$$SS_{AB} = \frac{(0.1)^2}{24}$$

$$\therefore SS_{AB} = \underline{\underline{0.0004}}$$

$$AC = \frac{1}{4n}\left((1) + ac + b + abc - a - ab - c - bc\right)$$

$$= \frac{1}{12}\left(-9.15 - 8.75 - 7.5 - 5.75 + 5.25 + 5.2 + 12.55 + 11.25\right)$$

$$= \frac{3.1}{12}$$

$$\therefore AC = 0.258$$

$$SS_{AC} = \frac{(3.1)^2}{24}$$

$$\therefore SS_{AC} = \underline{\underline{0.400}}$$

$$BC = \frac{1}{4n}\left((1) + a + bc + abc - b - ab - c - ac\right)$$

$$= \frac{1}{12}\left(-9.15 - 11.25 - 5.25 - 5.75 + 7.5 + 5.2 + 12.55 + 8.75\right)$$

$$= \frac{2.6}{12}$$

$$\therefore BC = 0.217$$

$$SS_{BC} = \frac{(2.6)^2}{24}$$

$$\therefore SS_{BC} = \underline{\underline{0.282}}$$

$$ABC = \frac{1}{4n}\left(a + b + c + abc - (1) - ab - ac - bc\right)$$

$$= \frac{1}{12}\left(-5.25 - 7.5 - 12.55 - 5.75 + 9.15 + 5.2 + 8.75 + 11.25\right)$$

$$= \frac{3.3}{12}$$

$$\therefore ABC = 0.275$$

$$SS_{ABC} = \frac{(3.3)^2}{24}$$

$$\therefore SS_{ABC} = \underline{\underline{0.454}}$$

$$\Rightarrow SS_{Sub-total} = 17.873$$

$$SS_T = \sum_i \sum_j \sum_k y_{ijk}{}^2 - \frac{y_{...}{}^2}{abcn}$$

$$= 198.535 - \frac{(65)^2}{24}$$

$$\therefore SS_T = 20.320$$

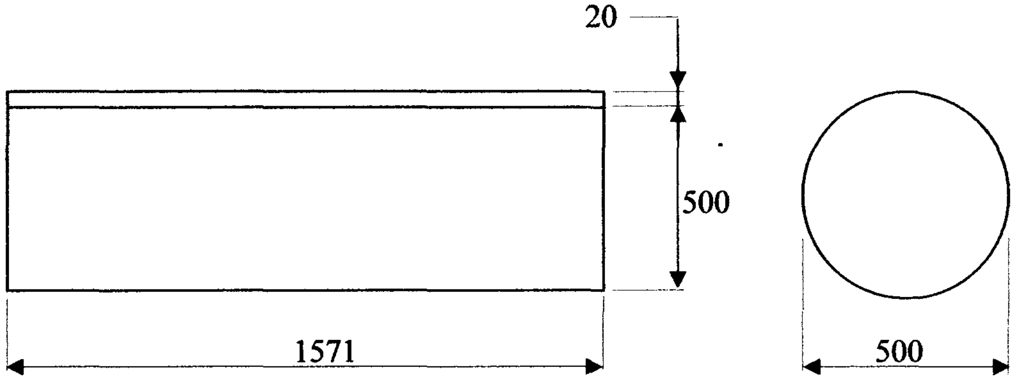
$$SS_E = SS_T - SS_{Sub-total}$$

$$= 20.320 - 17.873$$

$$\therefore SS_E = 2.447$$

APPENDIX II

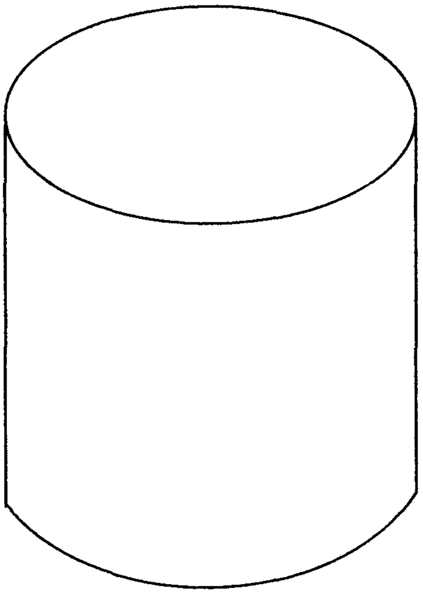
MACHINE PARTS DEVELOPMENT



Development of mixing chamber (Upper cylinder)

