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DESIGN AND DEVELOPMENT OF DRUM GRANULATOR

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..../..../2019

Özge TUFAN

ÖZET

TAMBUR GRANÜLATÖR TASARIM VE GELİŞTİRMESİ

Özge TUFAN

Yüksek Lisans Tezi, Makine Mühendisliği

Tez Danışmanı: Prof. Dr. İsmail Böğrekci

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Tezin konusu, ilaç, gıda, kimya, deterjan, kompost gübre üretim sektörlerinde yaygın olarak kullanılan tambur granülatör tasarımı ve geliştirmesidir. Tasarlanan tambur granülatörün üretim kapasitesi yaklaşık 10 ton/sa, tambur devri 11 d/dk'dır. Yaş granülasyon yöntemlerinden biri olan tambur granülatörde tasarlanan nozul sistemi ile granülatöre beslenen malzemeye belirli bir oranda su verilerek nemlendirme işlemi gerçekleştirilmektedir. Tamburun toplam boyu 8m, tamur çapı 2m'dir. Tambur, dişli ile tahrik edilmektedir ve eğim açısı 2-3°dir. Tez konusu tambur granülatörde (saf gübre için) yaklaşık %60-65 nem oranına sahip 2-4 mm granüller elde edilmektedir.

Tambur granülatör süreci, ön hazırlık süreci ile başlamış, rakip ürün özellikleri, firma araştırması ve pazar araştırması ile tasarlanan granülatörün hedefleri belirlenmiştir. Tasarım sürecinde tahrik sistemi tasarımı, redüktör seçimi, tambur tasarımı ve şasi tasarımı gerçekleştirilmiştir. Sonrasında analiz yapılarak, şasi dayanımı ve tambur dayanımları incelenmiştir. İmalatı tamamlanan granülatörün deneme süreci gerçekleştirilmiş, geliştirme & iyileştirme çalışmaları yapılmıştır.

Geliştirme çalışmalarında; malzemenin tambur yüzeyine yapışmasını önleyen PVC konveyör bandı montajı, 2,5° tambur eğim açısında ortaya çıkan taşma problemlerini önleyen tambur giriş tasarımı, malzemenin birikmesini önleyen çıkış tasarımı yapılmıştır. Ayrıca, fire (reject) oranını azaltmak amacıyla beslenen malzeme ağırlığına göre verilen su miktarını ayarlayan bir sistem yapılarak granül üretim sistemine önemli bir katkı sağlanmıştır.

Anahtar Kelimeler: Granül, Granülatör Tasarımı, Tambur Granülatör, Yaş Granülasyon

ABSTRACT

DESIGN AND DEVELOPMENT OF DRUM GRANULATOR

Özge TUFAN

Master Thesis, Mechanical Engineering

Supervisor: Prof. Dr. İsmail BÖĞREKCİ

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The subject of the thesis is the design and development of drum granulator which is widely used in pharmaceutical, food, chemical, detergent, compost fertilizer production sectors. The production capacity of the designed drum granulator is approximately 10 tons / h and the drum speed is 11 rpm. With the designed nozzle system of the drum granulator, which is one of the wet granulation methods, humidification process is carried out by adding water to the material fed to the granulator. The total length of the drum is 8m and the drum diameter is 2m. The drum is gear driven and has a tilt angle of 2-3°. 2-4 mm granules with a moisture content of about 60-65% (for fertiliser) are obtained in the drum granulator.

The drum granulator process started with the preliminary preparation process. In this process, competitor product characteristics, company research and market research were conducted in general and the targets of the designed granulator were determined. During the design process, drive system design, gearbox selection, drum design and chassis design were realized. Then, the frame strength and drum strength were analyzed. The trial process of the granulator was completed and development & improvement studies were carried out. In development studies; PVC conveyor belt assembly which prevents the material from sticking to the drum surface, drum inlet design which prevents overflow problems at 2.5 ° drum inclination angle, outlet design which prevents the material to be clogged when leaving the drum. Furthermore, in order to reduce the rejection rate, a system which adjusts the amount of water given according to the weight of the material fed has been made. This system has made a significant contribution to the granule production process.

Key Words: Granul, Granulator Design, Tumbling Granulator, Wet Granulation

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Özge TUFAN

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LIST OF ABBREVIATIONS

CAE	: Computer aided engineering
CAD	: Computer aided design
CF	: Centrifugal
CG	: Centrifugal granulators
CNC	: Computer numerical control
CPU	: Central processing unit
FEA	: Finite element analysis
FEM	: Finite element method
FG	: Fluidized granulator
MG	: Mixer granulators
PBE	: Population balance equation
PDE	: Partial differential equations
PDG	: Pneumatic dry granulation
RAM	: Random Access memory
Rpm	: Rate per minute
TG	: Tumbling granulators

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1. INTRODUCTION

In developed countries, organic farming and good agricultural practices are becoming widespread. At this point, the protection of soil is very important to ensure sustainability. In recent years, the processing of animal wastes and making them suitable for use in agricultural areas have become a very important issue. The main objective is to reduce the use of chemical fertilizers and the harmful effects of chemicals to the environment. However, certain processes need to be carried out in order to use animal wastes in agriculture. For instance, according to the Ministry of Environment and Urbanization, it is stated that in order to use animal wastes in agricultural areas, the hygiene process must be carried out [23]. Therefore, all the machines used in this process are important. A typical organic & organomineral fertilizer production process;

- Fertilizers and other animal wastes generated in animal shelters are collected in the pits by stripping & collecting. Regular removal of these wastes and improvement of shelter conditions are very important for animal health and milk yield.
- The mixers in the pits mix the fertilizer homogeneously. These mixers prevent sedimentation of the manure at the bottom of the manure pits and stratification on the surface.
- Submersible pumps deliver the homogeneous solid-liquid mixture in the fertilizer pit to the next process to be separated into phases.
- The separators separate the homogeneous mixture fed by pumps into solid and liquid phases.
- The solid material is conveyed to the composting machines for the fhygiene process. The solid material is kept at 70° For at least 1 hour. In this process, all harmful organisms in the fertilizer are eliminated.
- Compost, which is purified from harmful organisms, enters the maturation process. In this process, the material temperature is reduced, the contact with oxygen is increased and the carbon dioxide is dispersed with the compost mixing machines.
- Mineral material can optionally be added to the compost material. However, if mineral is added, it should be mixed homogeneously.

- The compost is then fed to the granulator. In this process, wet granulation method is generally applied. The material fed to the granulation is moistened by spraying liquid binders and granulated to the desired dimensions.
- The material that completes the granulation process by increasing the moisture content is dried with belt dryer etc. drying systems.
- The dry material is then sieved. In this process, granules of the desired size are packaged. Granules other than the desired dimensions are crushed to be processed and returned to the process.

Each machine is important in the above mentioned fertilizer production process. The drum granulator, which is the subject of this thesis, is an indispensable equipment of this process due to its ease of transportation and storage, ease of application and improvement of material structure [7]. Tumbling granulators are suitable for obtain 1 - 20 mm granules [2] . The drum is operated horizontally with an inclination of 2-3° [15]. Drum speeds are generally between 10-20 rpm [1]. The recycling rates of drum granulators are generally 2:1 and 5:1. [16].

The aim of this thesis is to design a granulator which is one of the most important processes of organic fertilizer production in the most appropriate way and to ensure the granulator to work in the most effective way with the development studies made as a result of the experiment.

2. LITERATURE REVIEW

In this literature study, firstly dimension expansion which is the basis of granulation is mentioned. Then granulation was defined and the benefits of granulation were explained. Granulation types are mentioned and granulation equipments are examined. Drum granulator which is one of the wet granulation types is introduced and explained in detail. In general, all topics are supported with the help of figures and tables.

2.1. Size Enlargement Principles

Size enlargement is a process so that powder materials enlarge permanently and become uniform. Agglomeration is carried out using drum or similar mixing elements. While liquid binders are used in some methods during particle growth process, binders are not used in some methods. The particle size varies according to the residence time of the fed material in the process and the properties of the added materials. There are many advantages of agglomeration equipments in many industries.

Agglomeration processes allow the formation of material in desired dimensions and in the desired structural form (important in powder metallurgy). It provides mixtures in the desired proportions and in certain quantities and this is an important issue in drug production and reduces dust formation. Reducing dust formation is important for waste particles or hazardous particles containing explosive material. Uniformly structured and non-decomposable product is obtained from powder particles. Also, this size enlargement process improves the product appearance, increases the fluidity of the material, increases the density of the material and facilitates transportation and storage [1].

Agglomeration is widely used in many industries to enhence the properties of the material and agglomeration provide to obtain desired quality and physical properties of the granules to customers.

There are several agglomeration techniques and processes that create bond between powder particles and create a granular form. Granulation method is one of the agglomeration process whereby agitation and it contains fluid-bed, pan (or disc), drum, and mixer granulators. In the formation of granules, the liquid binder may or may not be added to the base material. In processes where liquid binders are added, these binders may be solvents, fillers, etc. In this type of agglomeration, liquid binders or solvents sprayed onto fine powders to obtain uniform granules that have small nuclei. Agglomeration process may also occured with sintering process that has been made with increasing the heat and make granules with melting of binders. Beside sintering, compression is another agglomeration techniques that obtain granules such as tablets via applying pressure [2].

In a manufacturing plant, there are various operations to get granules such as mixing & blending, grinding & crushing, drying & cooling, sorting [3]. Typically manufacture plants, these operations start with dosing process to get desired formation that includes different rates of materials. Then the homogenuous mixture is obtained with mixing process. Then the mixture get into a size enlargement process such as a granulation. Many agglomeration operations in manufacturing, granulation process may have done with wet granulation and drying process will be need after wetting system. Agglomerated particles whose moisture content decreases are separated by their sieving process. When the particles reaching the desired dimensions are packaged, the other particles are fed back into the process. In addition, these operations may vary depending on their use in different industries.

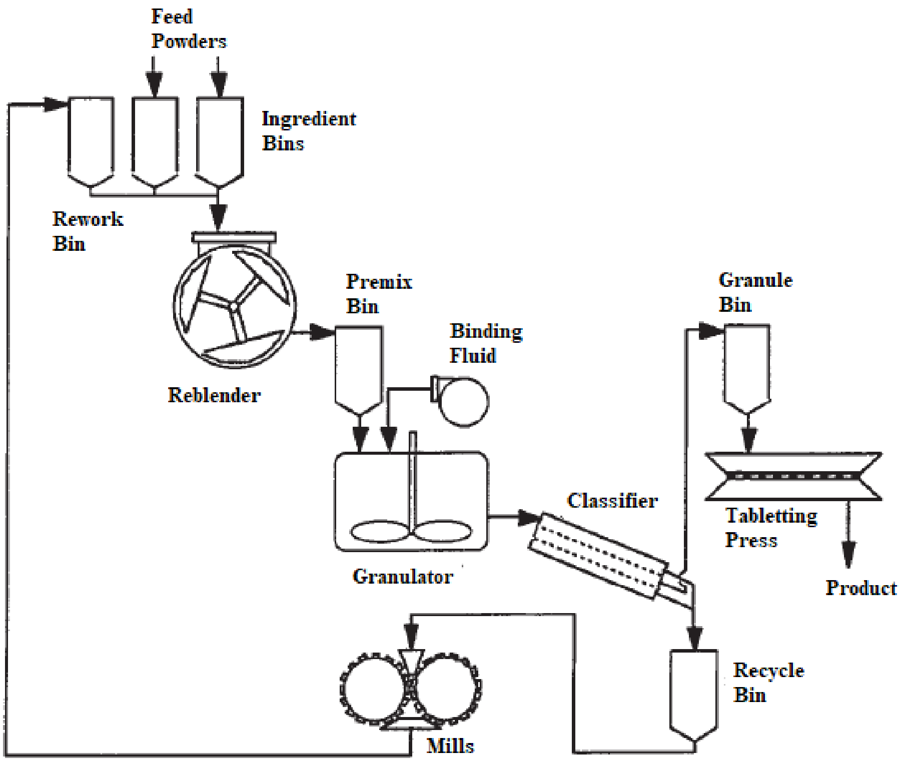


Figure 2.1 Typical agglomeration process in manufacture plants [2]

Agglomeration process enhences the features of the powder particles such as flowability and decreases the dustiness. According to Schaafsma, these properties of particles may be the important factors in production plants for instance the material fed into porcess is toxic or there is a situation for dust explosion risk. Also, granules are higher dissolution rate than powder material and higher bulk density. the higher bulk density of granules provide to decrease the transporting cost and a better compactability [4].

2.2. Granulation

Granulation is a size enlargement process that commonly used in many industry such as agrochemical, food, detergent, pharmaceutical, manure management, mineral processing and chemical industries [5].

D.M. Parikh defined the granulation is particle design and the properties obtained by granulation depend on the physical and chemical properties of the binder [6].

This method has some advantages that decrease dustiness, increase the uniformity of each granule, facilitate measurig (especially in pharmaceutical industry for making tablets), ease of packaging for beter marketing and transportion issues, enhence the appearance of the product. The ganulation method provides to get the homogen mixture without any material segregation during the process, improve the material structure, flowability and electrostatic properties of powders [7]. Also, granulation process enable to obtain the desired granule are controlled by a combination of the formulation.

According to A.D. Salman, there are many different types of equipment which enable agglomeration of powder particles to form larger masses and the process when carried out a mixing device is usually described as granulation [8].

There are many equipment to meet the requirements of different industries and production capacities, granule sizes and granule densities vary according to the use of these equipment [3]. These equipments are shown in Table 2.1.

Table 2.1 Granulator eqipments and applications [2]

Method	**Product Size (mm)**	**Granule Density**	**Scale of Operation**	**Additional Comments**	**Typical Applications**
TG **Drum** **Disc**	0,5 - 20	Moderate	0,5 – 800 t/h	Very spherical granules	Fertilizers, iron ore, nonferrous ore, agricultural chemicals
MG **Continuous high shear** **Batch high shear**	0,1 – 2 0,1 - 2	Low High	Up to 50 t/h Up to 500 kg, batch	Handless very cohesive materials well, both batch and continuous	Chemicals, detergents, clays, carbon black Pharmaceuticals, ceramics
FG **Fluidized**	0,1- 2	Low	100-900 kg,	Flexible,	Continuous:

beds **Spouted beds** **Wurster coaters**			batch; 50t/h continuous	relatively easy to scale, difficult for cohesive powders, good for coatig applications	fertilizers, inorganic salts, detergents Batch: pharmaceuticals, agricultural chemicals, nuclear wastes
CG	0,3 - 3	Moderate	Up to 200 kg, batch	Powder layering and coating applications	Pharmaceuticals, agricultural chemicals
Spray Methods **Spray drying** **Prilling**	 0,05– 0,5 0,7 - 2	 Low Moderate		Morphology of spray dried powders can vary widely	Instant foods, dyes, detergents, ceramics,pharmaceutical Urea, ammonium nitrate
Pressure compaction **Extrusion** **Roll press** **Tablet pres** **Molding pres** **Pellet mill**	 >0,5 >1 10	 High to very high	 Up to 5 t/h Up to 500 t/h Up to 1t/h	Very narrow size distributions, very sensitive to powder flow and mechanical properties	Pharmaceuticals, catalysts, inoranic chemicals, plastic preforms, metal parts, ceramics, clays, minerals, animal feeds

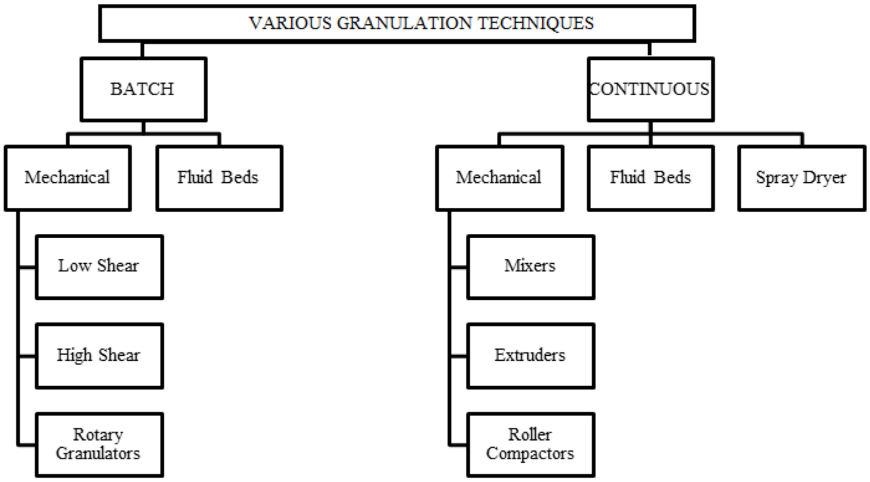


Figure 2.2 Various Granulation Techniques [9]

There are many techniques are enable to use to form a granule such as formation of solid bridges, binding, sintering, chemical reaction, crystallization or deposition of colloidal particles. To achieve desired properties of the granule in the process for the granulation of the main particles depends on control of the adhesional forces between particles. Also, if the distance between particles is reduced, van der waals forces and electrostatic forces can interact to create bond between particles. These forces are used in dry granulation methods. In wet granulation method, there are cohesive forces that creates the liquid birdges between particles. Also, electric forces contribute to keep particles together [9].

According to Salman A.D. there are many factors affecting granule quality such as size distibution, porosity, attritional ability, dispersability, dissolution rate, strength, shape, color and homogenity.

Size Distribution: This property is depend on industries but narrow size range of granules are generally prefered in manufacturing plants.

Porosity: Porosity is defined as the ratio of the volume of pores to the volume of bulk material and is usually expressed as a percentage. As the porous structure of the granule increases, it provides better dissolution of the granule in the application stage.

Attritional ability: The abrasion state of the granule can cause dust formation again. Particularly in the packaging and transport processes, dust formation is more likely to occur, and when such products reach the customer, this is a negative condition.

Dispersability: According to the material structure of the granules, the dispersibility during application may vary according to the sector in which it will be used.

Dissolution rate/time: The dispersibility of the granules in an appropriate and suitable environment is related to the dissolution property. Since the use of granules for different purposes may require different dissolution times, the granule formation process needs to be well designed.

Strength: Granular strength is crucial for minimizing dust formation and attiritional rates and granule strength and dissolution rate are inversely proportional to each other.

Shape: It is important that the shape of the produced granules affects the granular property suach as flowability, dust formation in some industries. Granular shapes can also affect customer preference.

Color: The color of the granules can affect customer preference.

Homogenity: It is important to ensure the same homogenity in each granule between batches in many industries such fertilizer, chemical and pharmaceutical.

In order to obtain good quality granules, control of two main factors is important among the above mentioned factors. these are size and porosity [8].

Iveson stated that porosity, binder content and composition are independent properties of granules and significantly affect the granule growth process and excludes studies which assume that the granule size is the only independent granule property that controls coalescence [10].

It is important to ensure the same structure and properties in each granule between batches especially in pharmaceutical industry. Each granule should be well defined and constant in every batch. However, it is not possible to achieve the desired granule homogenity in every batch. In such cases, screenin processes are used for improve the quality of the granules and granules that exceeding the desired dimensions are sent to reprocessing. Reprocessing can be included grinding, mixing e.t.c. The disadvantage of this process is the high amount of material that requires reprocessing. It is desired to produce well defined and constant granules "right first time" without sieving especially in pharmaceutical industry for production of drugs. According to Schaafshma, good process control may be provided by enabling the interaction of the agglomeration mechanism and the compounds that affect this mechanism. However, this is still a subject of research [4].

Granulation is a process that is still being worked on. Measurement, analysis, optimization, control and modeling studies are carried out in order to increase the intelligibility of this process and to introduce new process approaches. Granulation modeling is an important issue today. Since particle size distribution directly affects the quality of granules, it is a matter of priority and must be investigated in the granulation process. Mechanistic modeling and empirical modeling have been developed to investigate and understand granule size distribution.

The mechanistic modeling uses the principles of mass, energy, momentum, and population balances to study granule size distribution, but this type of modeling is highly time-consuming and costly.

The empirical modeling approach is based on real data that can be obtained at certain intervals. However, this practice is limited and data based on the interpretation of the results are not recommended.

The multivariate analysis approach relates to data that includes the measurement of independent variables. In the multivariate analysis approach, linear combinations of original variables are used and these variables cannot be measured. This modeling is also called statistical modeling and performs the granulation process using experimental results.

Population balance equation (PBE) is the process of estimating multivariate distribution functions using numerical simulation. Multivariate distribution is a function developed for situations where a property such as size is insufficient to characterize the solid particle formation process. PBE is likened to the mass and energy balance equation and is an engineering tool used to determine the final product properties. PBE-based models can be used to determine granulation process control and estimate size distribution. PBE-based models are a very suitable method for predicting size distribution and sensitivity analysis used to determine granulation process control. Because any change in the material conditions will directly affect the product quality [6].

Biggs et al. Presented an experimental technique using a population balance model of sludge agglomeration [22].

There are two main granulation techniques are widely used in industry; wet granulation and dry granulation.

2.2.1. Wet Granulation

In wet granulation, granules are obtained with using liquid binder or solvents. In dry granulation, granules are obtained with forces such as van der waals but not using any liquid materials [9]. Wet granulation provides an agglomeration of fine particles into larger particles with adding liquid binder or solvents and creates a liquid bridges between fine particles.

As depicted in Figure 2.3, particles are set in motion by a rotating vessel (this process can be batchwise or continously) and liquid binders are sprayed onto the particles. Pan (or disk), fluidized-bed, drum and mixer granulators are mostly used granulation equipments. Wet granulation process enhances powder flowability, compressibility [3].

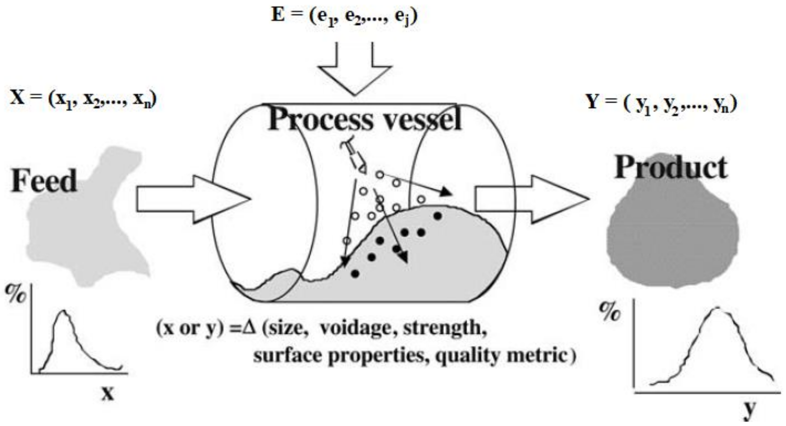


Figure 2.3 The schematic diagram of wet granulation operation [3]

There are three basic processes that affect granule density and size distribution: wetting and nucleation, growth and consolidation, attrition and breakage. In order to determine the granular properties correctly, each process should be evaluated separately.

Wetting and nucleation: The first process in wet granulation begins with the dispersion of the liquid binder in the powder particles. As the powder particles move through the drum, they are wetted by spray systems such as nozzles. In the formation of nuclei granules, liquid binders are joined to the powder particles by the action of capillary forces. It is the ideal nucleation that each drop coming out of the spraying system combines with the powder particles to form a core and this is called drop controlled nucleation.