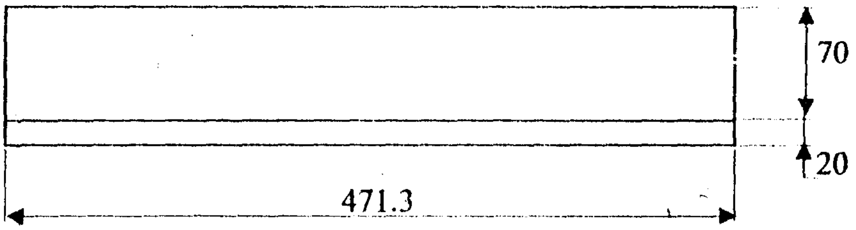
Top cover

Scale 1:20
All dimensions are in mm

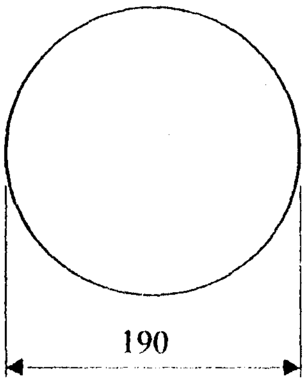


Upper cylinder

Fig. II.1 Working drawing for the development of mixing chamber (upper cylinder)



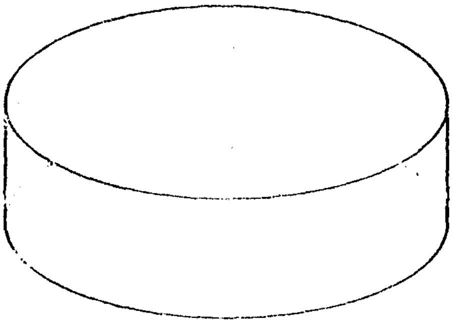
Development of mixing chamber (Lower cylinder)



Bottom cover

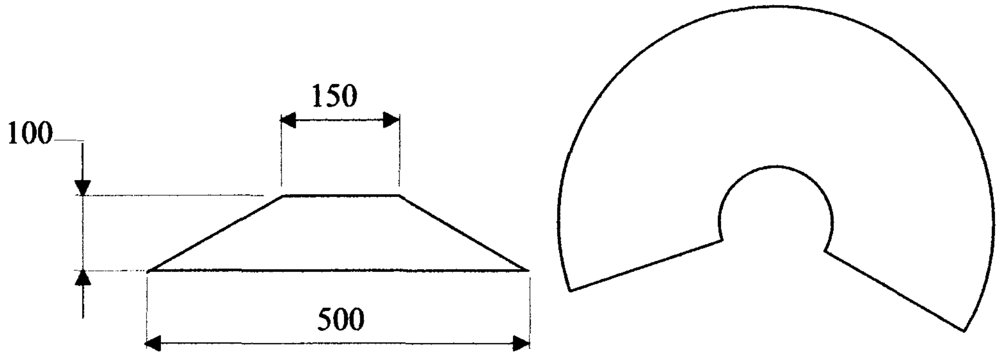
Scale 1:5

All dimensions are in mm



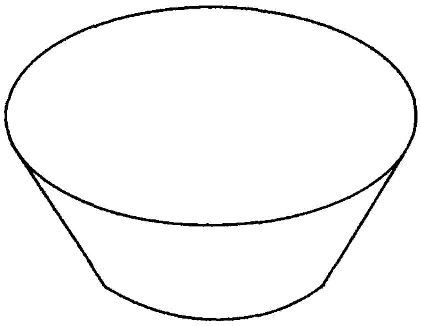
Lower cylinder

Fig. II.2 Working drawing for the development of mixing chamber (Lower cylinder)



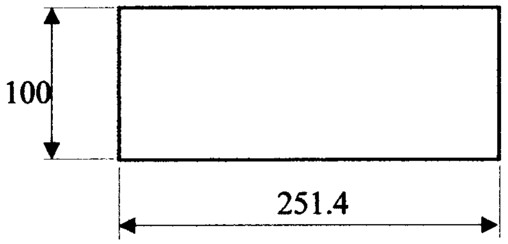
Scale 1:10
All dimensions are in mm

Development of frustum (middle chamber)