Growth and consolidation: When the wetting and nucleation process has been successful, the granule sonsolidation and coalescence will affect the density and size characteristics of the granule. Granular consolidation is due to granular deformation as a result of collision during the granulation process. The deformation of the granule is related to the mechanical properties of the granule and the collision energy and deformation affects the growth of the granule by the coalescence [11].

Breakage and Attrition: This process is related to breakage of the wet granules during granulation and attrition or fracture of dry granules. The breakage process in wet granules can control the final granule size in order to provide size limitation by breaking the large size granules or to facilitate distribution of the binder.

Attrition in dry granules causes dust formation. This process is particularly important when granule production and drying are carried out simultaneously [12].

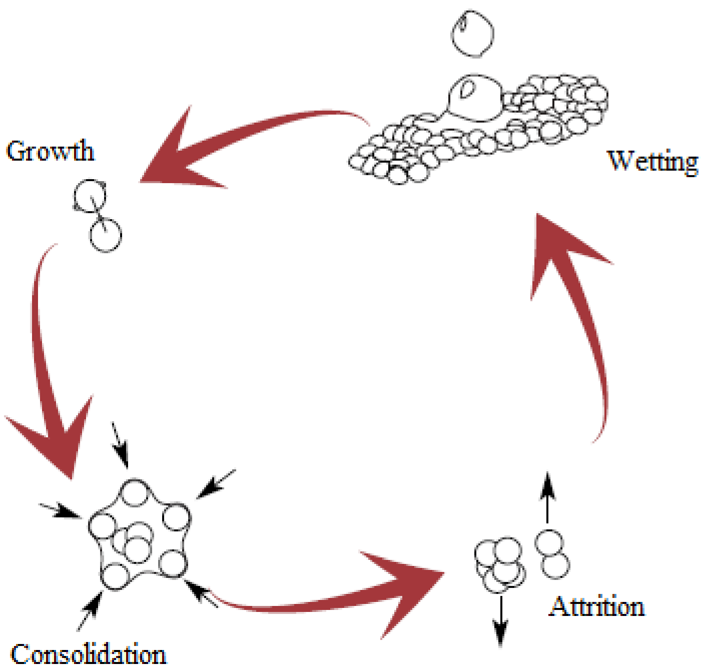


Figure 2.4 The rate process of wet granulation [3]

Verkojen et al conducted studies on the granule rate process and tested the breakage behavior of the granules and stated that the strength of the granules can be measured according to the breakage behavior. He used an image analysis technique in his studies and stated that the breakage were caused by high moisture rate [18].

2.2.2. Dry Granulation

Dry granulation is a continuous process that uses mechanical compressions at high pressure or compactions and get granules without any binders [12]. Dry granulation method is very advantageous because of its simplicity and low cost and there are three methods that widely used in industry such as direct compression, slugging, roller compaction [6].

As depicted in figure 2.5, particles are fed into a compresion vessels and particles become granular form due to pressure. This type of granulation is commonly used in pharmaceutical industry to obtain tablets Compression devices, roll presses, briqueting machines are typcally compaction processes [3].

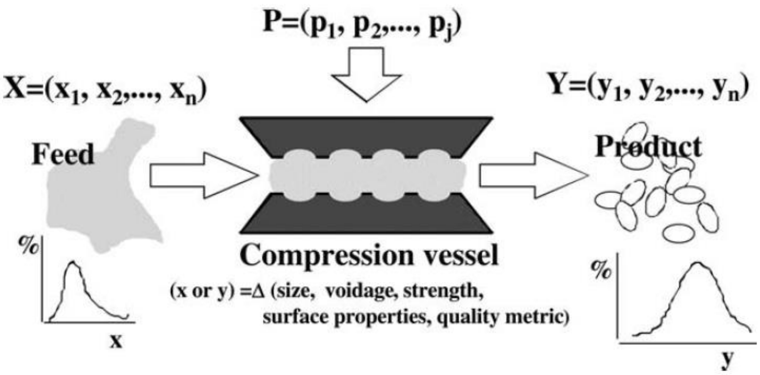


Figure 2.5 The schematic diagram of dry granulation operation [3]

Roller compaction and slugging are dry granulation applications. The schematic diagram of these applications are shown in figure 2.6. However, no progress has been achieved in dry granulation except pneumatic dry granulation.

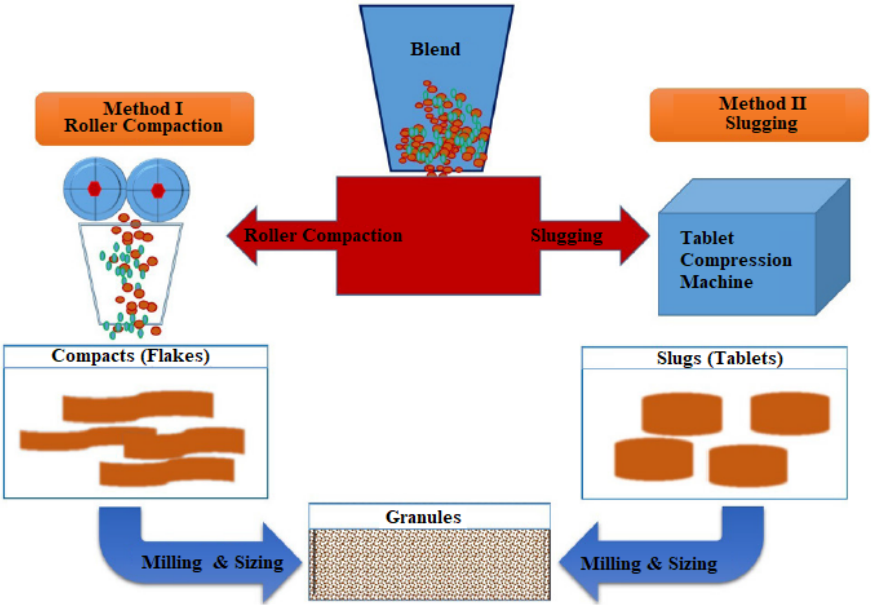


Figure 2.6 Schematic diagram of roller compaction and slugging applications [14]

Pneumatic dry granulation; PDG forms granules using a roller compaction method with air flow. The granules obtained by this technique have remarkable fluidity and compressibility. This method is carried out by applying force by a roller compactor to obtain a compressed mass. In this process, the materials which are below the desired granule size are sent to the rework process by pneumatic system, while the granules of the desired size are compressed into tablets. PDG is a suitable process for the production of granules where high flowability is desired. The tensile strength of the granules produced by PDG is about 0.5 MPa. It is also suitable for use in the pharmaceutical industry as it improves fluidity even in granules obtained using lower roll compaction forces. In addition, PDG is a very advantageous application due to its very fast processing time, low cost, almost no waste rate and no dust formation in the environment. However, the effect of the reprocessed material on the granule quality, the suitability of the system for low proportion mixtures and the brittle structure are still issues to be studied in this system. The schematic diargram of pneumatic dry graulation is shown in figure 2.7. [14].

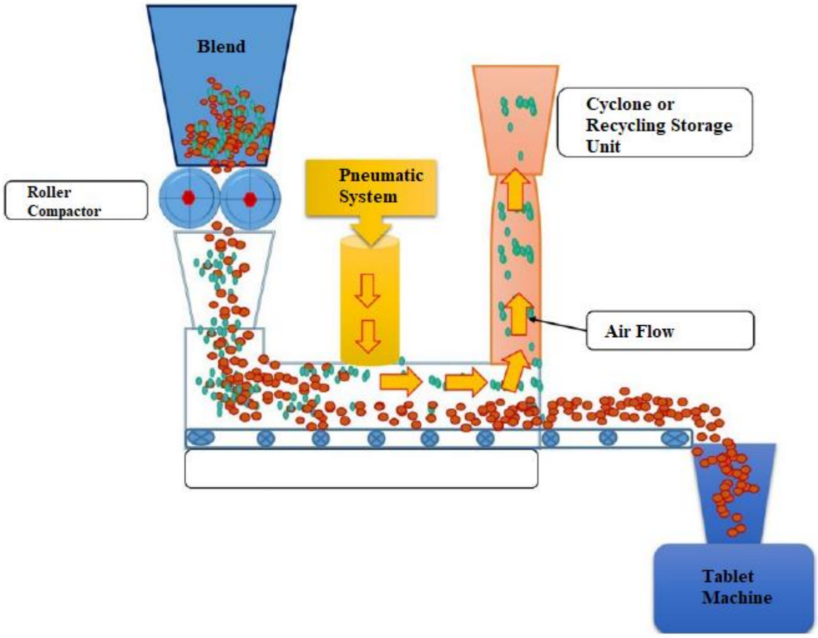


Figure 2.7 The schemtic diagram of pneumatic dry granulation [14]

2.3. Granulation Equipments

2.3.1. Tumbling Granulators

In Tumbling granulators, the particles are activated by the rolling motion caused by the balance between gravity and centrifugal forces. Disc and drum granulators are the most used granulation equipments in tumbling granulators. These type of granulators are suitable for obtain 1-20 mm granules. In tumbling granulators, granule growth by coalescence is hard to control, large particles are more suitable than small particles for coating. In the mining industry, drums with diameters of up to four meters and capacities of up to 100 t/h are commonly used [2] .

2.3.1.1. Disc Granulators

The disk granulator consists of a non-deep cylindrical tray. This tray is inclined approximately 45-70° horizontally and rotational speeds vary between 10-30 rpm. The types of materials that can be used as input in the pan granulator, the required power and production capacity are shown in Table 2-2. The capacity and power are shown in Table 2.3.

Table 2.2 Pan granulator applications [1]

Dish Size (m)	**Motor (kW)**	**Capacity (kg s^{-1})**	**Material**	**Remarks**
0.36	0.18	0.013	Tungsten Carbide	16 x 60 mesh micropellets
0.36	0.18	0.0044	Alumina	
0.99	0.55	0.13	Phosphate rock	85% 4 x 30 mesh product
0.99	0.55	0.076	Bituminuous coal filter cake	Feed to pan dryer
0.99	0.55	0.076	Berly ore mix	Feed to sinter belt
0.99	0.55	0.15	Copper precipitate	
1.37	2.2	0.28	Frit enamel mix	Feed to furnace
2.59	11	8.5	Zinc concentrate sinter mix	Micropelletized sinter machine feed

2.59	11	0.85	Chromate	For electric ore furnace
2.59	7-3	0.93	Bituminuous coal fines	For coking furnace
3.05	15	1.7-2.3	Raw shale fines	For expanding in rotary kiln
3.05	18	2.8	Bituminuous coal filter cake	
3.66	22	3.4	Zinc sulphide ore	For fluid bes roasting of 4 x 30 mesh pellets
4.27	37	11	Nitrogen fertilizer material	Feed hot melt and recycle
5.49	44	11	Magnetite ore	Feed to travelling grate – indurating section

Table 2.3 Capacity and power comparison in a pan granulator [1]

Disc Size, cm	1120 kg/m³ material		2000 kg/ m³ material	
	Pelletizing		Pelletizing	
	Approx capacity (t/ h)	Drive (kW)	Approx capacity (t/ h)	Drive (kW)
550	30	30	40	37
460	18	18	25	22
365	10	8	15	12
275	5	4	10	5.5
185	3	2	5	4
100	0.5	0.75	1	0.75

As the pan granulator continues to rotate, the feed material and binder continue to be added to the process. Figure 2.8 shows a schematic drawing of the pan / disc granulator. As can be seen in the figure, the small particles grow with the help of the liquid binder and form granules by rotation.

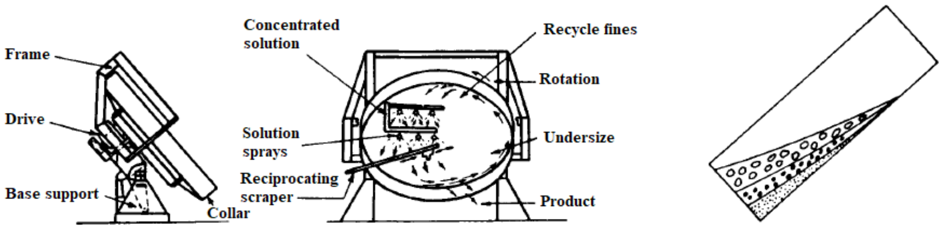


Figure 2.8 The schematic drawing of the pan/disc granulator [24]

Granules reaching sufficient dimensions are separated from the process. Due to the granule forming mechanism, the pan granulator forms granules with a more uniform structure than the drum granulator. For instance, if a pan granulator is used in fertilizer production, it is possible to obtain granules of approximately 1.6-3.3 mm in size and a production capacity of 14.3 kg/min.m². In pan granulators, granulator height is designed as cylindrical tray diameter [1].

2.3.1.2. Drum Granulator

Drum granulation process is one of the wet granulation technique. Drum granulator includes a rotary drum that mixes fine particles and liquid binders at certain rates and get homogenous granules [7].

A schematic design of a drum granulator is shown in Figure 2.9. It consists of a rotating drum inclined approximately 2-3 degrees horizontally. The inlet section generally consists of a closed ring to prevent backflow of materials from the drum. At the outlet of the drum there is also a closed ring which increases the depth of the drum. There are conveying systems in the entrance or exit sections of the drum that allow the transfer of materials. The liquid binder which provides the granule formation of the entering material is sprayed by the spraying system such as nozzle in the drum.

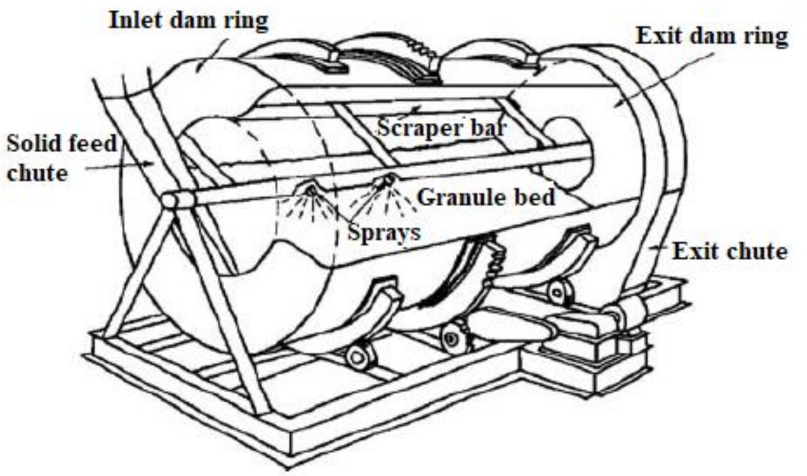


Figure 2.9 A schematic design of a drum granulator [24]

Drum granulator is a preferred equipment since 1930 in various sectors such as composite production plants, fertilizer plants etc [15].

Drum granulators are widely used in fertilizer and metallurgical industries to get high production capacity applications. Recycle rates are lower than pan granulators. The material that is fed into drum may be moistened before or liquid binder may be sprayed into the drum for obtain required wetting rates. Drums generally operate with several degrees of longitudinal slope to help the granules flow through the drum. If drum speed is too low, the material granule formation will not be achieved. if the speed is too high, the material will stick to the drum surface and various designs will be required to scrape the surface.

The retention and average residence time are controlled by the drum length, with some systems requiring longer retention time for formation of the grain. The common retention time is 1 to 2 minutes. In manufacture plants, recycle rates of the drum granulation process are often between 2:1 and 5:1 and grinding and blending operations may be required for reprocessing. Also, changes in the amount of material in reprocessing affect both the moisture content and the size distribution in the drum [16].

Although drum granulators commonly have a horizontal inclination of 2-3°, this inclination can reach up to 10° in various applications. Diameter ratios generally vary between 2-3 m and drum rotations vary between 10-20 rpm. It is recommended to use half of the critical speed to achieve a lower granule size range in the dry material. Suitable liquid binder and agglomeration equipment according to the material to be used are shown in Table 2.4 [1].

Valiulis et al. Conducted a dynamic simulation for the control of DAP fertilizer granulation. made statistical interpretation using basic principles such as growth, mass, heat transfer [19].

Zhang et al. Conducted studies on the size distribution and control of the reworked granules in the fertilizer granulation process. In the simulations, the relation of the rework size distribution with the other variables in the process was revealed [20].

Table 2.4 Suitable liquid binder and agglomeration equipment according to the material to be used [25]

Material	**Binder**	**Agglomeration Equipment**
Activated Charcoal	Lignosulfonate	Turbulator
Alumina	Water	Turbulator/Disc
Animal Feed	Molasses	Ring Extruder
Boric Acid	Water	Disc Pelletizer
Carbon Black & Iron Powder	Alcohol-Carbowax	Turbulator
Carbon, Synthetic Graphite	Sodium Silicate	Turbulator / Disc
Cement, Raw Mix	Water	Disc Pelletizer
Cement Kiln Dust	Water	Turbulator / Disc
Charcoal	Starch Gel	Briquetter

Chrome Carbide	Alcohol	Disc Pelleziter
Clay, Attapugite	Water	Turbulator / Disc
Clay, Bentonite	Water	Turbulator
Coal, Anthracite	Pitch	Briquetter
Coal, Bituminous	Lignosulfonate	Disc Pelletizer
Coal Dust	Water	Turbulator
Coke, Petroleum	Pitch	Briquetter
Continuous Casting Flux	Water	Turbulator / Disc
Copper Smelter Dust	Sodium Silicate	Turbulator
Copper Sulphite Concentrate	Sodium Silicate	Disc Pelleziter
Detergent Dust	Water	Disc Pelleziter
Dolomite Kiln Dust	Water	Turbulator / Disc
Dye Pigment	Lignosulfonate	Turbulator / Disc
Electric Furnace Dust	Water	Turbulator / Disc
Fertilizer	Ammonia	Drum
Flourspar	Sodium Silicate	Disc Pelleziter
Flourspar	Lime-Molasses	Briquetter
Flyash (boiler)	Water	Turbulator / Disc
Flyash (high carbon)	Lignosulfonate	Briquetter

Glass Batch	Caustic Soda	Disc Pelleziter
Glass Batch	Water	Briquetter
Herbicide	Lignosulfonate – Water	Turbulator / Disc
Herbicide	Clay – Carbowax	Briquetter
Iron Ore	Bentonite – Water	Drum
Lignite	Gilsonite – Water	Turbulator / Disc
Limestone	Clay – Water	Turbulator
Manganese Ore	Lime – Molasses	Briquetter
Manganese Oxide	Sulfuric Acid	Turbulator / Disc
Phosphate Rock	Phosphoric Acid	Turbulator / Disc
Plastic Powder	Alcohol	Disc Pelleziter
Potash Fines	Water	Disc Pelleziter
Sodium Borate	Sulfuric Acid	Turbulator / Disc
Sulfur Powder	Clay	Compactor
Tungsten Carbide	Alcohol	Disc Pelleziter
Zeolite	Clay – Water	Turbulator / Disc

Table 2.5 Performance data [26]

Application	Diameter (cm)	Length (cm)	Installed Power (kW)	Rotational Speed (rpm)	Approximate Capacity (t/h)
Fertilizer granulation	152 244	305 488	11 55	10-17 8-14	7.5 40

Particle size enlargement in drum granulator; The general mechanism of particle growth is an important factor in determining growth rate and granule properties. According to Walker, the following factors are the main applications accepted in the granulation systems.

1. Nucleation formed by a random association of elementary particles

2. A transition region dependent on either

(a) coalescence in preferential mode

(b) crushing and layering

3. A ball growth region

Of these mechanisms, 1 and 2 (a) and 3 should be applied in cases where granule sizes are more widely distributed and granule sizes are desired to be independent of each other, and 1 2 (b) and 3 should be applied in cases where granular size distribution is narrower and dimensions are required to be standard.

Figure 2.10 shows the various granule formation mechanisms. Nucleation occurs when non-particulate materials combine to form new particles. Non-particulate materials cover the surface of the particles is called layering. The formation of a layer of small particles around the granules is referred to in the literature as

"Iayering" or "snow-balling", or "onion-Iayering" and there are type of the coalescence [15]. Layering is a mechanism that ensures the continuous growth of granules formed by the incorporation of moist particles. This does not affect the number of granules but causes an increase in the granule mass. In all environments where the feed is carried out in normal amounts, layeing and core formation occur together [17] .Another meaning of growth is crystallization. Coalescence is when two particles join together to form a single granule, which can be called agglomeration. Other growth mechanisms that occur during the formation of weak granules are crushing and layering and abrasion transfer.

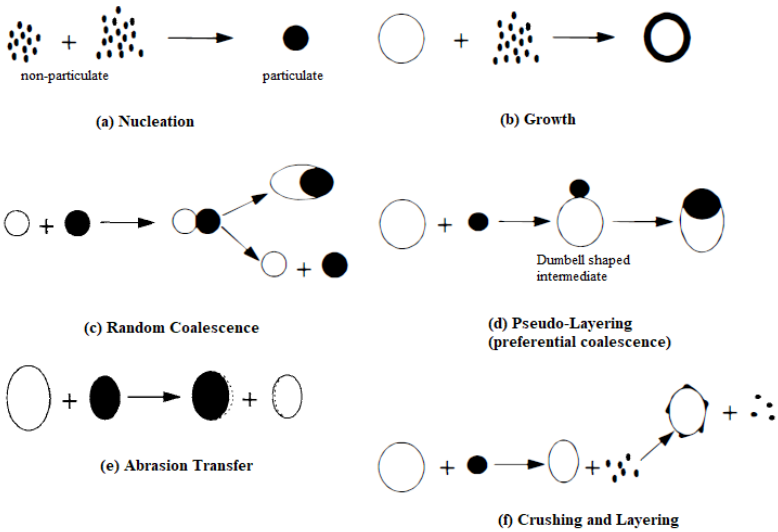


Figure 2.10 The various granule formation mechanisms

Effect of moisture on drum granulator: The basic way to achieve a successful granulation process is the correct relationship between solid and liquid material and this situation depends on the granulator type, formulation and temperature. The moisture content can generally be expressed as a percentage of the water volume of the granule and, in practice, the volume ratio of liquid to solid is preferred. The situation of solid and liquid materials in the drum showing tendency to granulate or agglomeration is an issue studied by researchers. One of these is the natural surface tension of the liquid which holds the moistened solid particles together. The second is that the particles come into contact with the liquid by mechanical force while in the drum. These forces must occur together and at the same time.

This surface tension results in the aggregation of particles in the drum granulator with increased moisture content, giving the granules plasticity and can be deformed without decomposition by applied mechanical force. The moist particles in the drum granulator grow in contact with each other by the rolling motion. The surface tension contributes to this, but the continuation of the rotational movement will result in greater granule sizes [15].

Verkoeijen et al. have shown that granules with a moisture content of 0.20 - 0.25 will have maximum strength [18].

Effect of size distribution: Feeding method and properties of input particles is a factor affecting granulator equipment. Most of the granulation studies have been made by using the size distributions of these basic particles which form the granule and feed into the granulation process. Several studies investigated by Walker indicate that the rate of granulation formation increases in direct proportion to the growth of the basic particle size, but the strength of the final product (granule) decreases.

However, in the drum granulator, the granulation process is carried out by feeding non-deformable particles having a large size distribution. As this size distribution expands, it begins to coincide with the size distribution of the granules obtained [15].