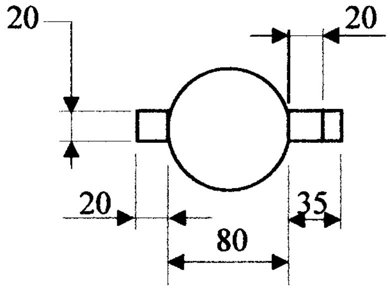


Frustum

Fig. II.3. Working drawing for the development of frustum of mixing chamber

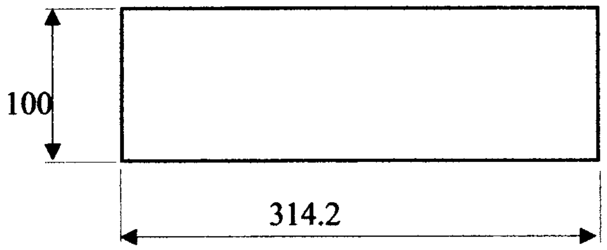


Development of transfer port

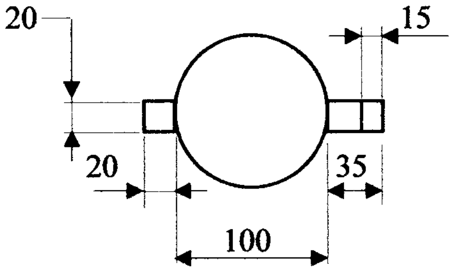


Flap for transfer port

Scale 1:5
All dimensions are in mm.

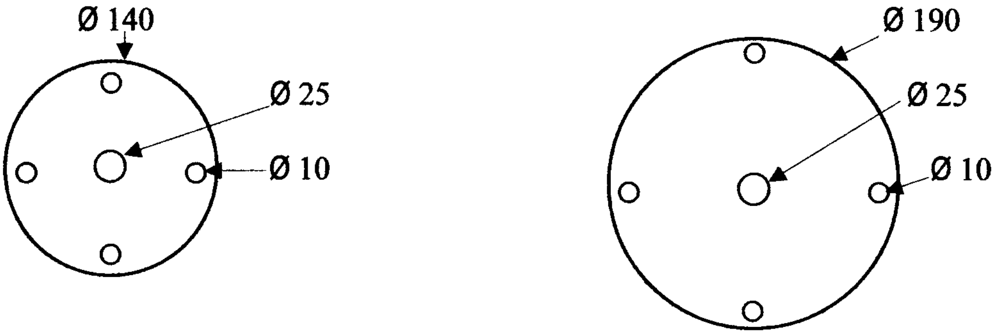


Development of discharge port



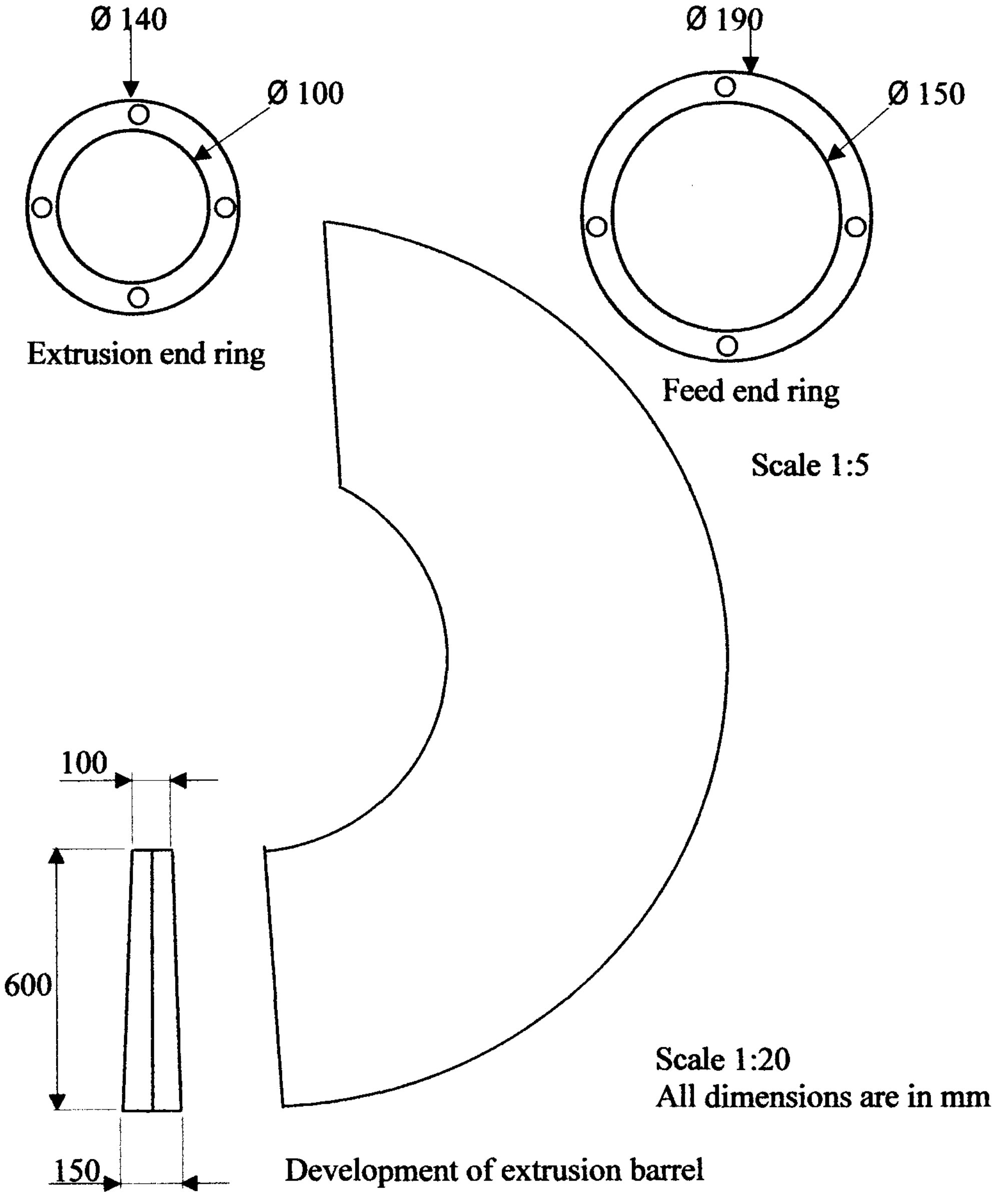
Flap for discharge port
Scale 1:5
All dimensions are in mm

Fig. II.4 Working drawings for the development of ports and flaps



Extrusion end cover

Feed end cover



Extrusion end ring

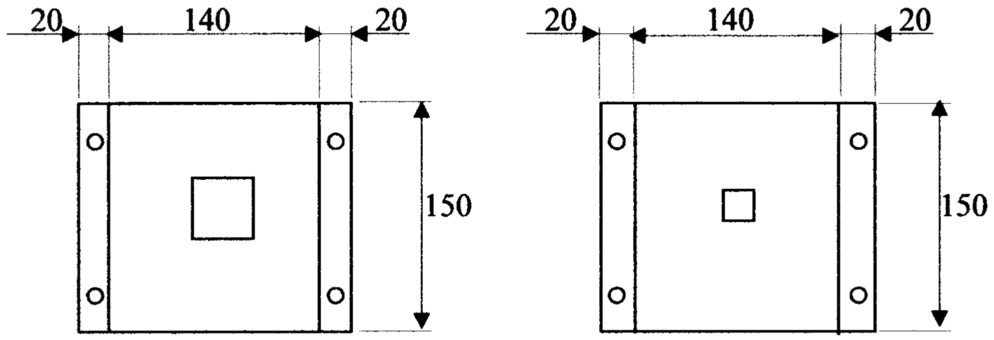
Feed end ring

Scale 1:5

Scale 1:20
All dimensions are in mm

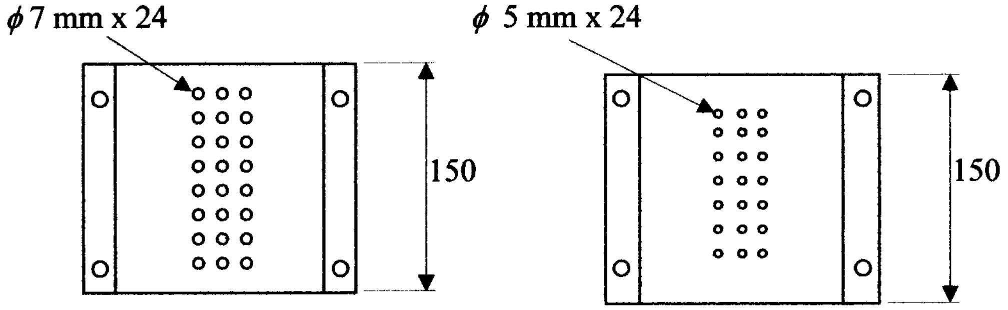
Development of extrusion barrel

Fig. II.5 Working drawings for the development of extrusion barrel



40 x 40 mm square die.

20 x 20 mm square die

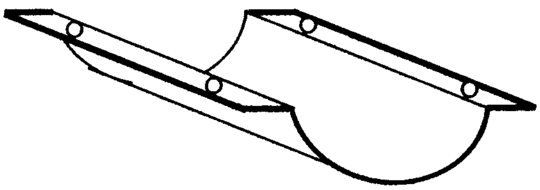


7 mm diameter die.

5 mm diameter die.