Effect of Rotational Speed on Drum Granulator: In drum granulator designs, many parameters such as drum length, drum diameter, inclination angle, drum speed are important in determining the degree of agglomeration and the physical properties of the granule to be obtained and some of these parameters affect the total time (also called retention time) spent by the input materials in the drum. Among these parameters, the drum speed is the most varied. In the drum granulator, at a low drum speed (a), the particles slide on the surface of the drum and slowly begin to mix at the bottom of the drum. As the drum speed is increased (b), the particles start to roll, and when the critical speed is reached (c), granules are formed by the agglomeration process in layers. All these processes are shown schematically in figure 2.11.

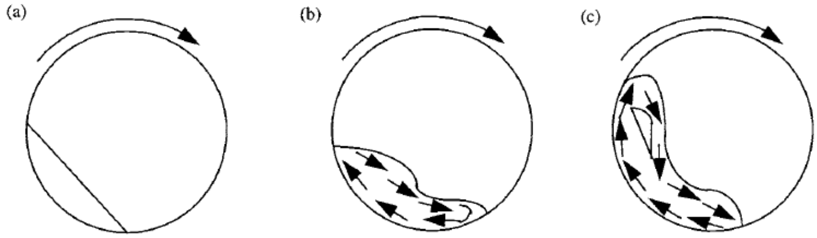


Figure 2.11 Motion of particles at various rotational speeds.

The critical speed (critical drum speed) is the speed at which the incoming material rotates with the drum by the centrifugal force. Agglomeration cannot take place at this rate. The optimum drum speed should be half the critical drum speed. The critical speed also corresponds to the speed at which the Froude number is equal to unity, where the Froude number is the dimensionless ratio of the inertial to gravitational forces:

$$Fr = n^2 D/g \qquad (1)$$

When the Fr = 1, the optimum rotational speed then equals

$$n_{Fr} = 42.4\, D^{-0,5} \qquad (2)$$

where

n = rotational speed (rpm); and

D = drum diameter (m).

In the drum granulator, the material coming into the granulator (including reworked material) is fed to the inlet of the drum. At the inlet of the drum, due to natural segregation, the powdered particles condense at the bottom of the drum. larger particles condense on the surface of the drum [15].

2.3.2. Mixer Granulator

In Mixer granulators, particles and liquid binders are set in motion by agitator such as propellers and granules are obtained with this agitating process. Mixer granulator can obtain less than 2 mm high-density granules. Also, mixer granulators are less sensitive to production conditions than tumbler granulators.

But, power and maintenence costs are higher than tumbler granualtors. Except for high density continuous granulation systems, mixer granulators are not suitable equipment for high production capacity in large granule sizes. The granules obtained in mixer granulators may not be round in shape. However, mixing density is higher than drum type granulators. In mixer granulators, the size and density of the granules are influenced by the process of wetting the particles and the density of the resulting mixture. Since the mixer granulator system performs a larger compression and mixing process compared to drum granulators, less moistening process is sufficient for granule production.

There are two mixer granulator equipments are commonly used in industry; Low-speed mixers and High-speed mixers.

Low Speed Mixers; Low speed mixers have a horizontal drum. A shaft passes through the center of this drum and a plurality of mixing elements are mounted on the shaft. With these mixing elements, the particles are mixed in the middle section. pug mill and paddle mills are the most known equipment in low-speed mixers. The properties of a pug mill in fertilizer granulation are given in table 2.6.

Table 2.6 The properties of a pug mill in fertilizer granulation

Model	**Material bulk density (kg/m^3)**	**Approx. capacity, (t/h)**	**Size (width x length), (m)**	**Plate thickness, (mm)**	**Shaft dimeter, (mm)**	**Speed (rpm)**	**Drive (kW)**
A	400	8	0.6 x 2.4	6.35	76	56	11
A	800	15	0.6 x 2.4	6.35	76	56	15
A	1200	22	0.6 x 2.4	6.35	76	56	18
A	1600	30	0.6 x 2.4	6.35	76	56	22

B	400	30	1.2 x 2.4	9.5	102	56	22
B	800	60	1.2 x 2.4	9.5	102	56	37
B	1200	90	1.2 x 2.4	9.5	102	56	55
B	1600	120	1.2 x 2.4	9.5	127	56	75
C	400	30	1.2 x 3.6	9.5	127	56	37
C	800	60	1.2 x 3.6	9.5	127	56	75
C	1200	90	1.2 x 3.6	9.5	152	56	110
C	1600	120	1.2 x 3.6	9.5	152	56	147
C	2000	180	1.2 x 3.6	9.5	178	56	200

Batch planetary mixers; Batch planetary mixers require 10-20 kW power to achieve a production volume of 100-200 kg and are widely used in the pharmaceutical industry.

High-Speed Mixers; In these mixers, a shaft passes through the center. these shafts have mixing parts and rotate at a speed of about 200-3500 rpm. Granules of 0.5-1.5 mm dimensions are obtained from these high speed rotating mixers. These high speed rotating mixers can be designed horizontally or vertically and the average granule production time is only a few seconds. This type of granulators are widely used in the chemical sector, especially in the pahermaceutical sectors.

The schematic diagram of horizontal (a) and vertical (b) high shear mixer granulators are shown in figure 2.12 [2].

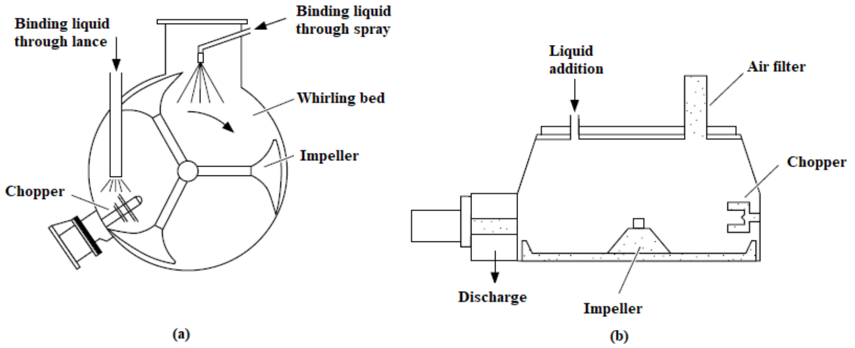


Figure 2.12 The schematic diagram of horizontal (a) and vertical (b) high shear mixer granulators

Litster et al. observed the efficiency of liquid dispersion upon core formation in mixer granulators. In the studies, nucleation-based experiments were performed and it was shown that the dimensionless sprey flux Ψ_a should be less than 0.1 in drop controlled nucleation [21].

2.3.3. Fluidized-Bed and Related Granulators

According to Schaafsma, the fluidised bed granulation has different processes such as wetting, drying and grinding is carrying out in the same bed, so control of the fluidised bed granulation technique is difficult. In order to control the formation of granules, it is necessary to understand the mechanism and their interactions with each other.

According to Aulton And Banks, there are three main factors affect the granulaiton process; equipment related factors, process related factors and product or formulation related factors [4].

In fludized granulators, powders are activated by air and high porosity and high strength layered granules produced by this method. Fluidized granulators are commonly used in fertilizer production plants, industrial and agricultural chemical production plants and pharmaceutical industry. Advantages of fluidized-bed granulators are high volume density, concurrently granulation and drying processes, the good mixing and heat transfer properties of fludiezed beds. Also fluidized granulators are achieved the same product quality during the process so, It is often used where the standardized granule quality is important, such as in the pharmaceutical industry.

Disadvantages of fluidized-bed granulators are high operating expense with related to air handling and dust holding and also, reprocessing because of the uncontrolled size enlargement [2].

2.3.4. Centrifugal Granulators

In centrifugal granulators, particles are set in motion by a horizontal high-speed rotating disc. This type of granulators are mostly used in pharmaceutical industry. Bed diameters can be a range of 178 to 1170 mm to get a range of 3-5 kg to 400-575 kg throughout. Such granulators produce denser and more round granules. The operating cost of CF granulators, whose initial investment cost is higher than other granulators, is acceptable. CF granulators generally have rotor speeds between 45-360 rpm and production capacities between 3-80 kg. The schematic diargram of CF granulators are shown in figure 2.13 [2].

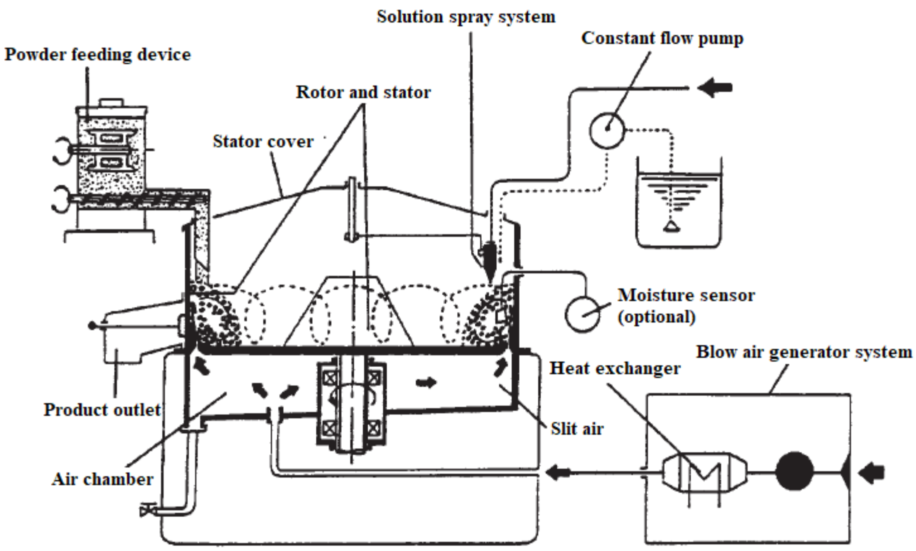


Figure 2.13 The schematic diagram of CF granulators [27]

3. MATERIAL AND METHOD

3.1. Material

Autodesk Inventor software was used in the design and 3D modeling process of the granulator and ANSYS software was used in the analysis process.

3.1.1. Design Process Materials

Autodesk is one of the world's leading software providers for 3D design, construction, planning and entertainment. Autodesk Inventor is one of the most widely used CAD applications for designing, visualizing and simulating products at the start of the manufacturing process.

The models created with Autodesk Inventor are 3D numerical models. In this way, in the digital environment, the form, suitability and function of the design can be tested, the need for physical prototypes can be minimized and costly engineering changes can be reduced. Inventor includes special tools for the production of precise and accurate manufacturing images directly derived from the 3D model.

3.1.2. Analysis Process Materials

ANSYS; It is an engineering program in which analysis and simulations can be performed in computer aided engineering studies. It enables effective studies in different disciplines such as mechanics, structural analysis, computational fluid dynamics and heat transfer.

The ANSYS program, which is one of the most widely used CAE (computer aided engineering) programs in our country as in the whole world, uses the finite element method. The finite element method is used to analyze the objects of complex geometry, which are very difficult to analyze in one piece, by dividing them into small and multiple pieces. The results obtained from the analysis of a finite number of elements are combined to produce a single and consistent analysis result.

Developed for nearly 45 years, this program is one of the most preferred programs today. The program has different components produced for different engineering studies. Analysis of objects in complex structures can be done with ANSYS. This program, which uses the finite element method, simulates the real-world behavior of components and subsystems, resulting in realistic results.

With ANSYS software, linear and nonlinear torsion analysis can be performed as well as static analysis on parts and assemblies. The program gives effective results even at very low tolerances in mechanical simulations. Shape changes and stress distributions resulting from the force applied to the object can be displayed instantly at the end of the simulations.

During the analysis process, strengths were observed by finite element analysis (FEA) performed in the chassis and drum sections.

Finite Element Analysis (FEA) is a simulation of any physical phenomenon using a numerical technique called Finite Element Method (FEM). Engineers use this method to reduce the number of physical prototypes and experiments and to optimize components at the design stage to develop better products.

It is necessary to use mathematics to comprehensively and quantify any physical phenomena such as structure or fluid behavior, thermal convection, wave propagation, growth of biological cells, etc. Most of these operations are explained using Partial Differential Equations (PDEs). However, in the last few years, numerical techniques have been developed for a computer to solve these equations, and one of the leading ones today is Finite Element Analysis.

Differential equations can define not only natural processes but also physical phenomena encountered in engineering mechanics. These partial differential equations are complex equations that must be solved in order to calculate the relevant quantities in a structure and to estimate the specific behavior of the component under a given load. It is important to know that FEA only gives an approximate solution of the problem and that it is a numerical approach to obtain the true result of these partial differential equations. In its simplest form, FEA is a numerical method used to predict how a part or assembly behaves under certain conditions. It is used as a basis for modern simulation software and helps engineers find weak points in their design. The results of a simulation based on the FEA method are generally depicted with a color scale as shown in the figure.

In order to perform a finite element analysis with ANSYS software, the following processes are generally followed.

The solid model prepared with the 3D design program is imported into the analysis program.In the next step, the material is defined for the imported geometry with the material library. Then the mates of the geometry are entered in the analysis software.

After the contact section is completed, the external factors and the necessary constraints are added to the geometry in the setup section. External factors can be defined as acceleration, force, temperature, etc. in general.

After the setup process, the mesh is generated. As the mesh size becomes thinner, the solution will be more accurate. However, smaller mesh means more CPU and more RAM. Therefore, the optimum mesh size should be chosen according to the requirement of the designed geometry.

After the mesh is generated, the solution process is started. After the solution process is completed, the desired data is called to the program interface.

3.1.3. Production Process Materials

The following machines & equipments are used in drum granulator production.

Lathe: Turning to chip removal by giving a movement in the direction of the cutting tool to the part, the machines that perform these operations are also called lathe machines. In the lathe, generally cylindrical and conical surfaces are machined in outer inner parts with axial movement. In addition, screwing, drilling in various profiles, drilling holes, guiding, as well as grinding, milling, profile turning, spring winding, iron, steel, wood, plastic alloys and soft tools can be applied to the desired shape and shape operations. Parallel to the development of the industry, today's technology from the first primitive lathes has developed hydraulic controlled and numerically controlled (CNC) machine tools.

Figure 3.1 A Lathe

CNC Machining Center: CNC Machining Centers are machines designed for machining various workpieces. In these lathes, such as cnc milling machine chip removal is performed. However, in addition to milling, these machines also perform drilling, tapping, threading, etc. That is, any work on the workpiece connected to such CNC machines can be performed in a single bond.

With the help of machining center, prismatic workpieces can be machined simultaneously on 3 or 4 surfaces in one connection. The cutters to be used are placed in the magazine section of the machine and used in the necessary operations in the program. Magazines have a cutter capacity of 10, 30, 60, 80 or more. Robotic arms and equipments are used in the connection and unwinding of work pieces to the machine. This eliminates time losses in the operations.

Figure 3.2 CNC machining center

Cylindrical Grinder: If the sawdust is too much to be removed from the workpiece, it can be connected to the lathe in the first step to remove the chip by an insensitive process. This not only improves the process (cylindrical grinding), also saves time.

Grinding can be performed not only on cylindrical parts but also on rollers, hollow steel and other similar industrial parts. It is used to make the surface of the workpiece more usable. It is a process that ensures high surface quality of the cylindrical part.

Figure 3.3 Cylindrical grinder

Cylindrical Bending: Cylinder sheet bending machines are machines in which ring shape is formed by bending the thick iron they take in between by turning at least two cylinders made of big and thick metal by turning them side by side. It is seen that the power consumed by these machines during this process is provided by consuming a high level of electricity and large dynamo and motors are used to provide this power.

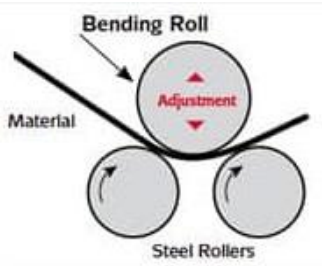


Figure 3.4 A schematic design of cylindrical bending

Figure 3.5 Cylindrical bending

Press Brake: Bending machines stand out in the shaping of various metal sheets which cannot be shaped by manpower. The processes that provide the needs of the sheet materials by means of millimetric calculations are called press brake. The machines in which these processes are performed are functional mechanisms with different tonnages and different models. The parts in this mechanism are upper mold, lower mold, numerical control unit and hydraulic axes. Upper mold is called as male mold and lower mold is called as female mold. The male mold presses the female mold and bends the sheet to provide the desired shapes. Female molds and male molds have V shape.

Figure 3.6 A press brake

Laser Cutting Machine: On a CNC laser cutter, the laser cutting head can easily cut by moving on the desired metal part to be cut. A capacitive height control system maintains the distance between the dividing end and the cut plate. This distance is important for the quality of the cut, because if the focal point is not well adjusted, the yield cannot be obtained. There are many parameters that also affect the cutting quality, but when all these parameters are checked correctly, the laser cutting process is quality, reliable and flawless.

Figure 3.7 Laser cutting machine

Gas Metal Arc Welding Machine: Gas metal arc welding is a welding process in which the heat required for welding is generated by the arc formed between an exhausted electrode and the workpiece. The solid wire electrode, which is continuously driven to the welding zone, melts and forms the welding metal as it is consumed. The electrode, welding bath, arc, and workpiece proximate areas are protected by gas or mixed gases from the welding torch from the harmful effects of the atmosphere. The gas must be able to fully protect the welding zone, otherwise a very small air intake will cause a defect in the weld metal.

Figure 3.8 Gas metal arc welding machine

3.1.4. Testing and Development Process Materials

The trial and development process materials are listed below.

Proportional Control Valve: Proportional Control Valve enables the transportation and control of the fluids that are produced by consuming energy and carrying the thermal energy in accordance with their purposes without any loss in order to meet the needs of the system.

The automatic control valve is generally the last control equipment that stops, adjusts or supplies the fluid in a piping system at any time and in such a way as to perform the control-safety functions. Control Valve is able to control pressure, temperature and flow rate in all processes where fluid is present. Water, hot water, oil, hot oil, steam, hot steam, nitrogen, acid and gas can be used in the control of all fluids such as liquid phase. It can also control high viscosity liquids and particulate fluids. A control valve is a valve that allows the flow of fluid to be adjusted, to reduce the pressure of the fluid or to change the direction of the fluid.

Proportional control valve is divided into two main groups as pneumatic (air supplied) and motorized (Volt fed) according to the supply signal. When needed, the control valve can be modulated with hand control, solenoid valve and limit switch.

Figure 3.9 A Proportional Control Valve

Electromagnetic Flowmeter: Electromagnetic flowmeters work according to Faraday's Induction Law. An electrically conductive fluid passes through the magnetic field in an electrically isolated pipe. A pair of coils is used to generate a magnetic field and electric current is passed through these coils. An electric field is formed between the electrodes in direct proportion to the flow rate of the liquid.

Electromagnetic flowmeters are generally used in water, wastewater and similar industries with electrical conductivity.

The most important advantage of this instrument is that there are no moving parts in electromagnetic flowmeters and it requires minimum maintenance.

Figure 3.10 A magnetic flow meter

Load Cells: A load cell is a transducer used to convert a force into an electrical signal. This transformation is indirect and occurs in two stages. With a mechanical arrangement, the perceived force changes the shape of a strain gauge. The strain gauge measures the deformation as an electrical signal. Because the strain changes the effective electrical resistance of the wire.

The load cells, based on weight indicators, briefly resemble electronic scales. Steel and aluminum are used as spring elements. 4 strain gauges are used in load cells. These strain gauges are formed in the form of Wheatstone bridge. When a voltage is applied to the bridge, the output voltage is proportional to the applied load. With this small tension, the weight of the applied pressure is measured. The load cells have 4 inputs, 2 inputs and 2 outputs. In some load cells, the total number of leads can be 6.

Figure 3.11 A load cell

Nozzles: Nozzle means the outlet end. It is used to control the direction of any fluid. It is used to change fluid inlet and outlet pressure. Change the speed of the fluid passing through it. Both ends of the nozzle are open. As the inlet part is wide and the outlet part is narrow, the velocity of the fluid increases In micro-lubrications, it is the outlet part that helps spray, atomize and separate the particles. Also called output nozzle

Figure 3.12 A nozzle

3.2. Method

The method section is briefly explained as granulator design, production methods, bearing calculations, strength analysis, gearbox selection and irrigation system design. Also, the experiments made after machine manufacturing are explained under this title. As a result of the experiments, the improvements made in the machine are explained as the last.

Under the topic of granulator design, there are drum design, chassis design, design of inlet and outlet sections, bearing designs.

Under the title of finite element analysis, there are chassis strength analysis, drum strength analysis and resistance analysis of the drum against torsion.

In the machine test section, the granules obtained and the problems that arise are mentioned.

In the Improvements section, solutions to the problems that arise in machine tests were found.

3.2.1. Design of the Drum Granulator

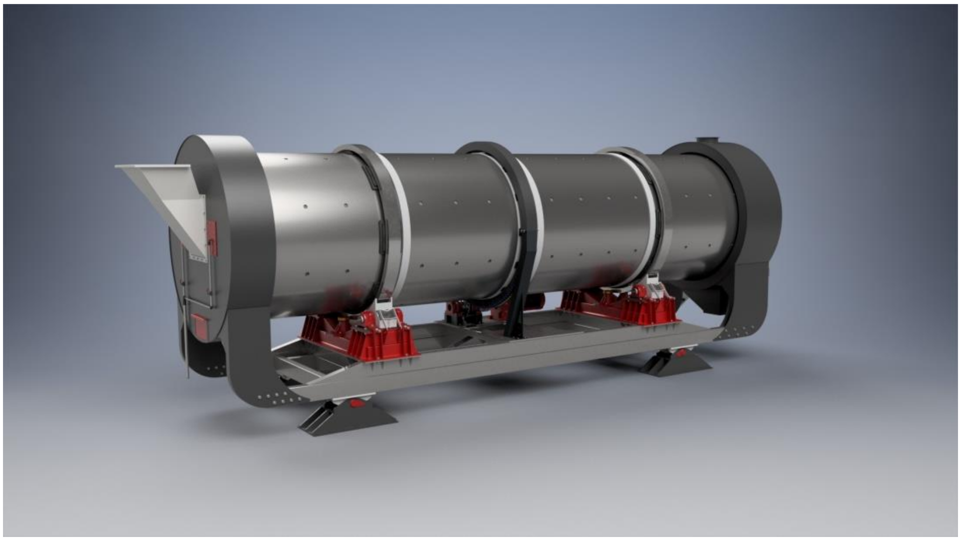


Figure 3.13 Design of drum granulator

Granulators are essential and important machines for compost management. Designing the most appropriate granulator according to the amount of material to be processed is also very important in terms of cost. The right diameter and the right length of the drum production is required.

Furthermore, the drum speed at which the machine will operate while stable is also very important. While calculating the required speed, the torque values required for continuous rotation of the drum should not be ignored.

In view of the reasons listed above, it is necessary to first examine the characteristics of competing machines when starting machine design.

Then, it is necessary to investigate the most needed machine capacity in the market.

Necessary researches have been made. Then desired features of the machine to be started are listed.

1. The machine to be designed must have a composting capacity of 10 tons/hour.
2. Drum diameter should be two meters.
3. Drum length should be eight meters.
4. The drum speed should be around 11 rpm.

The above four topics are our main design parameters.

ST37 steel is generally used in drum granulator design.