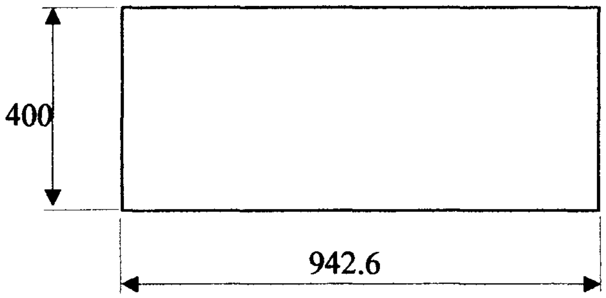
Scale 1:5

All dimensions are in mm

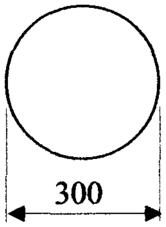


Die

Fig. II.6 Working drawings for the development of extrusion dies.

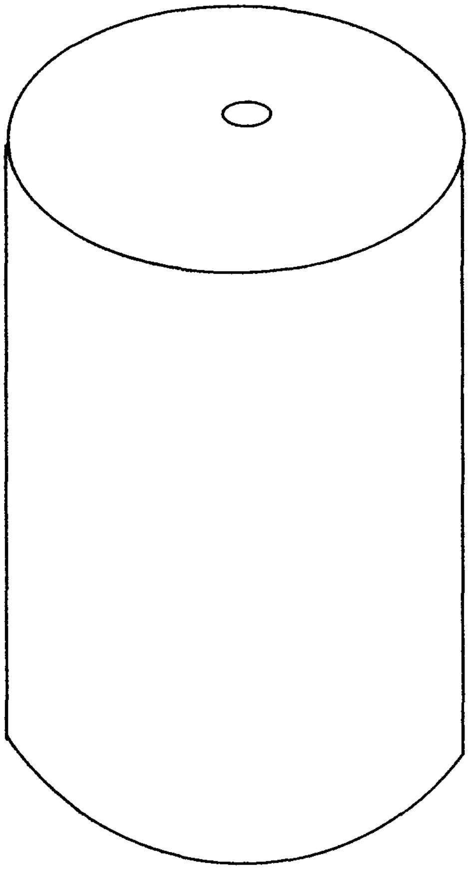


Development of Steamer (Outer cylinder)



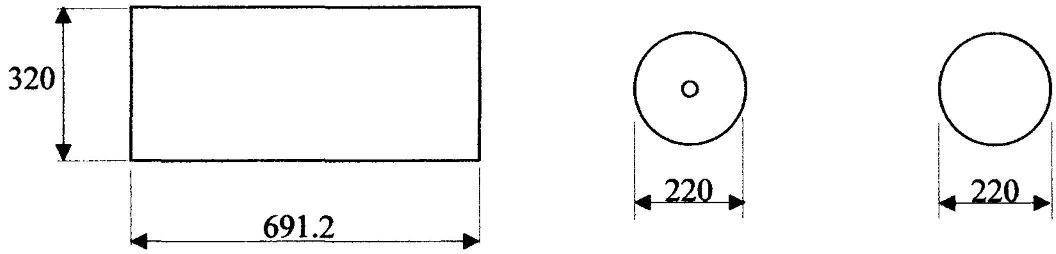
Top cover

Scale 1:15
All dimensions are in mm

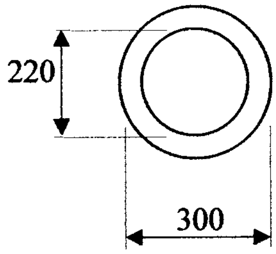


Steamer outer cylinder Scale 1:5

Fig. II.7 Working drawings for the development of steamer (outer cylinder)



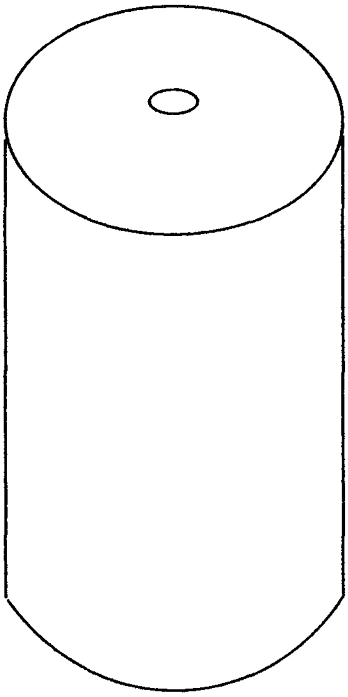
Development of Steamer (Inner cylinder) Top cover Bottom cover



Cylinder separator

Scale 1:15

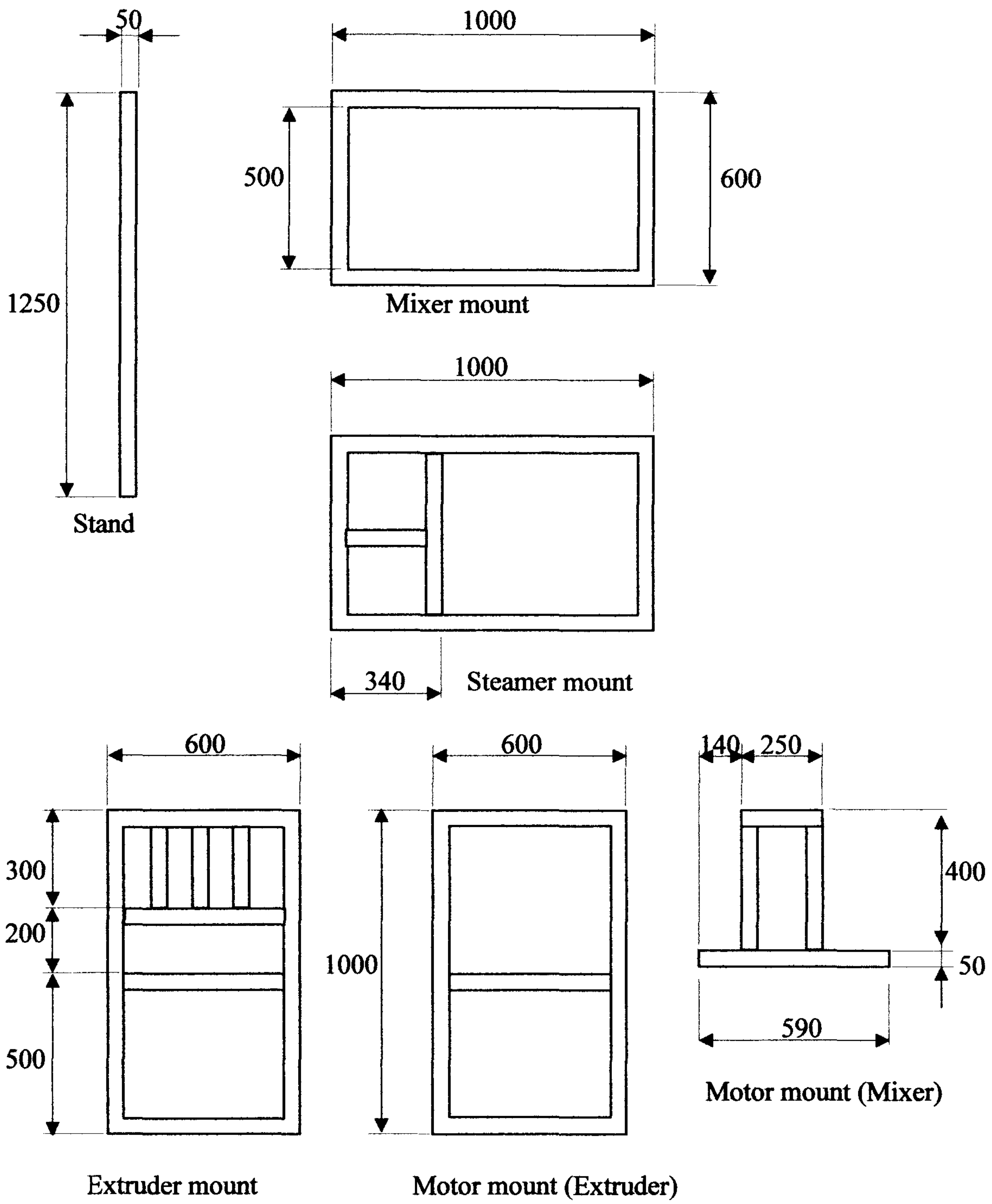
All dimensions are in mm



Scale 1:5

Steamer inner cylinder

Fig. II.8 Working drawings for the development of steamer (inner cylinder)