ST37 steels: Structural steels can be combined and used with manufacturing methods such as welded manufacturing, machining, plastic forming. Structural steels are the most widely produced and used steel methods worldwide. There are many application areas. All of the steel structure applications consist of this type of steel and the development levels of the countries are shaped according to the production and consumption amounts of structural steels. Structural steels, vehicles, machinery, bridges, highways, tunnels, tall buildings (skyscrapers), towers, etc. used in places.

Table 3.1 Chemical composition (% by weight)

Alloy Steel	ST37
C	0.217
Si	0.001
Mn	0.426
P	0.026
S	0.022
Mg	0.0001
Cr	0.064
Ni	0.001
Mo	0.001
Cu	0.001
Al	0.017
V	0.001
W	0.003
Fe	99.2199

The fact that ST37 structural steel is cheap and easily accessible and its mechanical properties are sufficient is a valid reason for its use in chassis manufacturing.

Tensile strength of ST37: 360 MPa

Yield strength of ST37: 240 MPa

Drum Design: As the granulator drum will be large, it is impossible to design a rotating drum between two bearings, as is often the case with common machines.

When the drum diameter, length and weight are taken into consideration, it is considered appropriate to rotate the drum on the wheels. Therefore, rolling surfaces should be added to the appropriate places on the drum.

Drum production method will be produced by cylindrical bending of sheet metal. As is known, the length of the drum is eight meters and it is very difficult to make an eight meter long cylindrical bend. Therefore, four sheets of two meters in length are cylindrically bent and welded together.

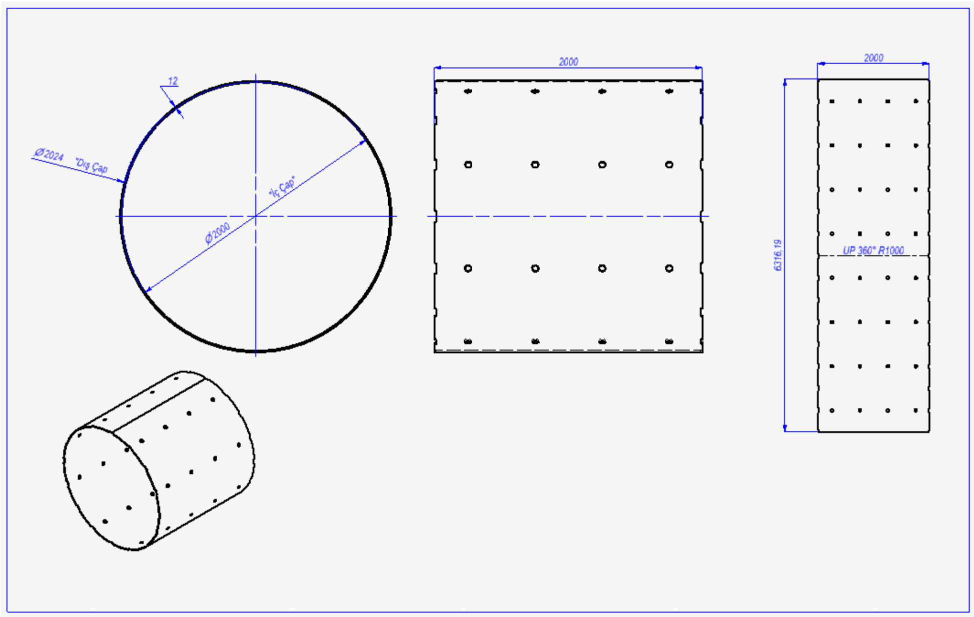


Figure 3.14 Technical drawing of the drum part

The above technical drawing is one of the four sheet metals of the manufactured drum. It is produced by 12mm thick sheet plasma cutting method.

As shown, certain areas of the drum have holes. The role of the holes will be explained in detail in the machine development section.

After four drum parts are welded one after the other, the rolling rings are also welded over the entire drum. Then, a flat rolling surface is formed by cylindrical grinding on these rings.

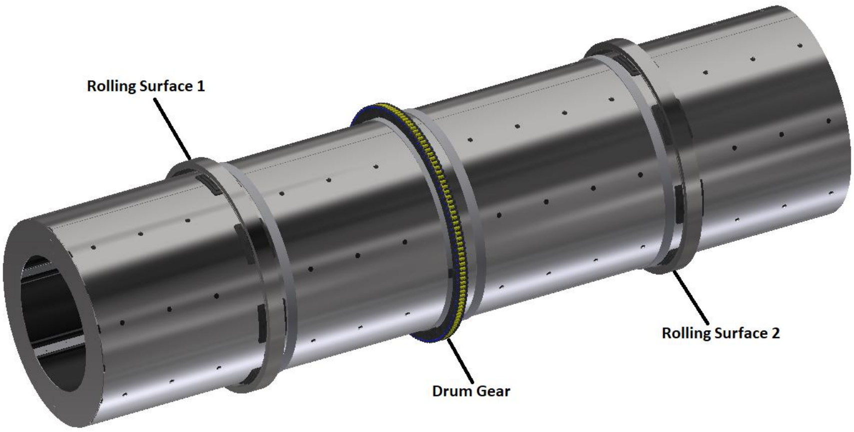


Figure 3.15 Drum assembly of the granulator

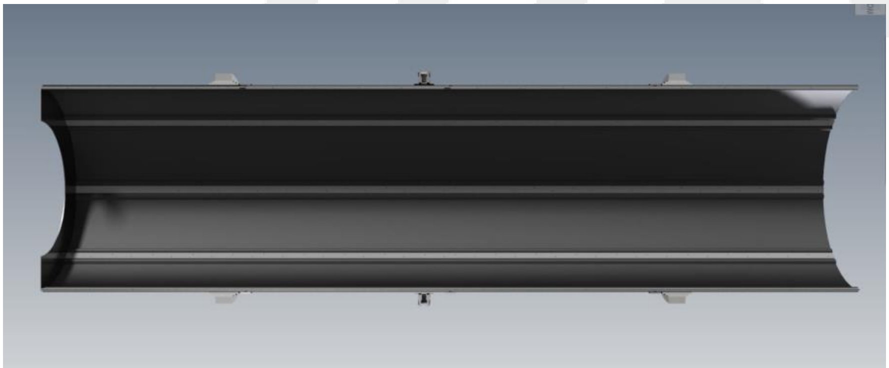


Figure 3.16 Sectional view of the drum layer

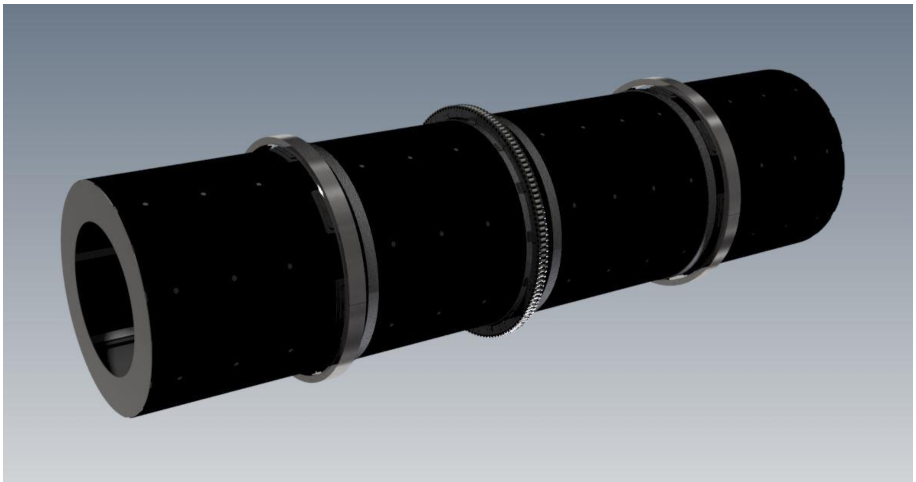


Figure 3.17 Final state of the drum design

Chassis Design: The granulator works in different ways to obtain different granules. One of the different operating modes is the angle between the drum axis and the horizontal axis. For this reason, a frame design has been made which allows the drum to be operated at different angles. In order to make angle changes at any time, four supported pivoting feet are designed.

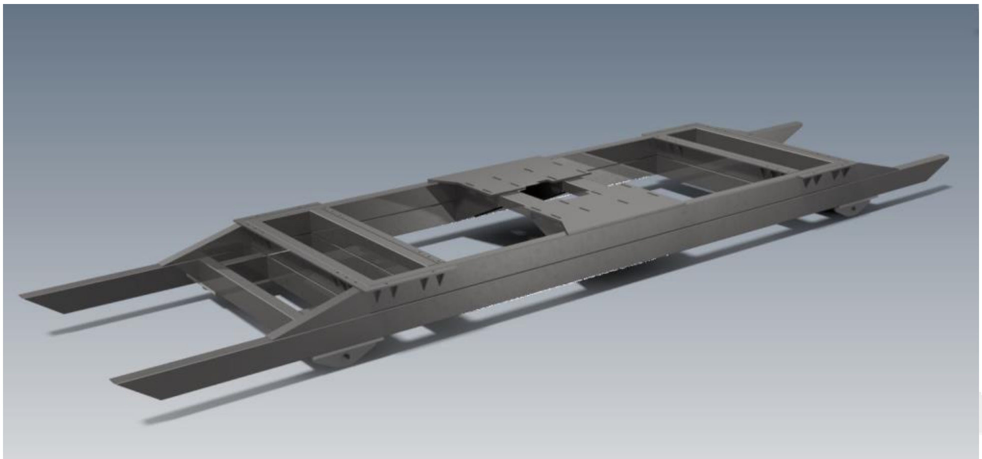


Figure 3.18 Chassis design of the drum granulator

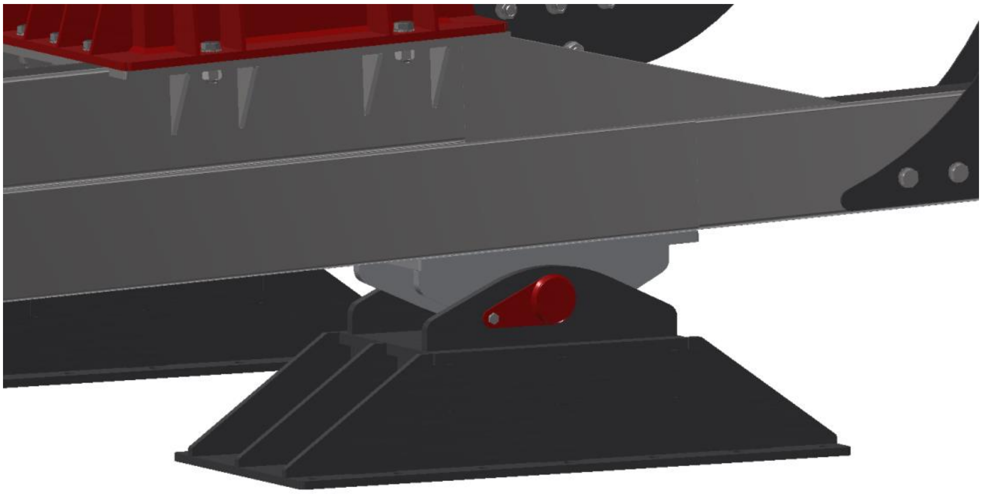


Figure 3.19 Pivoting feets

Two rolling surfaces were formed on the drum. These surfaces are also the surfaces that will carry the drum. Wheels are designed to carry the drum and allow it to rotate at the same time.

Figure 3.20 Drum wheels assembly

Four wheel mounts will carry the drum. Therefore, wheel assemblies must be connected to the chassis in pairs. Wheel frames are designed to connect the wheels separately from the main frame.

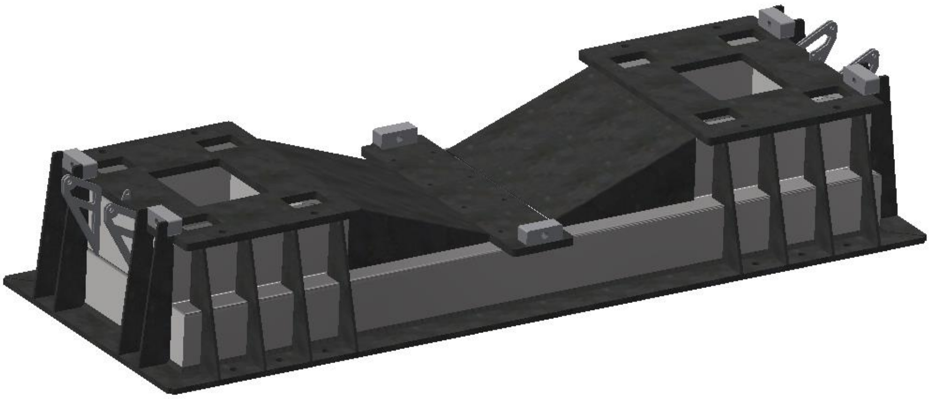


Figure 3.21 Wheel frame

Axial Fixing Wheels: Since the drum will operate at a certain angle (2°- 4°), it will want to move in the axial direction as it rotates. Therefore wheels designed to limit axial movement. Strength calculations of these wheels were also made.

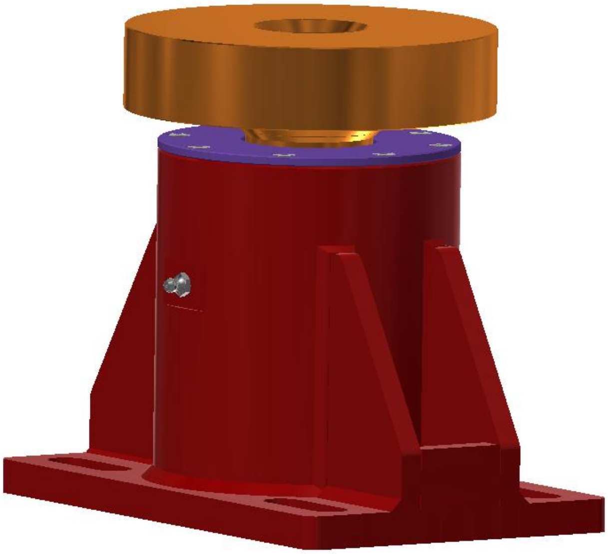


Figure 3.22 Limiting wheels

Calculations of limiting wheels;

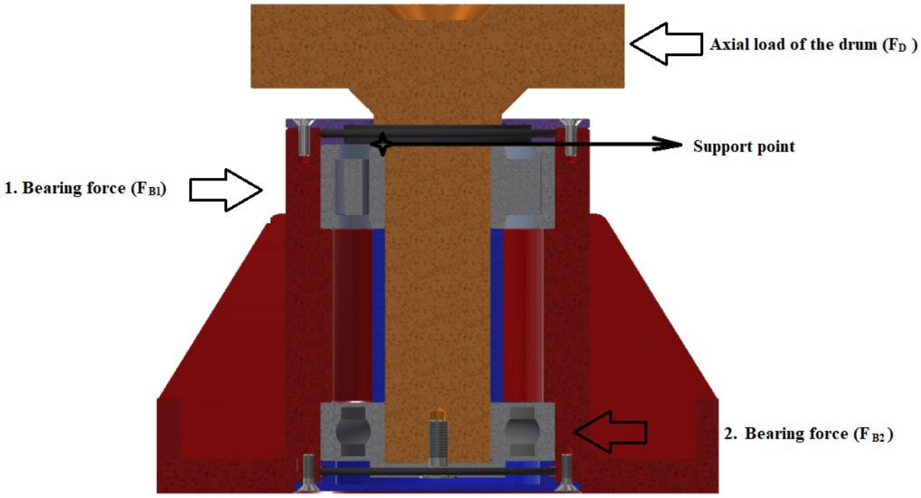


Figure 3.23 Placement of forces applied to bearings

2 degree angle; F_D = 2800 N

2.5 degree angle; F_D = 3500 N

3 degree angle; F_D = 4190 N

3.5 degree angle; F_D = 4900 N

4 degree angle; F_D = 5600 N

F_{B1} max = 154000 N

F_{B2} max = 31500 N

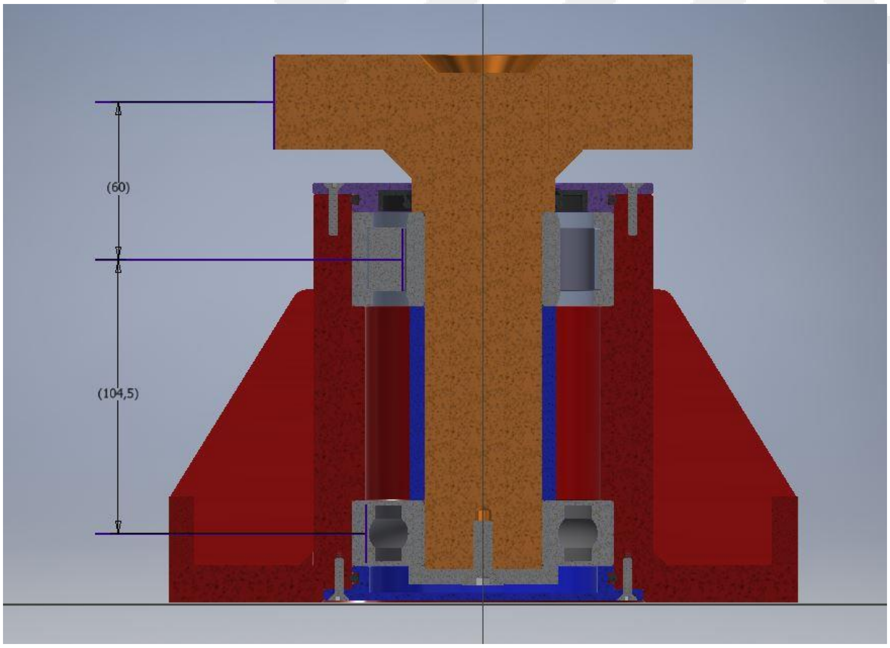


Figure 3.24 Dimensions of bearing arrangement

- NU bearing was chosen because bearing number 1 was accepted as support point.
- For the resistance of bearing loads; $104.5 \times F_{B2} \geq 60 \times F_D$.

$104.5 \times 31500 \geq 60 \times 2800$

$3.291.750 \geq 168.000$ (safe) (2 degree)

$104.5 \times 31500 \geq 60 \times 3500$

$3.291.750 \geq 210.000$ (safe) (2,5 degree)

$104.5 \times 31500 \geq 60 \times 5600$

$3.291.750 \geq 336.000$ (safe) (4 degree)

Shear strength of the shaft;

$\tau xy \geq F / A$ Shaft cross-sectional area = 1590.4 mm^2

$430 \geq 5600 / 1590.4$

$430 \geq 3.52$ (N/mm^2)(MPa)

Safe values are provided for C1050 types of steel.

The axial fixing wheels are mounted on the wheel frame just like the rolling wheels. Also, tensioning bolts have been added to the wheel frame to make the necessary position adjustments.

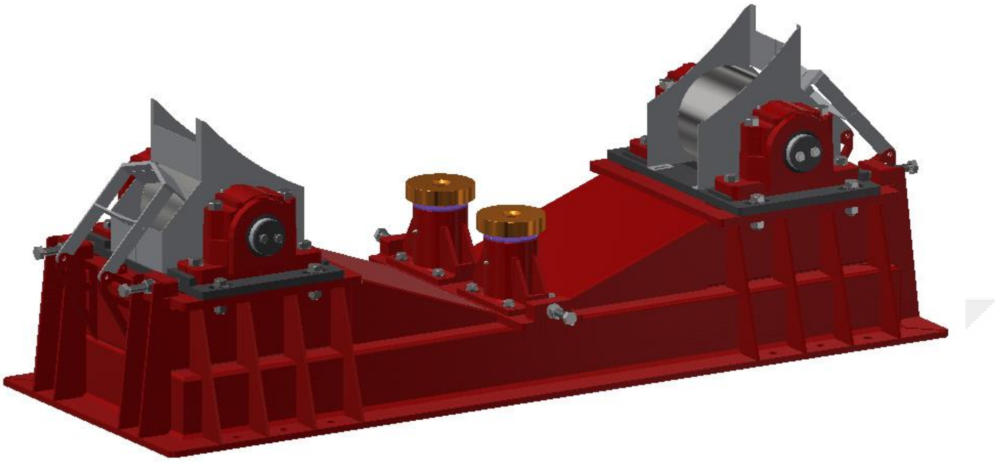


Figure 3.25 Wheel assembly of chassis

Material Inlet & Outlet Section Design: Two different machine parts are designed for the entry and exit of the compost and the necessary chemicals into the granulator.

There is an entrance hole in the entrance area in order to allow the material to enter into the machine by taking advantage of gravity. Since the irrigation system required for the formation of granules will also be installed in the entrance section, there are irrigation holes on both sides.

Same way, there is an exit hole at the bottom of the exit section for the disposal of the material from the machine by taking advantage of gravity. It was also decided that there would be a door in the exit section for manual intervention into the drum. In this way, the design of both machine parts has been completed.

Figure 3.26 Material inlet & outlet section

Gearbox Selection: At the beginning of the design, it was mentioned that the drum should rotate at approximately 11 rpm. In order for the machine to operate at this speed, the cycle rate on the drum and pinion gear must also be calculated.

4-pole asynchronous electric motors are produced to rotate at 1450 rpm.

For rotating the drum speed to 11 rpm, calculation of the total conversion rate on the machine:

$$i_{Total} = \frac{n_{motor}}{n_{drum}} = \frac{1450}{11} = 131.8$$

Also;

$$i_{Total} = i_1 \, x \, i_2 \, x \, i_3 \, x \, ...$$

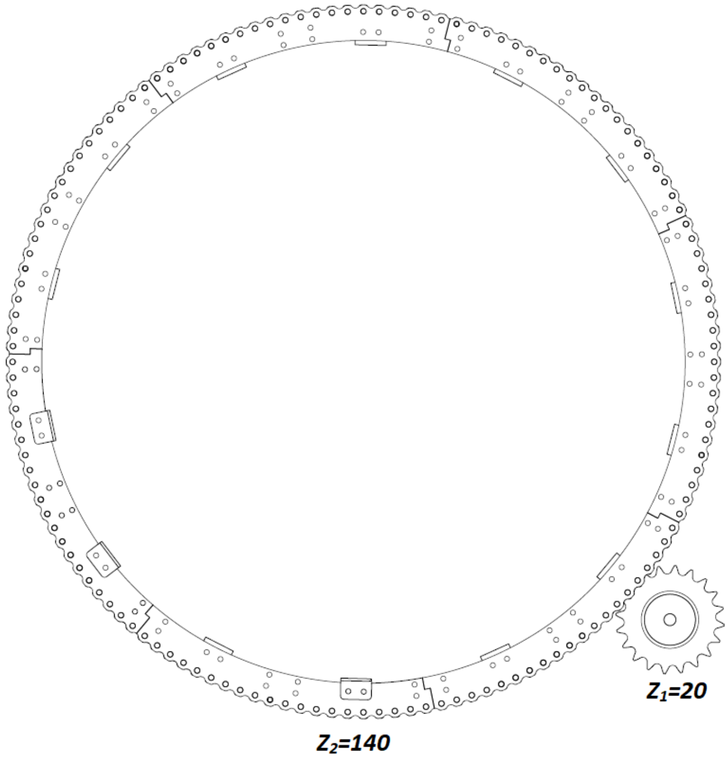


Figure 3.27 The schematic drawing of drum gears

$$i_1 = \frac{Z_2}{Z_1} = \frac{140}{20} = 7$$

Both calculations should be used together,

$131.8 = 7x\ i_{gearbox}$ and $i_{gearbox} = \frac{131,8}{7} = 18.8$

Gearbox cycle ratio calculated.