Stand

Mixer mount

Steamer mount

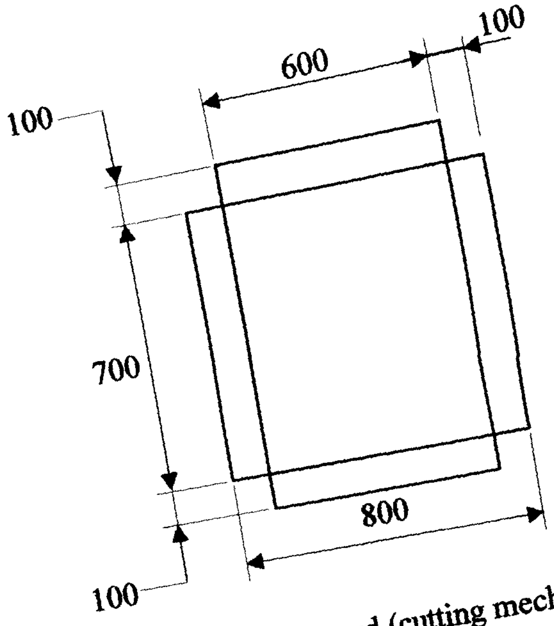
Motor mount (Mixer)

Extruder mount

Motor mount (Extruder)

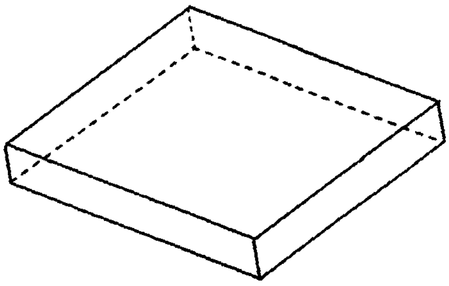
Scale 1:20
All dimensions are in mm

Fig. II.9 Working drawings for the development of frame



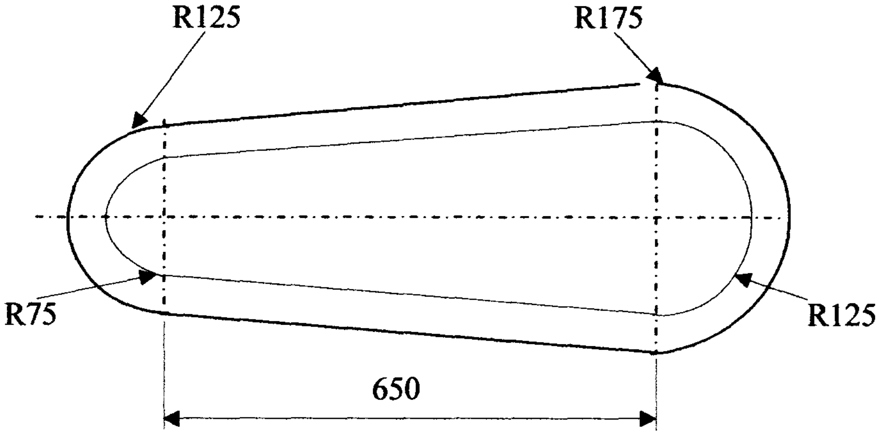
Development of guard (cutting mechanism d

Scale 1:20
mensions are in mm



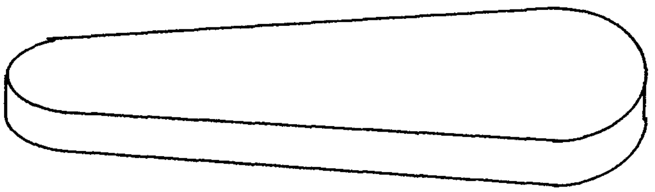
Guard (cutting mechanism drive)

Fig. II.10 Working drawings for the development of guard nism drive)



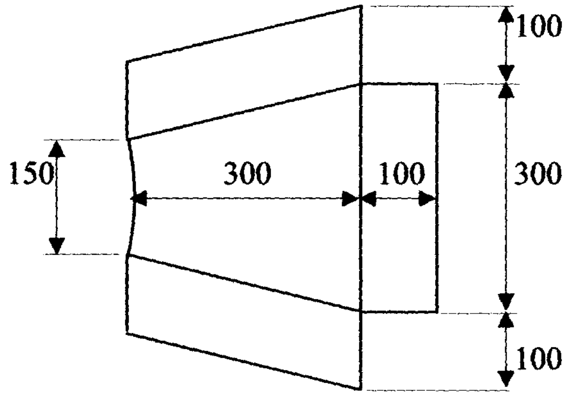
Development of guard for mixer's drive

Scale 1:10
All dimensions are in mm



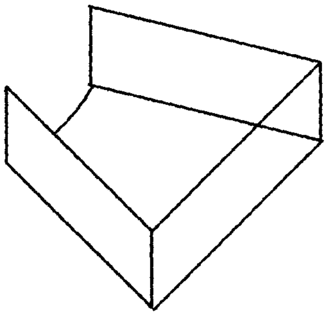
Guard for mixer's drive

Fig. II.11 Working drawings for the development of guard (Mixer drive)