The datasheet of the selected gearbox is added at the bottom.

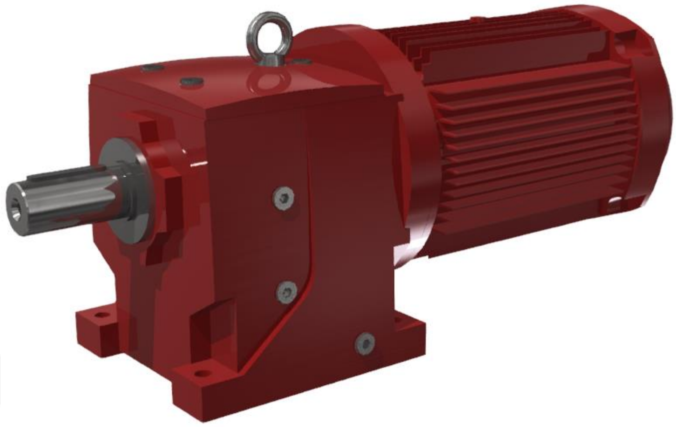


Figure 3.28 Gearbox of the drum granulator

Gearbox code: PA 62 18.16 M 160L/4A 3 M1

Measurement System	Metric	
Input Type	Electric motor connection	
Input Speed	1450	(rpm)
Output Speed	79.9	(rpm)
Exchange Ratio	18.16	
Frequency	50	(Hz)
Input Power	15	(kW)
Service Factor	1.7	
Rated Output Torque	1794	(Nm)

Irrigation System Design: The amount of water to be fed to the granulator is vital for the quality of the granules formed. The way water is added to the machine is also very important. Water should be added in a pulverized manner when it is applied on compost. Therefore, the selection of the nozzle should be made according to the pulverized capabilities. The flow and pressure losses of the nozzles should also be calculated.

Figure 3.29 Nozzles

There are two identical irrigation systems in the machine. Irrigation system; designed to be easily disassembled during maintenance, repair and renovation. 80 nozzles are sufficient to achieve the required water flow rate. However, 50 nozzles (100 in total) were added to each irrigation system to accommodate different material capacities and different material recipes.

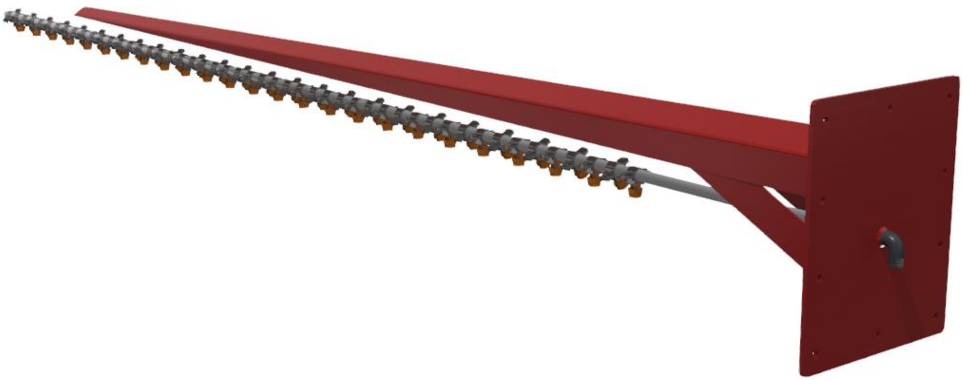


Figure 3.30 Irrigation system

3.2.2. Analysis of the Drum Granulator

3.2.2.1. Static Structural Analysis of Chassis

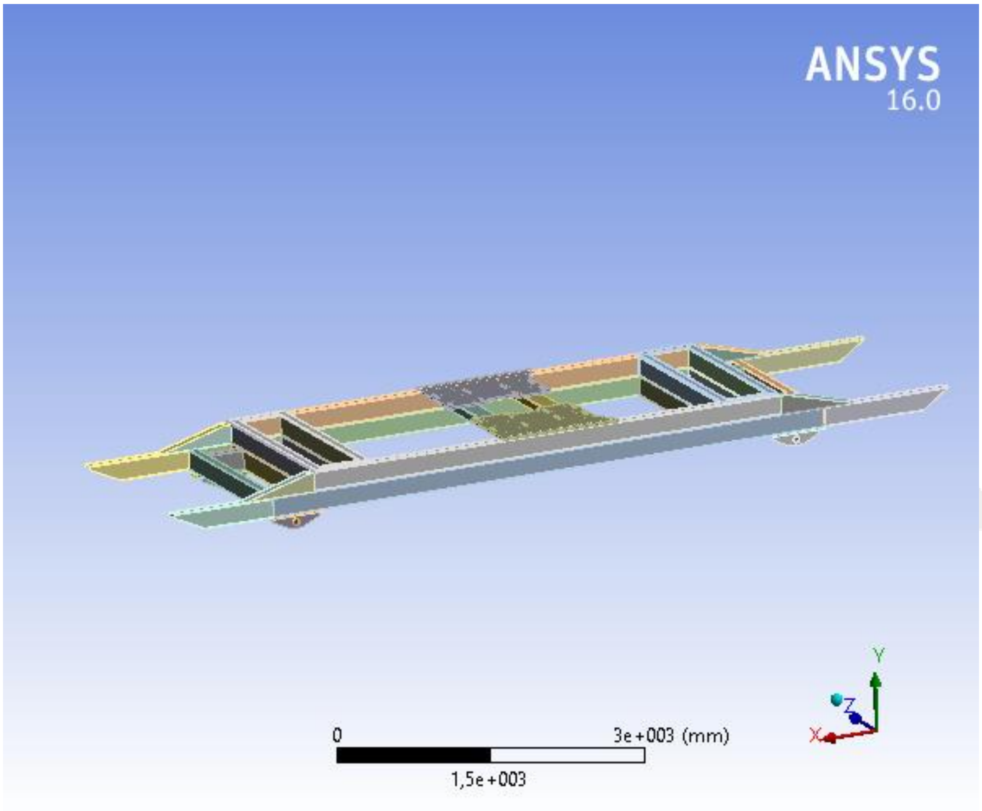


Figure 3.31 Chassis geometry

In order to obtain more universal results from the analysis, the unit selection is made as indicated in the table below.

The same unit systems will be used in two different structural analyzes after this one.

Units;

Table 3.2 Units of the statical analysis of te chassis

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees RPM Celsius
Angle	Degrees
Rotational Velocity	RPM
Temperature	Celsius

In the table below, there are the basic physical properties of the granulator chassis which will be analyzed statically.
Also, the amount of nodes and elements that the program will use to solve the analysis are indicated.

Geometry;

Table 3.3 Physical properties of drum chassis

Length X	8428.3 mm
Length Y	582.35 mm
Length Z	1970 mm
Volume	2.1665e+008 mm^3
Mass	1700.7 kg
Nodes	1003911
Elements	170837

Mesh;

Table 3.4 Mesh properties of the analysis

Physics Preference	Mechanical
Element Size	25.0 mm
Smoothing	High
Minimum Edge Length	0.707110 mm
Inflation Option	Smooth Transition
Nodes	1003911
Elements	170837

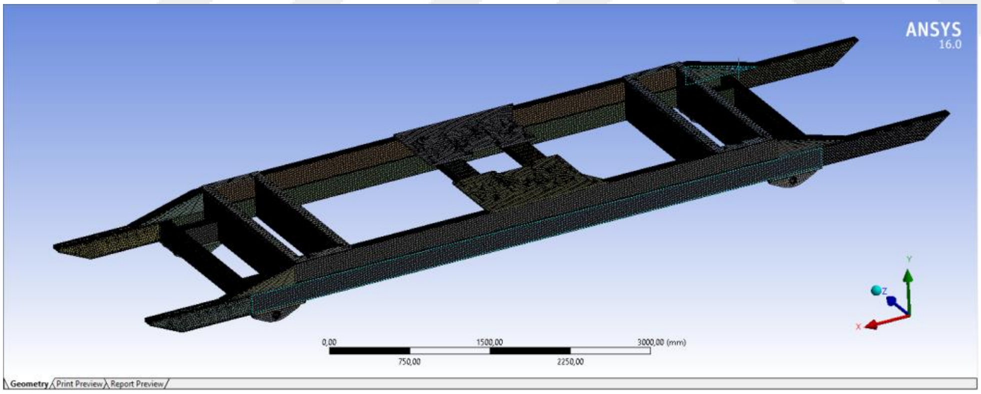


Figure 3.32 Mesh of the chassis

Static Structural; Firstly, it was decided to carry out structural analysis in five steps and each step was decided to be one second.

Since the temperature affected the behavior of the metals, the analysis was carried out at room temperature of 22 degrees Celsius.

Table 3.5 Analysis step timing

Step	Step End Time
1	1 s
2	2 s
3	3 s
4	4 s
5	5 s

Table 3.6 Accelerations

Object Name	Acceleration
State	Fully Defined
Geometry	All Bodies
Define By	Components
Coordinate System	Global Coordinate System
X Component	0 mm/s² (ramped)
Y Component	-9820 mm/s² (ramped)
Z Component	0 mm/s² (ramped)
Suppressed	No

The support point A shown in the image is fixed.

Bearing point shown in the visual B is considered as a moving bearing, adopted free on X axis but fixed on the Y and Z axes.

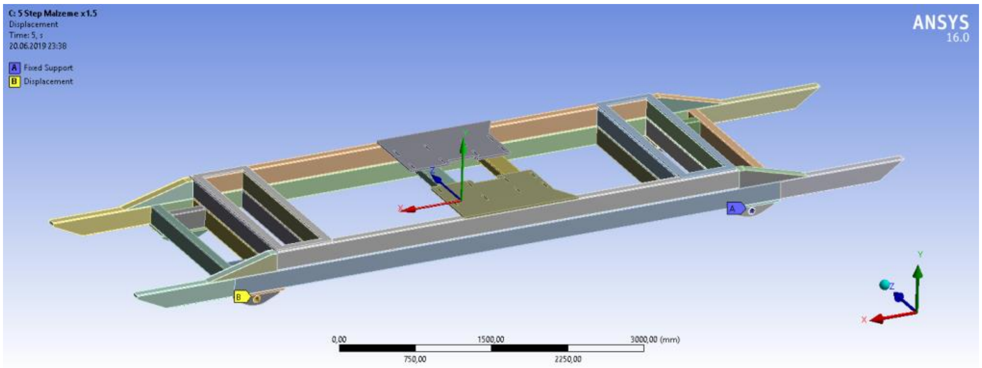


Figure 3.33 Fixing points

Table 3.7 Displacement of point B

Coordinate System	Global Coordinate System	
X Component	Free	Tabular Data
Y Component	0 mm (ramped)	Tabular Data
Z Component	0 mm (ramped)	Tabular Data

Simulation of Force Inputs: Three different forces were applied to the chassis; one is the sum of the weights of the motor, reducer and pinion gear in the drive section.

The other two forces are calculated from the weight of the drum delivered to the chassis via the carrier wheels and the weight of the material contained in the drum.

Machine vibration was also effective in the calculation of force applied to the chassis.

Assuming that the vibration on the machine is not more than 5 m / s², masses on chassis multiplied by 15 instead of the gravity acceleration (9.82 m / s²).

For example; the reason that force number three is 11745 N, weight of the drive group is 783 kg.

$F = m.a$

$F = 783 \times 9.81 + 783 \times 5$

$F = 11796.23$ N

Approximate total acceleration;

$a_{total} = 9.81 + 5 = 14.81 \text{ m/s}^2 \approx 15 \text{ m/s}^2$

$F_3 \approx 783 \times 15 = 11745$ N

The reason that force number one and two are 65250 N; drum weight is 8000 kg and instant total weight of the compost and water in the drum is 700 kg.

M_{total} = 8000 + 700 = 8700 kg

a_{total} = 15 m/s^2

F_{total} = 8700 x 15 =130500 N

Total weight is equally distributed to both sides;

$F_1 = F_2$ = 130500 / 2 = 65250 N

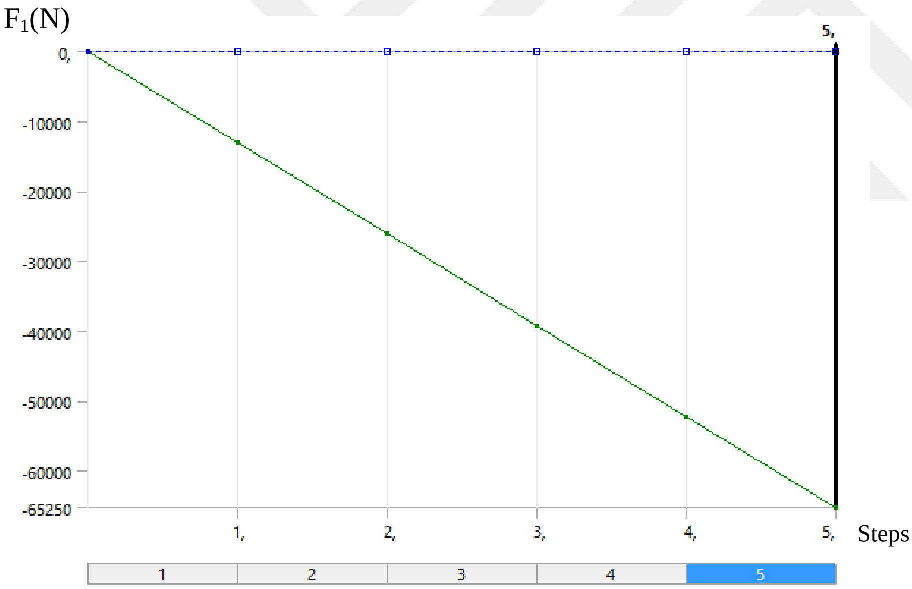


Figure 3.34 Graph of the applied force (F_1) to chassis

Table 3.8 Force (F_1) applied on time basis

Steps	Time [s]	X [N]	Y [N]	Z [N]
0	0	0	0	0
1	1	0	-13050	0
2	2	0	-26100	0
3	3	0	-39150	0
4	4	0	-52200	0
5	5	0	-65250	0

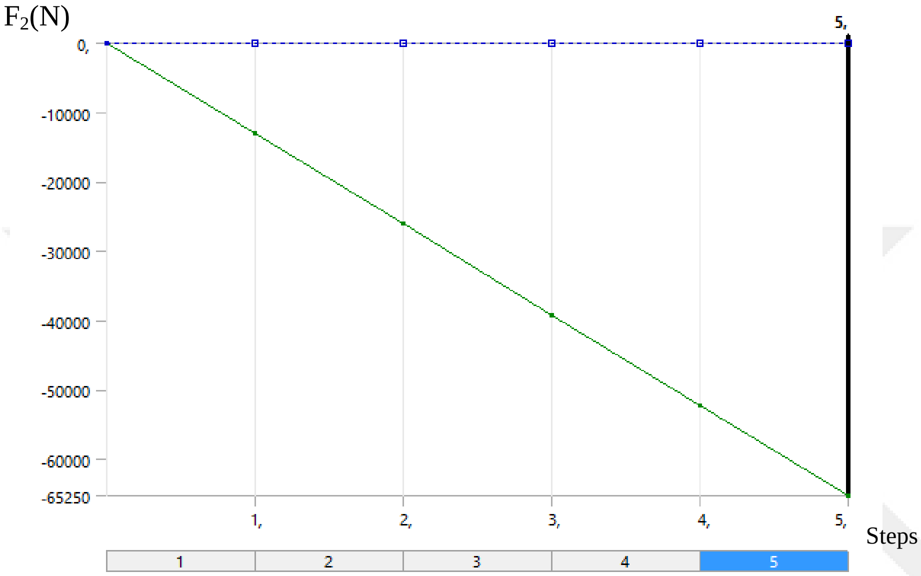


Figure 3.35 Graph of the applied force (F_2) to chassis

Table 3.9 Force (F_2) applied on time basis

Steps	Time [s]	X [N]	Y [N]	Z [N]
0	0	0	0	0
1	1	0	-13050	0
2	2	0	-26100	0
3	3	0	-39150	0
4	4	0	-52200	0
5	5	0	-65250	0

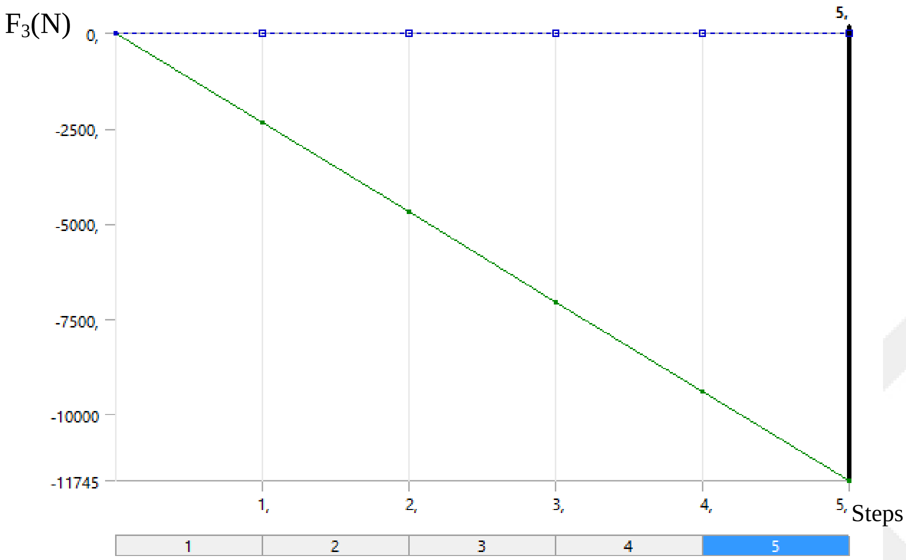


Figure 3.36 Graph of the applied force (F_3) to chassis

Table 3.10 Force (F_3) applied on time basis

Steps	Time [s]	X [N]	Y [N]	Z [N]
0	0	0	0	0
1	1	0	-2349	0
2	2	0	-4698	0
3	3	0	-7047	0
4	4	0	-9396	0
5	5	0	-11745	0

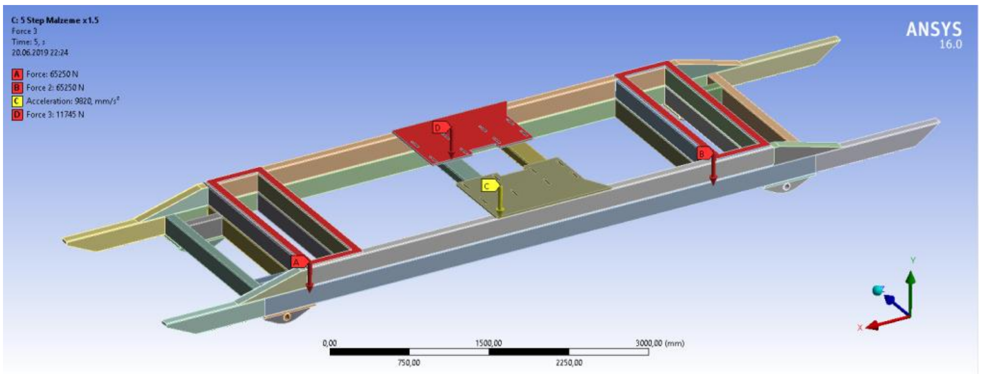


Figure 3.37 Placement of forces on the geometry

3.2.2.2. Torsion Analysis of Drum

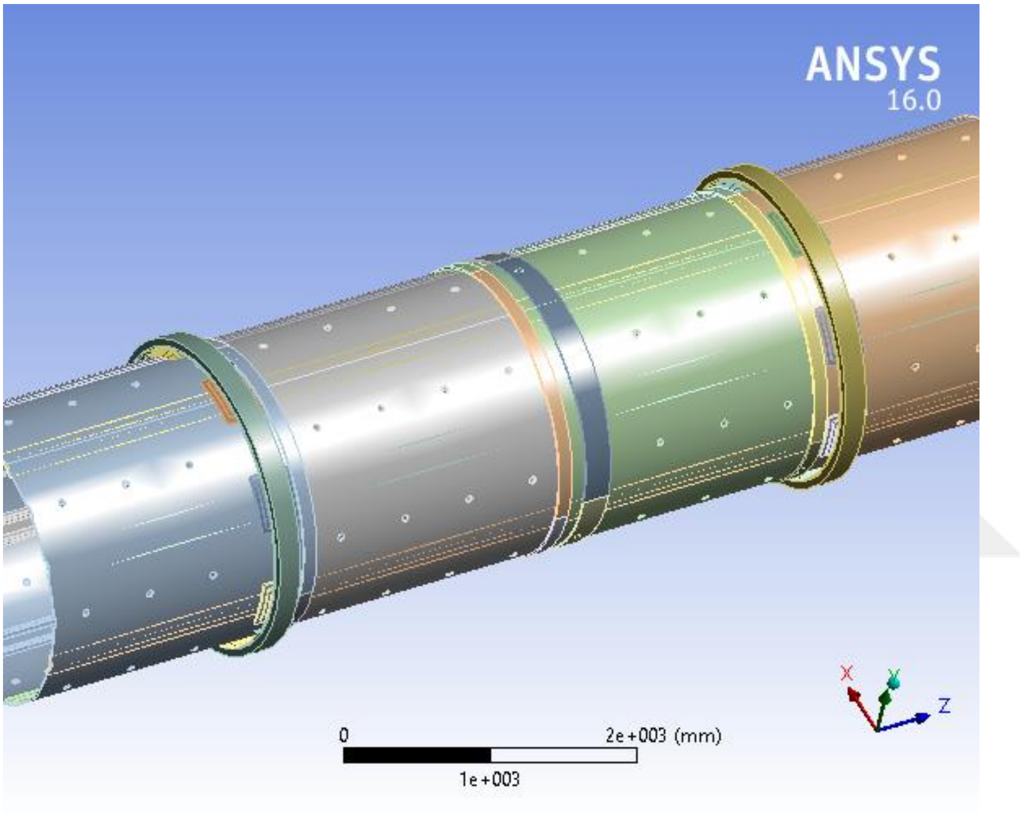


Figure 3.38 Drum geometry

Units;

Table 3.11 Units of the statical analysis of te drum

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees RPM Celsius
Angle	Degrees
Rotational Velocity	RPM
Temperature	Celsius

In the table below, there are the basic physical properties of the granulator drum which will be analyzed statically.

Also, the amount of nodes and elements that the program will use to solve the analysis are indicated.

Geometry;

Table 3.12 Physical properties of geometry

Length X	2707.3 mm
Length Y	2696 mm
Length Z	8006 mm
Volume	940630000 mm^3
Mass	7384 kg
Nodes	616621
Elements	85490

Mesh;

Table 3.13 Mesh properties

Physics Preference	Mechanical
Element Size	50.0 mm
Initial Size Seed	Active Assembly
Smoothing	Medium
Minimum Edge Length	1.57080 mm
Inflation Option	Smooth Transition
Nodes	616621
Elements	85490

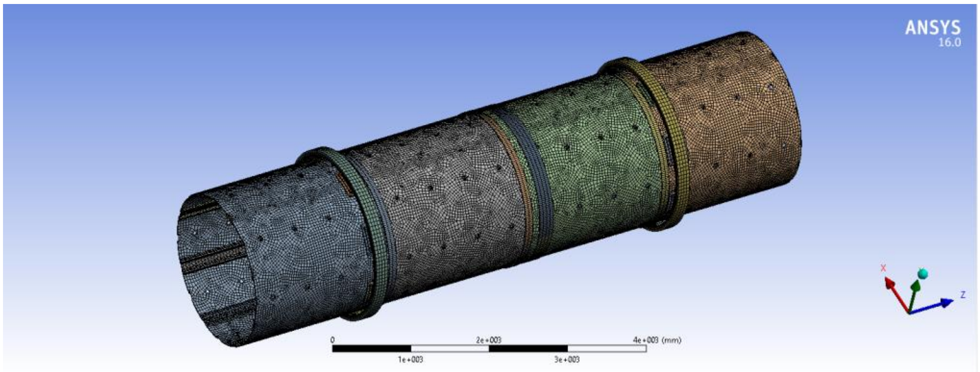


Figure 3.39 Mesh of the drum

Static Structural;

Table 3.14 Loads

Object Name	Fixed Support	Displacement	Moment
State	Fully Defined		
Geometry	1 Face		3 Faces
Type	Fixed Support	Displacement	Moment
Coordinate System		Global Coordinate System	Coordinate System
X Component		0 mm (ramped)	0 N·mm (ramped)
Y Component		0 mm (ramped)	0 N·mm (ramped)
Z Component		Free	12558000 N·mm

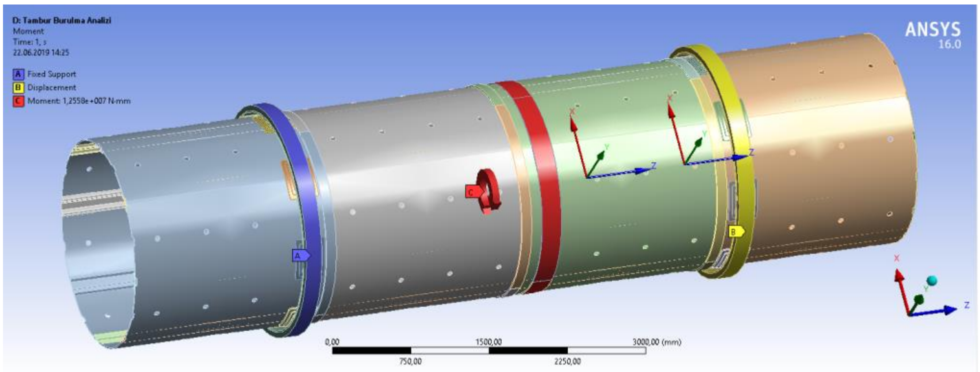


Figure 3.40 Loads of the drum

Face A: Fixed

Face B: Displacement (Free in Z axis)

Face C: Moment

Surface C is actually the surface on which the gear is located. Therefore, the torque from the gear unit is applied to the drum via this surface.

The maximum torque of the gear unit is 1794 Nm. Also, the pinion gear 20 teeth, drum gear 140 teeth are designed as. This gives us a gear ratio of 140/20 = 7

Therefore, the torque applied to the drum from the surface “C” calculated as;

$M_{gearbox} \times i_{total} = M_{bowl}$ 1794 x 7 = 12558 Nm

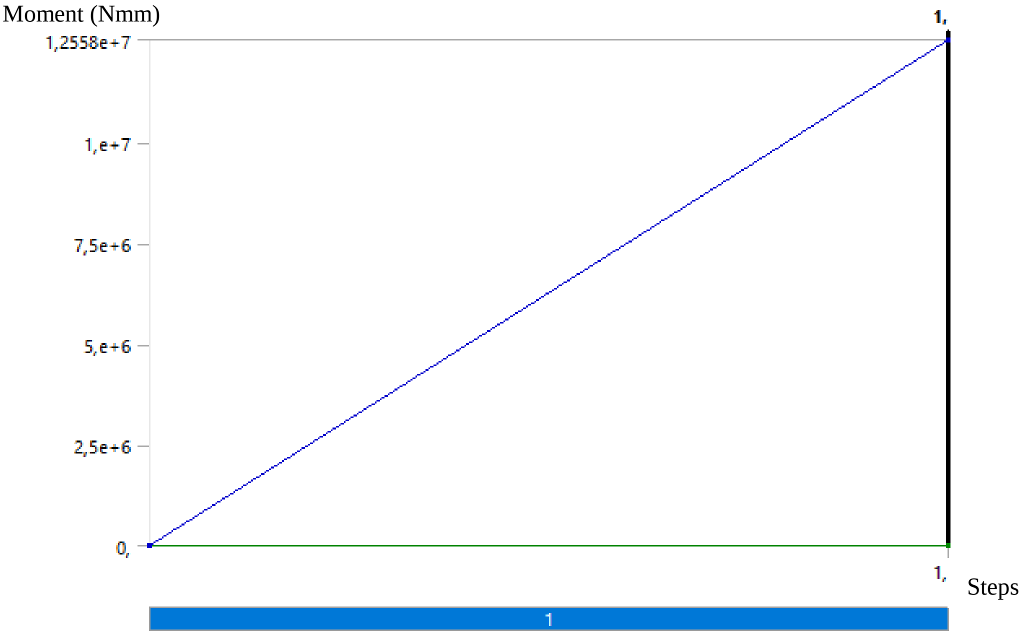


Figure 3.41 Moment

3.2.2.3. Static Structural Analysis of Drum

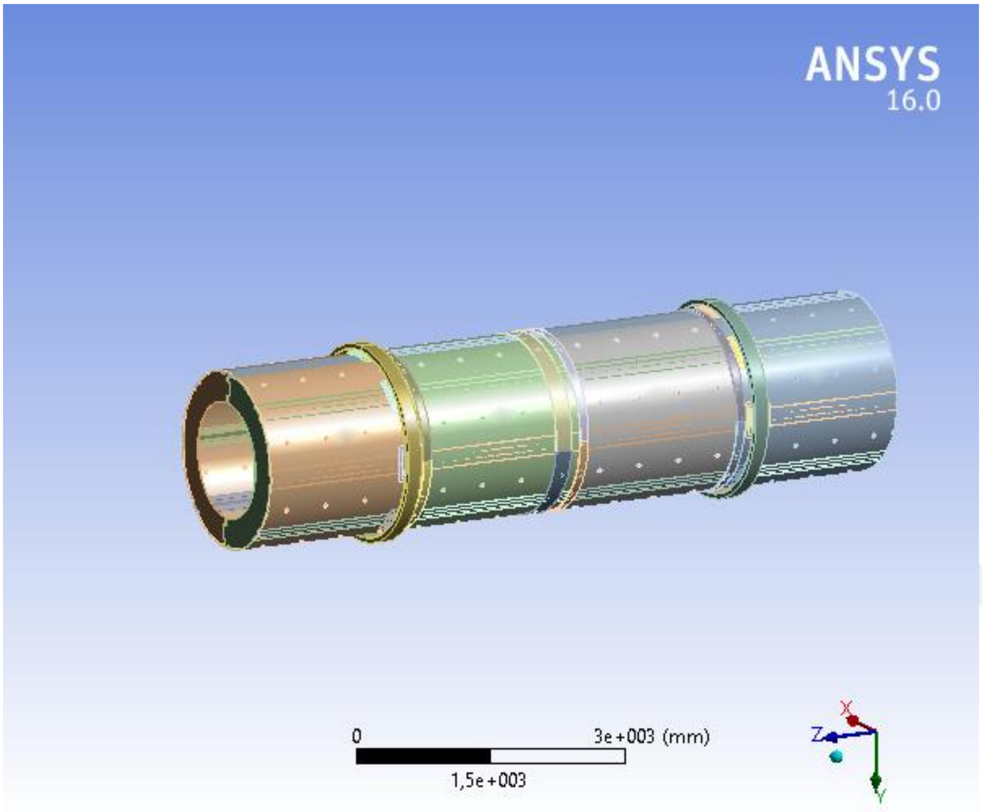


Figure 3.42 Drum geometry

Units;

Table 3.15 Analysis units of the drum

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees RPM Celsius
Angle	Degrees
Rotational Velocity	RPM
Temperature	Celsius

In the table below, there are the basic physical properties of the granulator drum which will be analyzed statically.
Also, the amount of nodes and elements that the program will use to solve the analysis are indicated.

Geometry;

Table 3.16 Physical properties of geometry

Length X	2707.3 mm
Length Y	2696 mm
Length Z	8006 mm
Volume	940630000 mm^3
Mass	7384 kg
Nodes	616621
Elements	85490

Mesh;

Table 3.17 Mesh properties

Physics Preference	Mechanical
Element Size	50 mm
Initial Size Seed	Active Assembly
Smoothing	Medium
Minimum Edge Length	1.57080 mm
Inflation Option	Smooth Transition
Nodes	616621
Elements	85490

The reason why the tables of the torsional analysis and the static analysis of the drum are the same is that only the scenario has been modified by dublicating the torsion analysis.

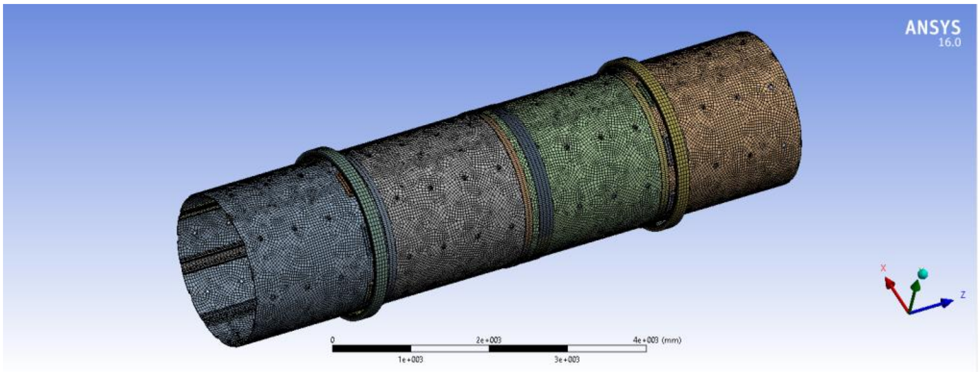


Figure 3.43 Mesh of the drum

Static Structural;

Table 3.18 Accelerations

Object Name	Standard Earth Gravity	Acceleration
State	Fully Defined	Fully Defined
Geometry	All Bodies	All Bodies
Coordinate System	Coordinate System	Global Coordinate System
X Component	0 mm/s² (ramped)	0 mm/s² (ramped)
Y Component	-9806.6 mm/s² (ramped)	-5000 mm/s² (ramped)
Z Component	0 mm/s² (ramped)	0 mm/s² (ramped)
Suppressed	No	No
Direction	-Y Direction	-Y Direction

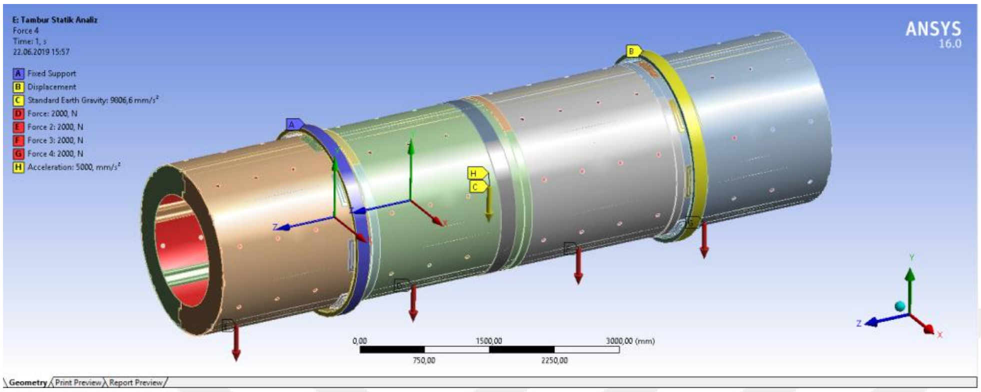


Figure 3.44 Loads of the drum

A: Fixed support

B: Displacement

C: Earth Gravity

D: Force

E: Force 2

F: Force 3

G: Force 4

H: Acceleration

The reason why the forces on the analysis are 2000 N; Itis assumed that 800 kg compost was in the drum. So, the mass of 800 kg was simulated as 8000 N force. The force of 8000 N is evenly distributed to the four part drum.

Table 3.19 Types of loads applied to the drum

Object Name	Fixed Support	Displacement	Force	Force 2	Force 3	Force 4
State	Fully Defined	Fully Defined	Fully Defined	Fully Defined	Fully Defined	Fully Defined
Scoping Method	Geometry Selection	Geometry Selection	Geometry Selection	Geometry Selection	Geometry Selection	Geometry Selection
Geometry	1 Face	1 Face	1 Face	1 Face	1 Face	1 Face
Type	Fixed Support	Displacement	Force	Force	Force	Force
Suppressed	No	No	No	No	No	No
Define By		Components	Components	Components	Components	Components
Coordinate System		Global Coordinate System	Global Coordinate System	Global Coordinate System	Global Coordinate System	Global Coordinate System
X Component		0 mm (ramped)	0 N (ramped)	0 N (ramped)	0 N (ramped)	0 N (ramped)
Y Component		0 mm (ramped)	-2000 N (ramped)	-2000 N (ramped)	-2000 N (ramped)	-2000 N (ramped)
Z Component		Free	0 N (ramped)	0 N (ramped)	0 N (ramped)	0 N (ramped)

3.2.3. Production of the Drum Granulator

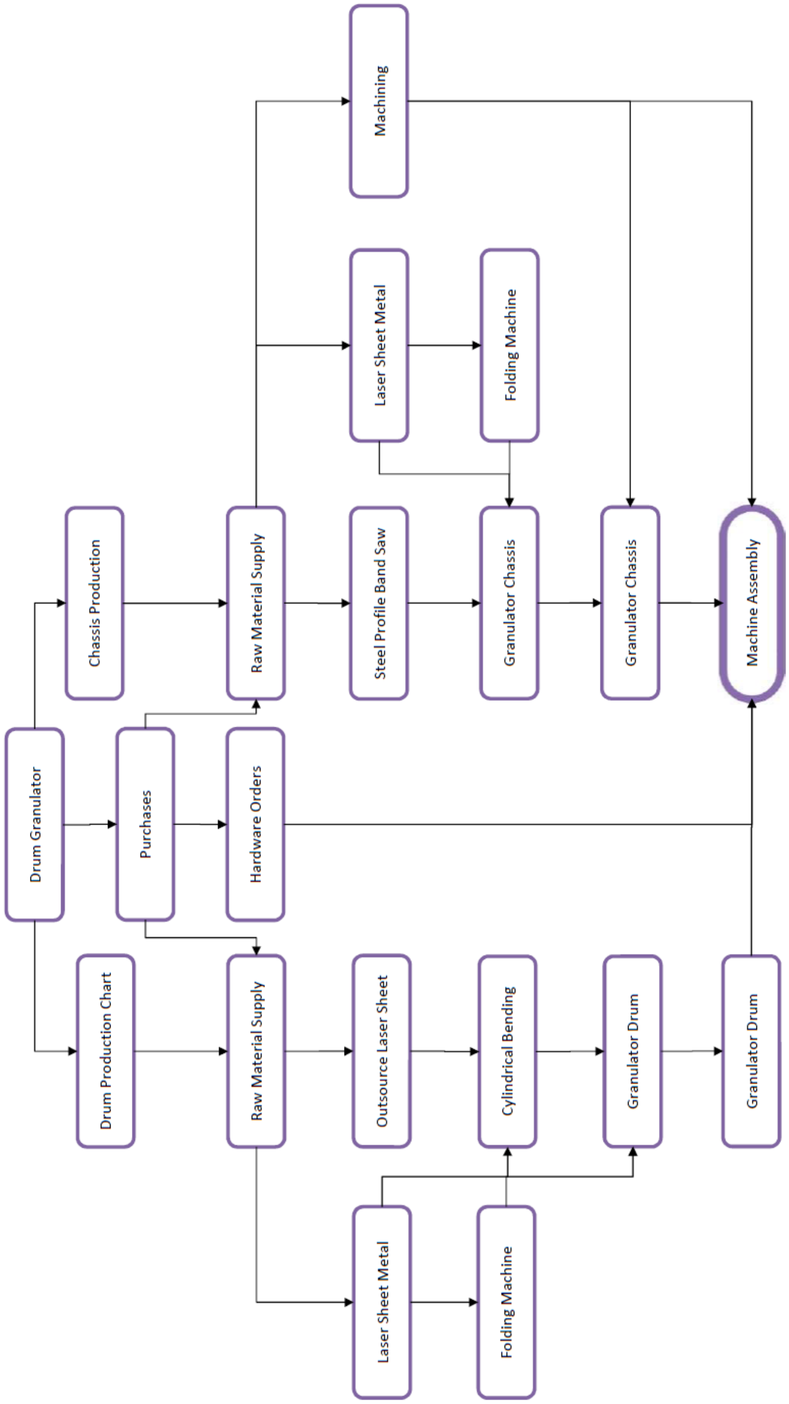


Figure 3.45 Production process of the drum granulator

3.2.4. Testing of the Drum Granulator

First Run: After the manufacturing process is completed, the drum granulator becomes ready for machine performance tests. The granulator is placed at the designated location within the plant. There are a few more things that need to be done before starting the tests.

First, the irrigation line of the machine must be connected to the artesian water line by means of a booster. Since the required water flow rate is maximum 5 m^3 / h, the capacity of the water line is sufficient. That is, there is no need for further development in this regard.

Power line complete for 15 kw motor and frequency-controlled motor drive connected. The first test was carried out after adjusting the drive gear and coupling. Compost, various chemicals or water were not added to the machine in the first attempt. In the first attempt, it is checked whether the machine has mechanical problems.

In the first operation of the granulator, the motor is run at low frequency. In the meantime, mechanical problems are tried to be detected visually and by listening to the sounds.

First Compost & Water Feeding: As a result of the experiments made without any material input into the machine, the first product processing attempts are started. Before starting, another consideration is the angle between the granulator and the horizontal axis. The angle of the drum with the horizontal axis is 3 degrees. According to the experiments, this angle will be changed later.

In the first experiments, the necessary information about the amount of water fed through the electromagnetic flow meter was obtained.

Unless any problems are observed, the motor frequency is increased step by step. When the motor driver reaches 50 Hz, problems may occur by continuing to run for a long time.

Figure 3.46 Electromagnetic Flow Meter

The amount of material added to the machine was also learned by means of conveyor which can measure instant weight. At the same time, this conveyor ensures that the blended compost comes to the granulator feed stably.

Figure 3.47 Weighing conveyor

Figure 3.48 Weighing conveyor touch screen

In the first trials of granule production, the reject material ratio was quite high. This is mainly due to the fact that the main binding element, chemical, is ammonia, but only water is used to produce granules.

According to the results obtained in trials using only water, the production of small granules is quite difficult. The way to obtain smooth granules is to produce larger granules by increasing the water flow rate.

Figure 3.49 (Oversized) Reject granules

In order to produce granules of 2-4 mm diameter with granule sizes suitable for packaging, ammonia, the main binder chemical, must be added in the recipe. In addition, granules that do not contain chemicals are easily disintegrated into powder.

After several days of experiments, it was found that for the formation of granules without chemical use, adding a 2.5 degree drum angle and adding 1 m^3/h water for 1 t/h compost was the best result.

When ammonia was added to the compost entering the machine, the participation rates changed. The way to add ammonia into the compost is to mix by adding urea.

340 kg of compost was added to 40 kg of urea and blended, then 1 t/h speed was given to the granulator.

In the experiment with urea added material, it was seen that giving 0.65 m^3 of water to 1 ton of material is enough to produce granules of 2-4 mm diameter.

Figure 3.50 Granules with a diameter of 2-4 mm (desired granule size)

Ammonia was added to granulate fertilizer, then dried and passed through the screen was found to be 27% reject material. As the chemicals such as potassium, phosphorus and nitrogen are added to the recipe, the ratio of reject material decreases further.

It was also determined that 15 kw motor value is very suitable for drum granulator. In the measurements, it was determined that the drum granulator uses 13.5 Ampere electric current.

3.2.5. Improvements of the Drum Granulator

After the completion of a prototype machine production and performance tests, design and method improvements should be made according to the current situation.

In the material outlet section on the drum granulator, there was a lack of design to prevent the granules from being easily discharged from the machine. During continuous production, material accumulation occurs at the bottom of the outlet section, making material flow difficult. The picture below shows the problem caused by the accumulated material.

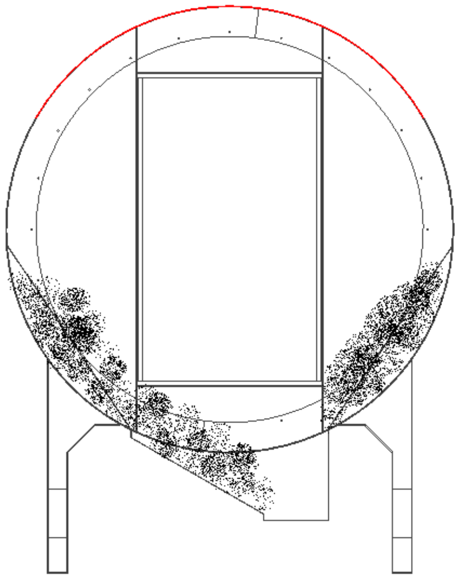


Figure 3.51 Material build-up at outlet section

In order to solve this problem, two sheets of metal sheet are added one on each side at the bottom of the outlet section. In this way, by increasing the pouring angle, the material is easier to be ejected from the machine. In the following picture, how the flow becomes easier with the metal sheets added is explained.

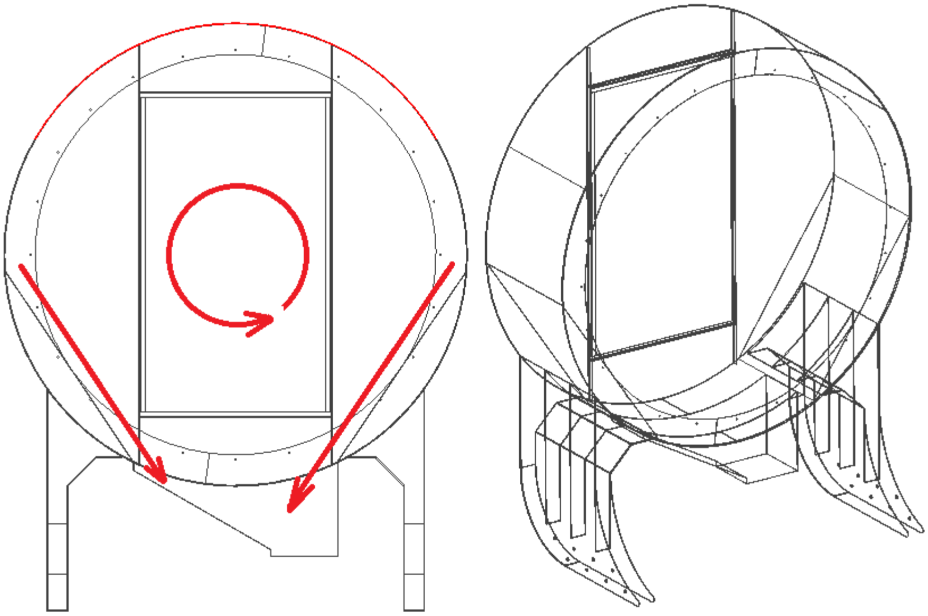


Figure 3.52 Increasing the flow angle

Another problem encountered in the trials is the overflow of material through the small cover at the product inlet during high capacity product processing. The reason fort this, the material on the drum, exceeds the threshold at the inlet. In order to solve this problem, by adding another constant obstacle to the threshold on the drum, the material is prevented from spilling over the threshold.