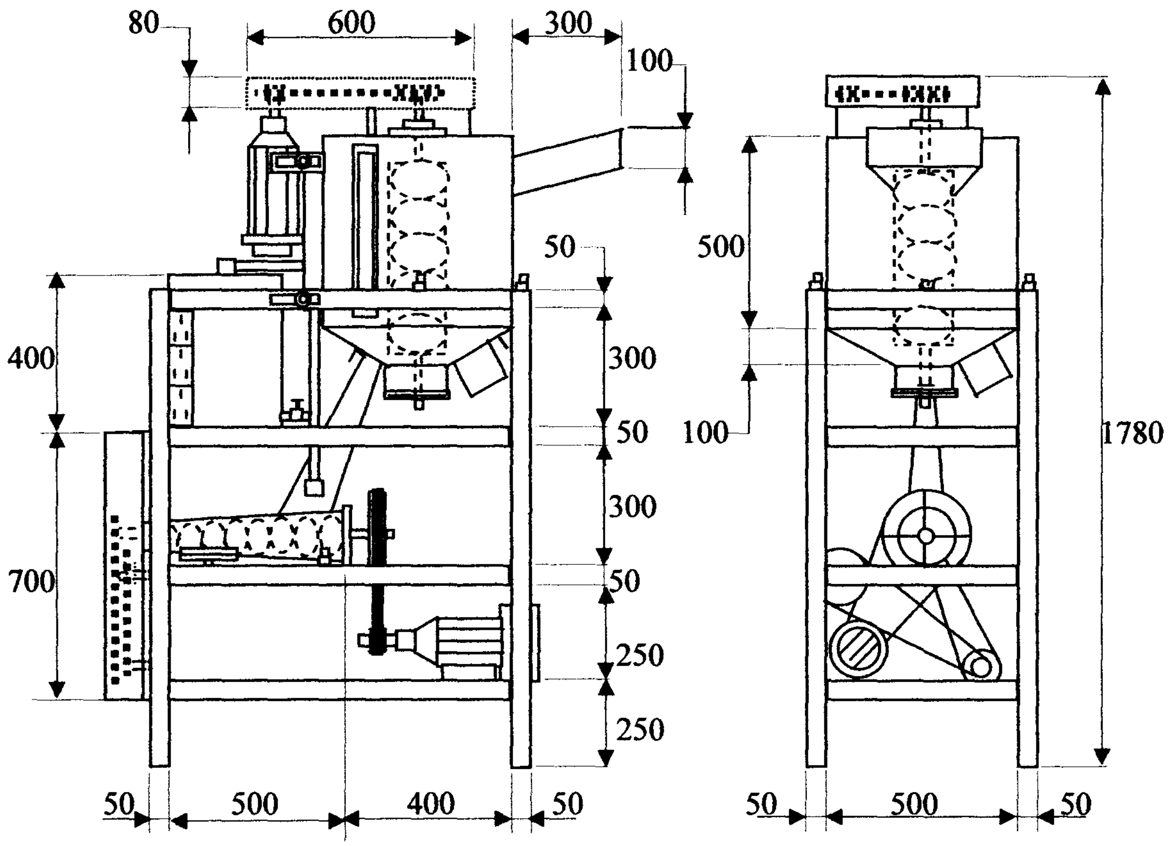
Development of hopper

Scale 1:10
All dimensions are in mm



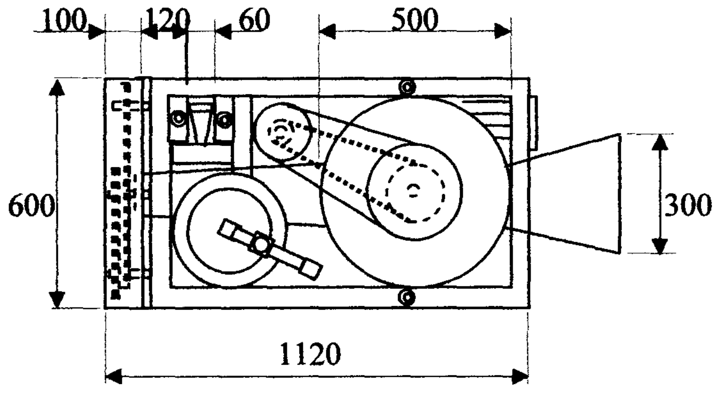
Hopper

Fig. II.12 Working drawing for the development of hopper



Front View

Side View



Plan

Scale 1:20
All dimensions are in mm

Fig. II.13 Orthographic Views of the Machine