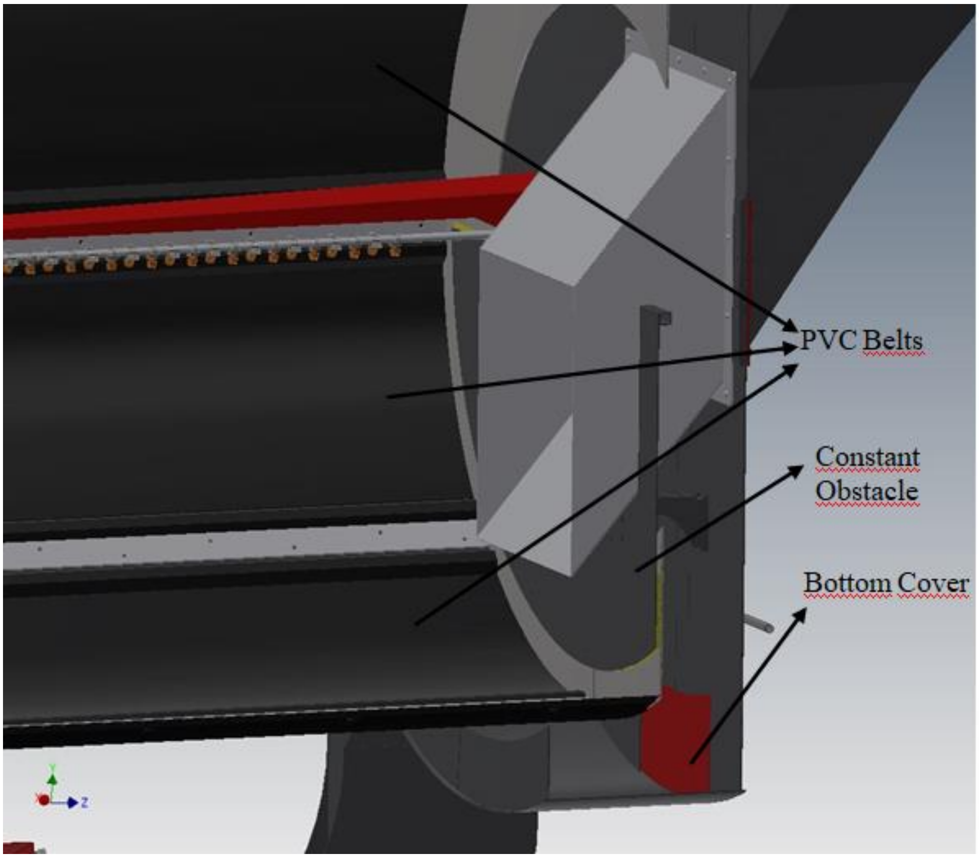


Figure 3.53 Bottom cover & constant obstacle & PVCs

In order to prevent friction between the metals on the fixed obstacle, semi-circular kestamide was installed.

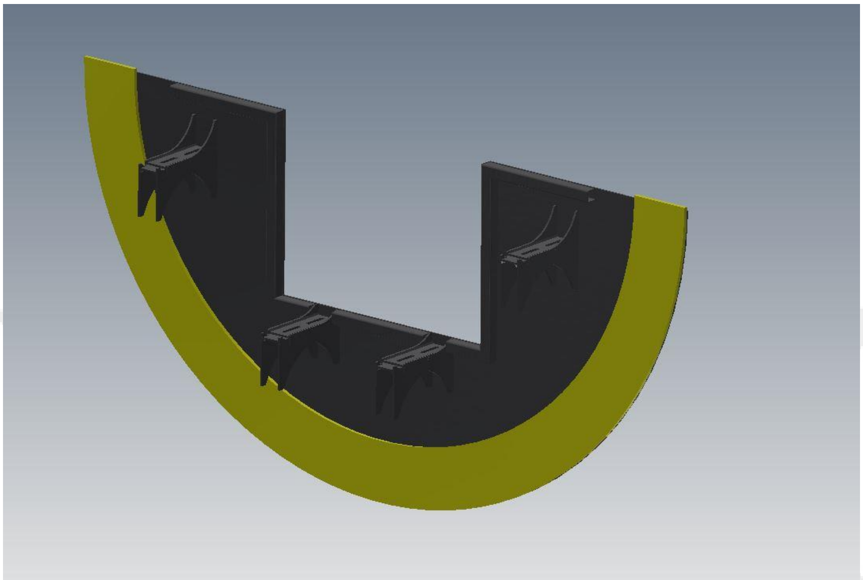


Figure 3.54 Design of the constant obstacle

There has also been a design change in the gear mechanism that could pose a risk. Since the granulator drum rolls on wheels, the tolerance of its position in the direction of the roller axis is not precise. In the first gear mechanism, the 2 inch chain is wound around the drum. In this design, the chain works as a spur gear. However, the chain drum does not have enough width in the direction of the cylinder axis. In the following image, the first gear design is shown.

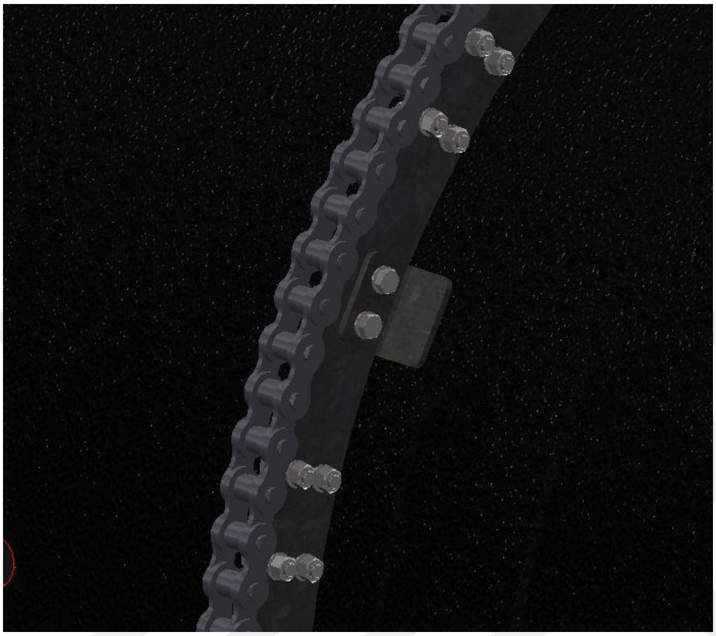


Figure 3.55 Old gear system design

To solve this problem, it is necessary to design a chain-like system with the same module as the 2-inch chain, but wider. Just like the gear, the rollers in the modules must rotate. Therefore, pins and bushings are included in the design. To ensure that the pins and bushings are together and in the right module, the appropriate sheet metals are cut on the laser cutting machine. The picture of the design is in the image below.

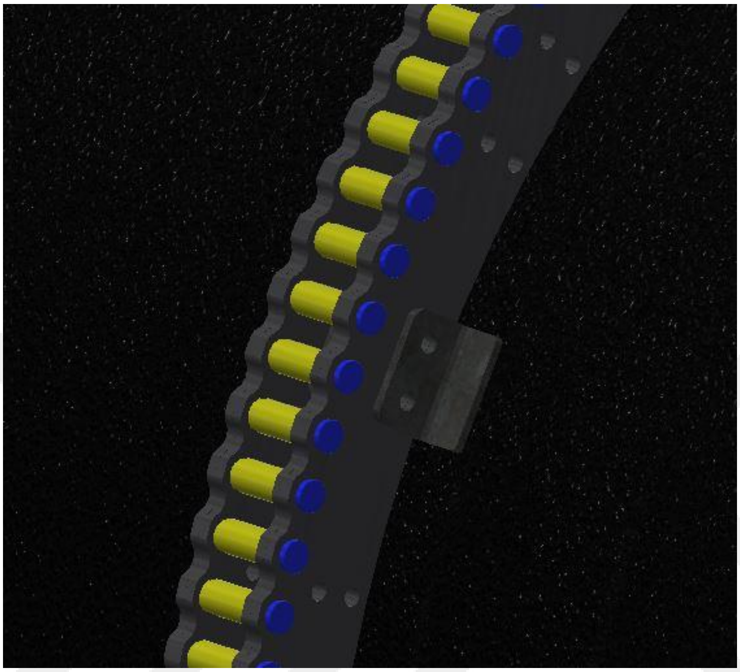


Figure 3.56 Old gear system design

Another innovative improvement in the machine is that there is no scraper or cleaning brush in the drum. Instead of a high-cost cleaner design, a suitable design for self-cleaning of the drum is made using gravity. In the design of the self-cleaning system, eight pvc belt were mounted along the drum axis. the inside of the drum can be thought of as if it were an octagon. However, as the drum rotates, while the PVC belts at the bottom of the drum are laid on the surface of the drum, the PVC belts at the top are suspended downward by gravity. The visual of this study is indicated in the first picture in the improvements section.

Other innovations in the machine are to improve granule quality and to ensure the continuity of this quality. In order to ensure the continuity of granule quality, it is necessary to add water and fertilizer at the same flow rate continuously into the machine. Also, the water-fertilizer ratio added to the machine must remain constant.

In order to keep this ratio constant, electromagnetic flowmeter, proportional controlled valve and conveyor belt which can weigh the product are added to the machine feeding section. These three machine elements continuously communicate with each other. In this way, the weighing belt informs the proportional controlled valve how many tons of material they feed per hour. Proportional-controlled valve decides how much water should be fed into the machine by the signals it receives from the electromagnetic flow meter. Instantaneous water pressure can be monitored with the manometer on the water line.

In this way, the granular quality does not deteriorate in case of pressure drops in the water line or in the fertilizer flow.

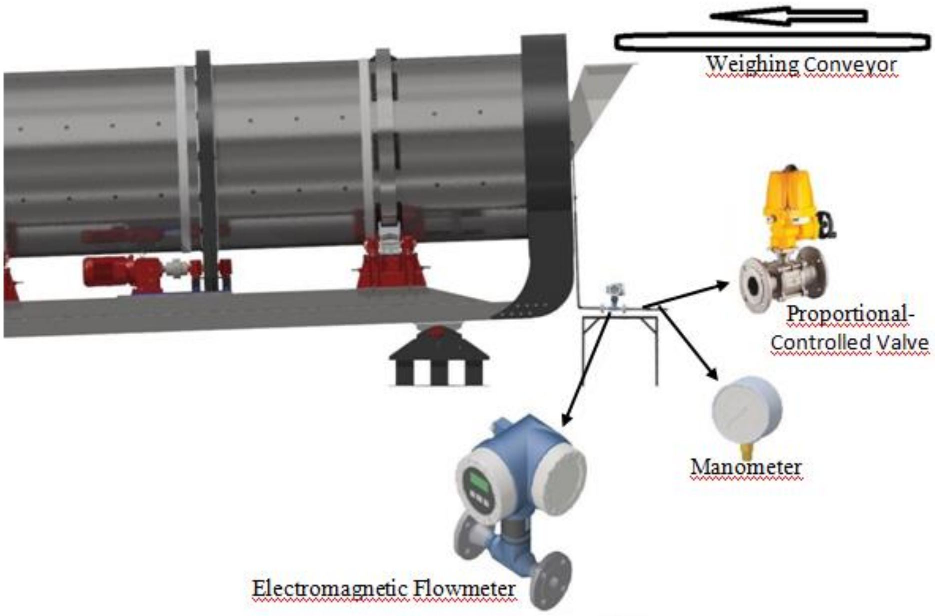


Figure 3.57 Self-control feeding diagram

4. RESULTS AND DISCUSSION

In this study, design, analysis, manufacturing and trial studies of drum granulator were performed.

4.1. Design Process Results

During the design process, drive system design, gearbox selection, drum design and chassis design was carried out. Drum length is 8m and drum diameter is 2m. However, since the cylindrical folding of the material in the drum size is not possible during manufacturing, 4 pieces of 2 meter lengths are cylindrical curled and welded. The drum is made of ST37 material with a wall thickness of 12 mm. According to the researches, drum granulators with 10t/h production capacity are generally operated effectively at 11 rpm. For this reason, the drum granulator was designed to have a drum speed of 11 rpm, engine speed of 1450 rpm, and a total gear ratio of (i) 131.8.

The frame is designed to allow the drum to operate on different slopes. In order to make angle changes at any time, four supported pivoting feet are designed. In addition, 4 drum wheels are designed to support the drum's rotational movement. During the inclined operation of the drum, the axial fixing wheels are designed to limit the drum. In the design process, the forces to axial fixation wheels were calculated. The force applied by the drum to the wheel is 5600 N and the force applied by the bearing is 31500 N. With respect to the positions of the force vectors specified in figure 3.8; the force applied by the bearing multiplied by the distance to the bearing point, must be greater than the drum force multiplied by the distance from the bearing point.

In addition, the shear strength of the fixing wheel was calculated. The fixing wheel shaft is made of C1050 steel. The tensile strength of C1050 steel is 36 N / mm². Since 36 ≥ 3.52, the fixing wheel design is safe.

104.5 x 31500 ≥ 60 x 5600

3.291.750 ≥ 336.000 (safe)   (4 degree)

Gearbox selection was made to decrease from 1450 rpm engine speed to 11 rpm drum speed. According to the calculations; the conversion ratio between the drum gear and the pinion gear is 7, and the ratio between the gearbox and the motor ($i_{gearbox}$) is 18.8.

4.2. Analysis Process Results

Solution of static structural analysis of chassis; The solution of the structural static analysis took approximately two and a half hours with the ordinary personal computer. In the structural analysis, it can be said that a healthy result was obtained because there were 1,003,911 nodes and 170,837 elements.

In addition, it has been observed that the mesh edges are approximately equal in length and closer results can be obtained.

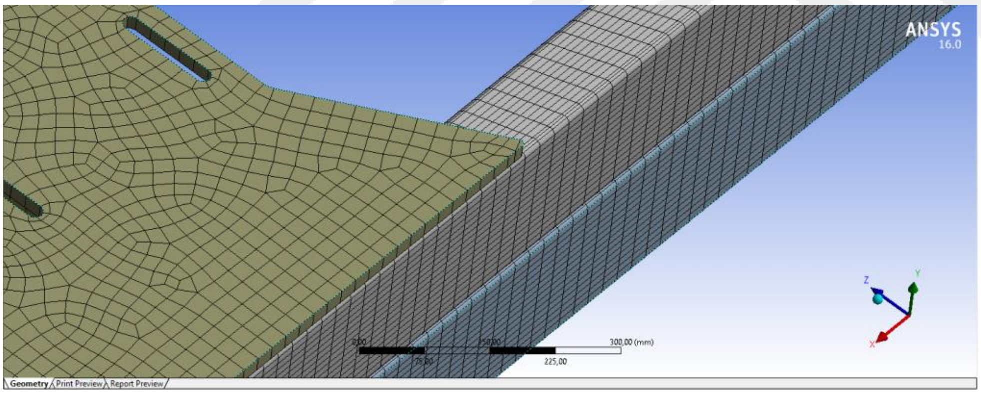


Figure 4.1 Mesh sizing of the chassis

In the table below, you can see the minimum and maximum values of total deformation and Equivalent Stress values of the results required for structural strength. This table is a summary of the results of the structural analysis of the chassis.

Table 4.1 Results of static structural analysis of chassis

Object Name	Total Deformation	Equivalent Stress
State	Solved	Solved
Type	Total Deformation	Equivalent (von-Mises) Stress

Minimum	0.10649 mm	28.344 MPa
Maximum	1.3349 mm	285.83 MPa

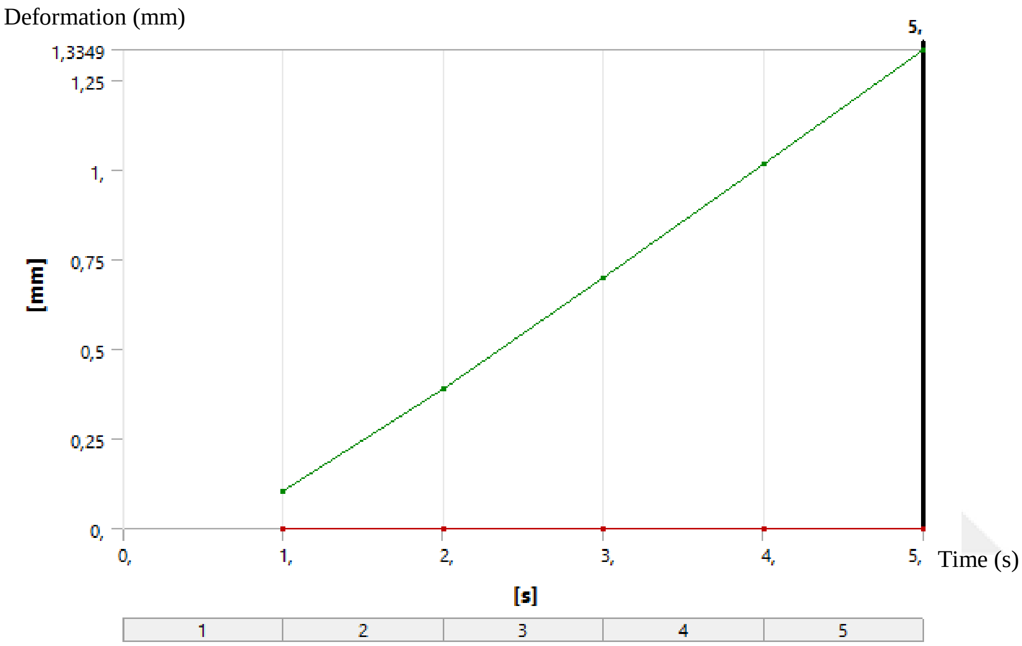


Figure 4.2 Total deformation

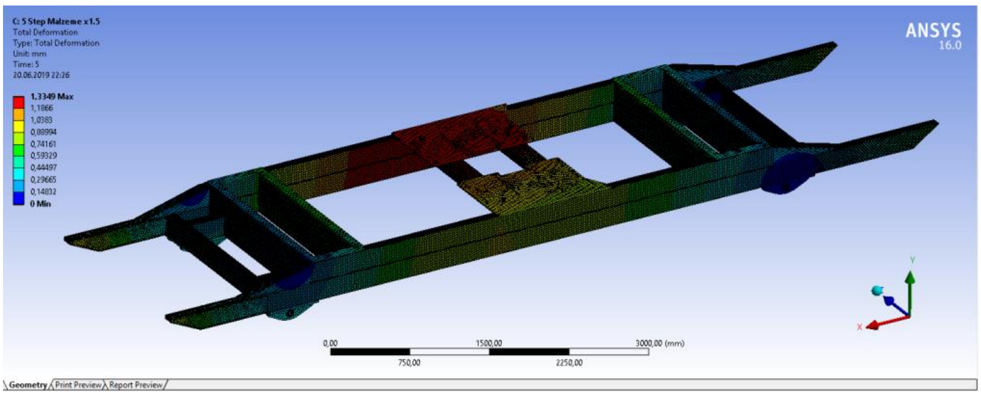


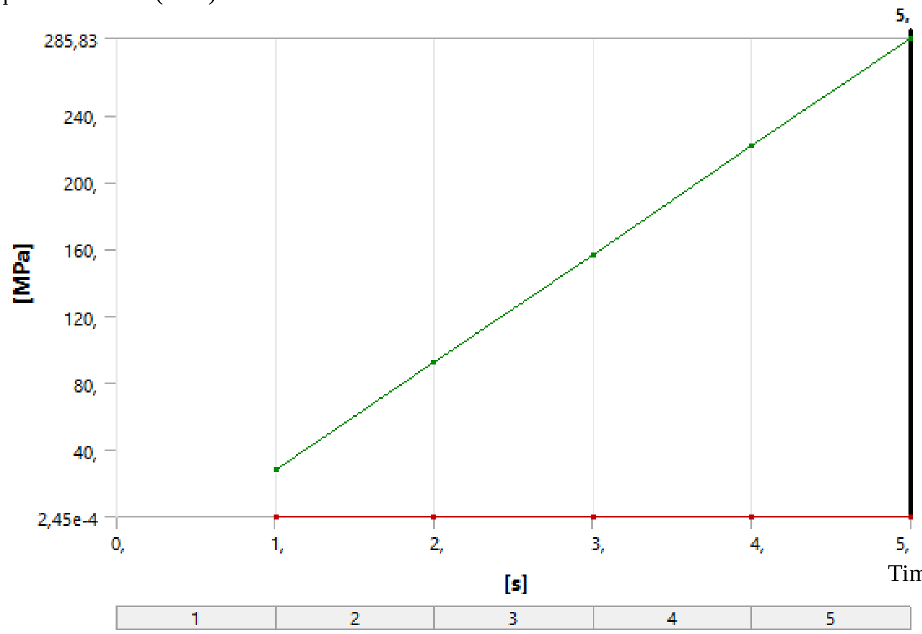
Figure 4.3 Total deformation

According to the total deformation results; maximum deformation is seen as 1,33 mm. most deformation is seen on the sheet on which the transmission is mounted.

Table 4.2 Total deformation

Time [s]	Minimum [mm]	Maximum [mm]
1	0	0.10649
2	0	0.3897
3	0	0.69958
4	0	1.0166
5	0	1.3349

Equivalent Stress (MPa)



Time (s)

Figure 4.4 Equivalent stress

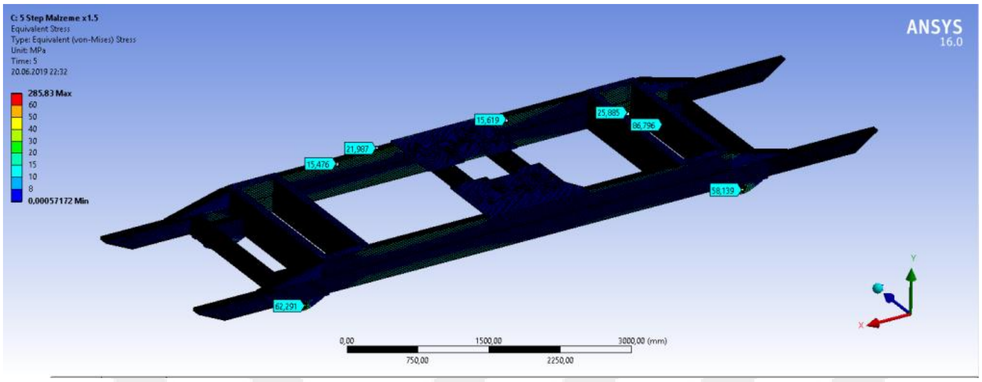


Figure 4.5 Equilavent stress

The yield stress of ST37 structural steel is 240 N/mm² (MPa). As can be read from the table and graph as the result of the analysis obtained the largest tension is 285.83 MPa.

But, this stress value is due to mesh errors found in the analysis and is a point value.

As can be seen from the stress analysis figüre 4.5, the maximum stress value is around 87 MPa.

This result shows that the tension of the structural steel is below the safe tension.

$\sigma_{yield} \geq \sigma_{max}$ in other words, 240 MPa ≥ 87 MPa

For this reason, stresses on the chassis are within safe limits

Table 4.3 Equilavent stress

Time [s]	**Minimum Equilavent Stress [MPa]**	**Maximum Equilavent Stress [MPa]**
1	0.000245	28.344
2	0.00035646	92.366
3	0.00039333	156.84
4	0.00047044	221.33
5	0.00057172	285.83

Safety Factor

Table 4.4 Safety factor

Object Name	Safety Factor
State	Solved
Scoping Method	Geometry Selection
Geometry	All Bodies
Minimum	0.87466
Maximum	15

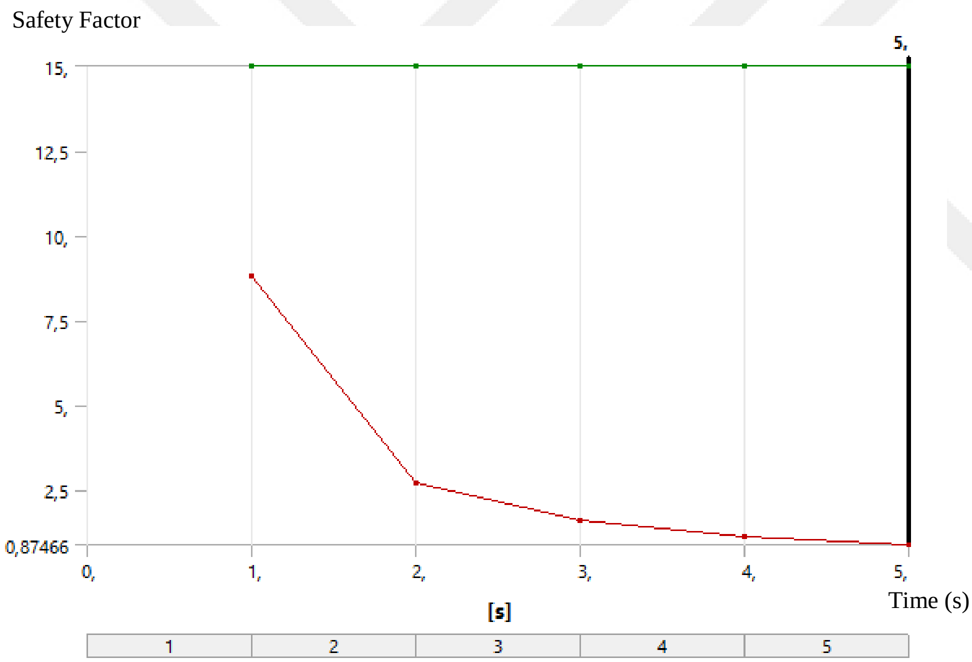


Figure 4.6 Safety factor

Table 4.5 Step by step safety factor

Time [s]	Minimum Safety Factor	Maximum Safety Factor
1	8.8201	15
2	2.7066	15
3	1.594	15
4	1.1296	15
5	0.87466	15

Equvalent Elastic Strain;

Table 4.6 Equvalent Elastic Strain

Object Name	Equivalent Elastic Strain
State	Solved
Scoping Method	Geometry Selection
Geometry	All Bodies
Results	
Minimum	1.0798e-008 mm/mm
Maximum	1.4291e-003 mm/mm

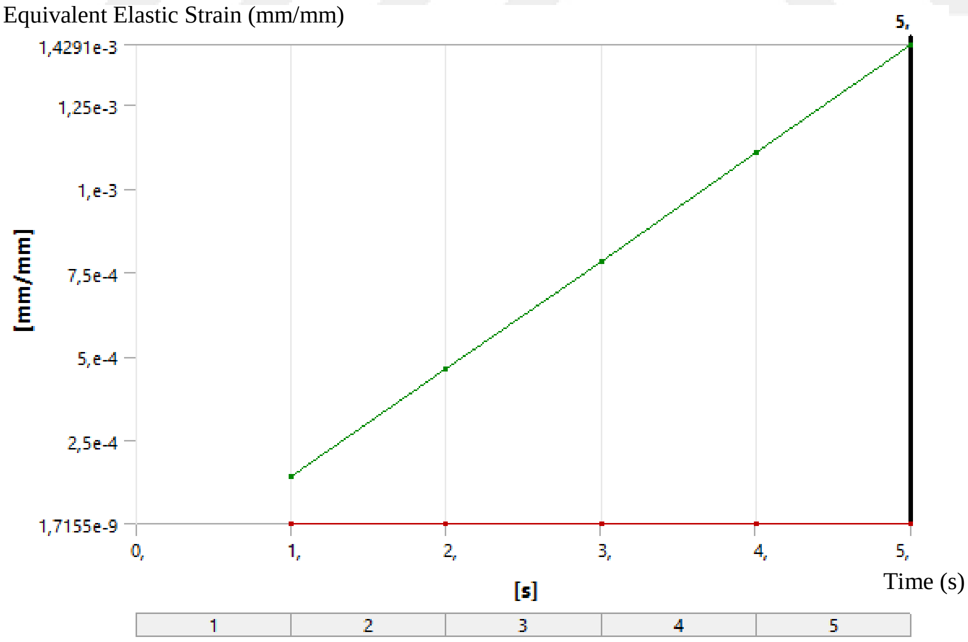


Figure 4.7 Equivalent elastic strain

Table 4.7 Step by step equivalent elastic strain

Time [s]	Minimum Equivalent Elastic Strain [mm/mm]	Maximum Equivalent Elastic Strain [mm/mm]
1	1.7155e-009	1.4172e-004
2	3.8496e-009	4.6183e-004
3	6.1982e-009	7.842e-004
4	8.4729e-009	1.1066e-003
5	1.0798e-008	1.4291e-003

Material Data; The entire chassis is made of ST37 structural steel. The table below lists the structural properties for the steel material used.

Table 4.8 Constants of the statical structural analysis of the chassis

Density	7.85 (gr/cm^3)
Coefficient of Thermal Expansion	1.2x10^{-5} (1/°C)
Specific Heat	434 (J/kg°K)
Thermal Conductivity	42.7 W/m.K
Resistivity	0.17 ohm.m

Solution of torsion analysis of drum; The solution of the structural static analysis took approximately one hour with the ordinary personal computer. In the structural analysis, it can be said that a healthy result was obtained because there were 616621 nodes and 85490 elements.

In addition, it has been observed that the mesh edges are approximately equal in length and closer results can be obtained like static structural analysis of granulator chassis.

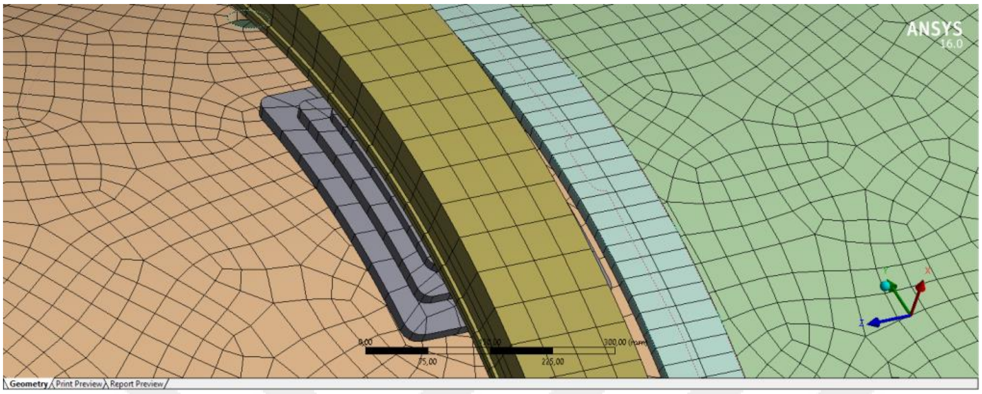


Figure 4.8 Mesh sizing of drum

Table 4.9 Results of the torsion analysis of drum

Object Name	Total Deformation	Equivalent Stress
State	Solved	Solved
Type	Total Deformation	Equivalent (von-Mises) Stress
Minimum	0 mm	0.000000094349 MPa
Maximum	0.0021668 mm	0.42245 MPa

As can be seen from the table, the stresses obtained are very small for steel (ST37).

Material Data; The entire chassis is made of ST37 structural steel. The table below lists the structural properties for the steel material used.

Table 4.10 Constants of the torsion analysis

Density	7.85 (gr/cm^3)
Coefficient of Thermal Expansion	1.2 x 10^{-5} (1/°C)
Specific Heat	434 (J/kg°K)
Thermal Conductivity	42.7 W/m.K
Resistivity	0.17 ohm.m

Solutions of static structural analysis of drum; The solution of the structural static analysis took approximately one hour with the ordinary personal computer. In the structural analysis, it can be said that a healthy result was obtained because there were 616621 nodes and 85490 elements.

In addition, it has been observed that the mesh edges are approximately equal in length and closer results can be obtained like the other analysis of the granulator.

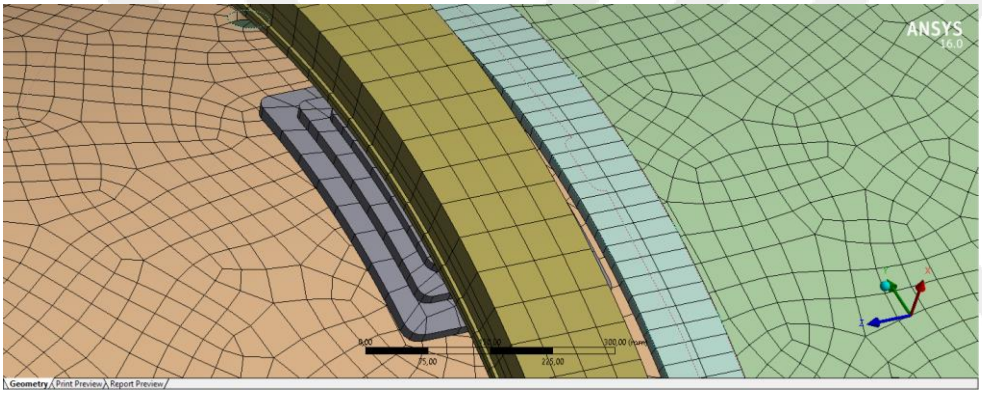


Figure 4.9 Mesh sizing of drum

Table 4.11 Results of the static structural analysis of drum

Object Name	Total Deformation	Equivalent Stress
State	Solved	Solved
Type	Total Deformation	Equivalent (von-Mises) Stress
Minimum	0 mm	0.000089844 MPa
Maximum	0.0052579 mm	0.94573 MPa

As can be seen from the table, the stresses obtained are very small for steel (ST37).

Material Data; The entire chassis is made of ST37 structural steel. The table below lists the structural properties for the steel material used.

Table 4.12 Constants of the static structural analysis of drum

Density	7.85 (gr/cm^3)
Coefficient of Thermal Expansion	$1.2x10^{-5}$ (1/°C)
Specific Heat	434 (J/kg°K)
Thermal Conductivity	42.7 W/m.K
Resistivity	0.17 ohm.m

4.3. Production Process Results

At the end of the production process, a prototype with the technical features in table 3 was produced.

Drum length	8000 mm
Drum diameter (Ø)	2000 mm
Drum speed	11 rpm
Inclination angle	2,5-3°
Production capacity	10t/h
Reject rate	max.%27
Engine speed	1450 rpm
Motor power	15 kW
Granule shape	Spherical

Granule size	2-4 mm
Binder type	Water
Nozzle number	100

4.4. Trial and Development Process Results

In the first trials of granule production, the reject material ratio was quite high. This is mainly due to the fact that the main binding element, chemical, is ammonia, but only water is used to produce granules.

According to the results obtained in trials using only water, the production of small granules is quite difficult. The way to obtain smooth granules is to produce larger granules by increasing the water flow rate.

In order to produce granules of 2-4 mm diameter with granule sizes suitable for packaging, ammonia, the main binder chemical, must be added in the recipe. In addition, granules that do not contain chemicals are easily disintegrated into powder.

After several days of experiments, it was found that for the formation of granules without chemical use, adding a 2.5 degree drum angle and adding 1 m^3/h water for 1 t/h compost was the best result.

When ammonia was added to the compost entering the machine, the participation rates changed. The way to add ammonia into the compost is to mix by adding urea.

340 kg of compost was added to 40 kg of urea and blended, then 1 t/ h speed was given to the granulator.

In the experiment with urea added material, it was seen that giving 0.65 m^3 of water to 1 ton of material is enough to produce granules of 2-4 mm diameter.

The following table shows the size distribution of the granules obtained after the experiment.

Table 4.13 Particle size distribution after testing the drum granulator.

Particle size (mm)	Percentage (%)	Material
< 2	35	Compost + water
2 – 4 (desired)	51	
> 4	14	
< 2	21	Compost + urea + water
2 – 4 (desired)	73	
> 4	6	

Figure 4.10 2-4mm granules

Figure 4.11 Bigger than 4mm granules

Figure 4.12 Powders (< 2mm)

5. CONCLUSIONS

There are many opinions about drum granulator and granulation technique.

According to Walker, In drum granulator designs, many parameters such as drum length, drum diameter, inclination angle, drum speed are important in determining the degree of agglomeration and the physical properties of the granule to be obtained and some of these parameters affect the total time (also called retention time) spent by the input materials in the drum [15].

Therefore, during the thesis, every parameter in drum granulator design was examined and studies were carried out to obtain maximum granule formation. Common technical features of drum granulators are given below.

Couper et al. stated that drum granulators are generally operated at a horizontal angle of 2-3°. Diameter ratios generally vary between 2-3 m and drum rotations vary between 10-20 rpm. It is recommended to use half of the critical speed to achieve a lower granule size range in the dry material [1].

According to Capes and Fouda's research, 10-17 rpm drum speed, 15 HP engine power, 3m drum length and 1.5m drum diameter are needed to reach 7.5t/h production capacity in fertilizer granulation. In order to reach 40t/h production capacity, 8-14 rpm drum speed, 75 HP engine power, 5m drum length and 2.5m drum diameter are required [26].

The subject drum granulator has a drum length of 8m and a drum diameter of 2m. The drum granulator operates with 11rpm drum speed and 15 kW motor power and has 10 t/h production capacity. In the above study, 7.5 t/h production capacity was achieved at 11kW, while the granulator we produced produced 10t/h product by operating the drum designed in larger dimensions at 15kw. The drum has a foot design that can work horizontally at 2-3°. It is particularly suitable for working at 4 °.

According to Salman A.D. there are many factors affecting granule quality such as size distibution, porosity, attritional ability, dispersability, dissolution rate, strength, shape, color and homogenity [8].

Schaafma stated that there is a high rate of recycle rate in the granulation process and the difficulty of granulation process control. However, what is most desirable in the industry is to produce granules correctly the first time and do not require any sieving and crushing processes [4].

However, according to Ennis et al. In manufacture plants, recycle rates of the drum granulation process are often between 2:1 and 5:1 and grinding and blending operations may be required for reprocessing. Also, changes in the amount of material in reprocessing affect both the moisture content and the size distribution in the drum [16].

After the production of the drum granulator subject of the thesis, trial studies were carried out. Even in the first trials, although the desired granule size was 2-4mm, (As the desired granule size decreases, process control becomes more difficult and recycle rate increases.) a recycle rate of 27% was achieved. With the development studies carried out, a system was designed to feed water according to the weight of the incoming material. Sensor technologies are used in system design. This study made an important contribution to the reduction of recycle rate by feeding the granulator itself optimally.

The above-mentioned study is a solution to the problems that Ennis and Schaafma mentioned.

In addition, according to Ennis et al.; If drum speed is too low, the material granule formation will not be achieved. if the speed is too high, the material will stick to the drum surface and various designs will be required to scrape the surface [16]. According to the studies performed by Ennis et al., It is stated that scraper designs are used for material adhesion. In the development of the drum granulator subject of the thesis, the surface of the drum was covered with PVC conveyor belt. This material prevents the manure from sticking to the drum surface and has a positive effect on reducing rejection rate and granular production capacity.

In the light of the aforementioned studies, the design of the drum granulator which is widely used in pharmaceutical, food, chemical, detergent, compost fertilizer production sectors has been carried out. The design was supported by analysis and its strength was confirmed. Afterwards, manufacturing was carried out and trial studies were started. In the light of the data obtained during the trial studies, development & improvement studies were conducted.

In development studies; PVC conveyor belt assembly which prevents the material from sticking to the drum surface, drum inlet design which prevents overflow problems at 2.5° drum inclination angle, outlet design which prevents the material to be clogged when leaving the drum. Furthermore, in order to reduce the rejection rate, a system which adjusts the amount of water given according to the weight of the material fed has been made. This system has made a significant contribution to the granule production process.

REFERENCES

[1] Couper, J.R., Penney, W.R., Fair, J.R., Walas, S.M., 2010. Disintegration, Agglomeration and Size Separation of Particulate Solids. **Chemical Process Equipment**. Elsevier, pp.357-393.

[2] Snow, R.H., Allen T., Ennis, B.J., Litster, J.D. 1999. Size Reduction and Size Enlargement. Perry's Chemical Engineers' Handbook. The McGraw-Hill Companies, Chap20. pp.1-89.

[3] Ennis, B.J. 2005. Theory of Granulation: An Engineering Perspective. Handbook of Pharmaceutical Granulation Technology,(Swarbrick J.). Taylor & Francis Group, pp.7-77.

[4] Schaafsma, S.H. 2000. Down-Scaling of a Fluidized Bed Agglomeration Process. University of Groningen, Holland.

[5] Adetayo, A.A., Litster, J.D., Pratsinis, S.E., Ennis, B.J. 1993. Population Balance Modelling of Drum Granulation of Materials With Wide Size Distribution. **Powder Technology** (Mort P., Teleki A., Wu C., Yu A.B.), Elsevier, Volume 82, pp.37-49.

[6] Parikh, D.M. 2007. Recent Advantages in Granulation Theory, Modeling and Process Control. Tablets & Capsules.

[7] Wang, F.Y., Cameron, I.T. 2002. Review and Future Directions in the Modelling and Control of Continuous Drum Granulation. Powder Technology (Mort P., Teleki A., Wu C., Yu A.B.), Volume 124, Elsevier, pp.238-253.

[8] Sochon, R.P.J., Salman, 2010. A.D. Particle Growth and Agglomeration Processes. Chemical Engineering and Chemical Process Technology (Pohorecki, R., Bridgwater, J., Molzahn, M., Gani, R., Gallegos, C.), Volume 2, UNESCO, pp.299-317

[9] Parikh, D.M. 2005. Introduction. Handbook of Pharmecutical Granulation Technology (James Swarbrick), Taylor & Francis Group, pp1-7,U.S.A

[10] Iveson, S.M. 2002. Limitations of One-Dimentional Population Balance Models of Wet Granulation Porcesses. **Powder Technology** (Mort, P., Teleki, A.,Wu, C., Yu, A.B.) Volume 124, Elsevier, pp.219-229

[11] Litster, J.D. 2003. Scale-up of Wet Granulation Processes: Science Not Art, **Powder Technology** (Mort, P., Teleki, A.,Wu, C., Yu, A.B.) Volume 130, Elsevier, pp.35-40

[12] Hapgood, K.P., Iveson, S.M., Litster, J.D., Liu, L.X. 2007. Granulation Rate Processes. Handbook of Powder Technology Book (Salman, A.D., Hounslow, M.J., Seville, J.P.K) Volume 11, Elsevier, pp.898-975

[13] Michrafy, A., Zavaliangos, A., Cunningham, J.C. 2007. Dry Granulation Process Modeling. Predictive Modeling of Pharmaceutical Unit Operations (Pandey, P., Bharadwaj, R.), Elsevier, pp.71-97

[14] Shanmugam, S. 2015. Granulation Techniques and Technologies: Recent Progresses, **BioImpacts**, 5(1), pp.55-63

[15] Walker, G.M. 2007. Drum Granulation Processes. Handbook of Powder Technology Book (Salman, A.D., Hounslow, M.J., Seville, J.P.K) Volume 11, Elsevier, pp.219-254

[16] Ennis, B.J., Witt, W., Weinekötter, R., Sphar, D., Gommeran, E., Snow, R.H., Allen, T., Raymus, G.J., Litster, J.D. 2008. Solid-Solid Operations and Processing. Perry's Chemical Engineers' Handbook (Green, D.W., Perry, R.H.), The McGraw-Hill Companies, Chapter 21 pp 8-147

[17] Sastry, K.V.S., Dontula, P., Hosten, C. 2003. Investigation of Layering Mechanism of Agglomerate Growth During Drum Pelletization, **Powder Technology** (Mort, P., Teleki, A.,Wu, C., Yu, A.B.), Volume 130, Elsevier, pp.231-237

[18] Verkoeijen, D., Meesters, G.M.H., Vercoulen, P.H.W., Scarlett, B. 2002. **Powder Technology** (Mort, P., Teleki, A.,Wu, C., Yu, A.B.) Volume 124, Elsevier, pp.195-200

[19] Valiulis, G., Simutis, R. 2009. Particle Growth Modelling and Simulation in Drum Granulator-Dryer, **Information Technology and Control**, Volume 38, ResearchGate

[20] Zhang, J., Litster, J.D., Wang, F.Y., Cameron, I.T. 2000. Evaluation of Control Strategies for Fertiliser Granulation Circuits Using Dynamic Simulation, **Powder Technology** (Mort, P., Teleki, A.,Wu, C., Yu, A.B.), Volume 108, Elsevier, pp.122-129

[21] Litster, J.D., Hapgood, K.P., Michaels, J.N., Sims, A., Roberts, M., Kameneni S.K. 2002. Scale-up of Mixer Granulators for Effective Liquid Distribution. **Powder Technology** (Mort, P., Teleki, A.,Wu, C., Yu, A.B.), Volume 124, Elsevier, pp.272-280

[22] Biggs, C.A., Lant, P.A. 2002, Modelling Activated Sludge Flocculation Using Population Balances. **Powder Technology** (Mort, P., Teleki, A.,Wu, C., Yu, A.B.), Volume 124, Elsevier, pp.201-211

[23] Environment and urban ministry. 2015. Official Newspaper. **Compost Rescprit,** Section 1, issue.29286

[24] Sherrington, P.J., Oliver, R. 1981. **Granulation**. Heyden. London

[25] Koerner, R.M., MacDougal, J.A. 1983. Briquetting and Agglomeration. Institute for Briquetting and Agglomeration. Erie. PA

[26] Capes, C.E., Fouda, A.E. 1984. Prilling and Other Spray Methods. in Fayed and Otten, pp.294-307

[27] Dekker, M. 1989. Pharmaceutical Pelletization Technology (Ghebre, I.,Sellasie,)

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