KAUNAS UNIVERSITY OF TECHNOLOGY

MECHANICAL ENGINEERING AND DESIGN FACULTY

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DESIGN CONSIDERATIONS AND PERFORMANCE MODELING OF PELLETIZED BIO-FUEL SCREW FEEDERS

Final project for Master degree

Supervisor
Assoc. Prof. Dr. Evaldas Narvydas

KAUNAS, 2015

KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY
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(Title and code of study programme)

DESIGN CONSIDERATIONS AND PERFORMANCE MODELING OF PELLETIZED BIO-FUEL SCREW FEEDERS

Final project

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme MECHANICAL ENGINERING

The final project of Master studies to gain the master qualification degree , is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Design considerations and performance modeling of pelletized bio-fuel screw feeders

Approved by the Dean 2015 y. May m. 11 d. Order No. ST17-F-11-2

2. Aim of the project

To review the designs of the screw feeders used for bio-fuel supply, to model the performance of most sufficient feeders by means of finite element analysis, to perform a parametric analysis and to suggest improvements for design

3. Structure of the project

The final project consists of: summary in Lithuanian and English; introduction with emphasized aim and topicality of the project; literature survey; presentation of the research methods; research results; conclusions and list of references.

4. Requirements and conditions

To prepare final project according to KTU regulations and requirements. Conditions: to analyze the presented screw feeder and to perform modifications with two filling conditions of the hopper: 0.3 m and 0.45 m and mass flow rate according to the screw rotational speed from 5 rpm to 30 rpm

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2015 June 1st.

Given to the student

Thillai Balaji Sankaravel

Task Assignment received Thillai Balaji Sankaravel _______________________
(*Name, Surname of the Student*) (*Signature, date*)

Supervisor Assoc. Prof. Dr. Evaldas Narvydas _______________________
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Sankaravel, T B. Biokuro granulių sraigtinių tiektuvų konstrukcijų analizė ir veikimo modeliavimas. *Magistro* baigiamasis projektas / vadovas doc. dr. Evaldas Narvydas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas, Mechanikos inžinerijos katedra.

Kaunas, 2015. 45 psl.

SANTRAUKA

Projekto tikslas yra sukurti sraigtinio tiektuvo modelį, ištirti jo deformacijas, įtempius, išnagrinėti granulinio bio-kuro kamščių susidarymo galimybes ir jo veikimą, esant užduotam tiekiamo kuro masės srautui. Darbe pristatomi trys variantai naujo dizaino sraigtinių tiektuvų, kuriuose sraigtas yra be ašies ir jų deformacijos bei įtempiai palyginti su įprastu sraigtiniu tiektuvu su ašimi. Panaudoti du variantai tiektuvo bunkerio dizaino tiriant granulių kamščių susidarymą tiektuve, kuriame sraigtas yra su ašimi. Bunkerio variantas, kuriame kuro strigimas yra mažesnis, toliau naudojamas tiektuvų, kurių sraigtas neturi ašies, tyrimuose. Granulinių dalelių masės srautas yra apskaičiuotas visais nagrinėtais tiektuvo variantais. Iš apskaičiuotų rezultatų matyti, kad du iš trijų naujo dizaino tiektuvų veikia efektyviai, o jų deformacijų ir įtempių vertės yra mažesnės lyginant su įprastais tiektuvais, kurių sraigtai turi ašis.

Sankaravel, Thillai Balaji Sankaravel. Design considerations and performance modeling of pelletized bio-fuel screw feeders. Master of Mechanical Engineering final project / supervisor Assoc. Prof. Dr. Evaldas Narvydas; Kaunas University of Technology, Mechanical Engineering and design faculty, Mechanical Engineering department.

Kaunas, 2015. 45 p.

SUMMARY

The goal of project is to design the active shafted screw feeder model to analysis its deformation, stress, possibilities of pelletized bio-fuel jamming in its hopper and performance using its mass flow rate. The implementation of new design three different axle free screw feeder used in this project in order to reduce its deformation and stress values when compared active shafted screw feeder. Two hopper designs are used for analysis of pellets jamming with initial active shafted screw feeder. The hopper with less jamming is considered for further research by assembling the rest three different axle free screw feeder and jamming analysis are done. The mass flow rate of the pelletized particle is calculated for all screws used in this project. From results it shown that the two out of three newly designed screw feeder are efficient in performance, less deformation and stress values are reduced when compared to the existing shafted screw feeder.

Table of Contents

List of Figures

List of Tables

INTRODUCTION

A screw feeder can be defined as "A mechanism for handling bulk (pulverized or granulated solids) materials, in which a rotating helicoids screw moves the material forward, toward and into a process unit" based on McGraw-Hill Dictionary of Scientific & Technical Terms, 6E, Copyright © 2003 by The McGraw-Hill Companies. In this research project the screw feeder used as material handling equipment which used to standardize the flow of pelletized particle from hopper to the Fluidized bed combustion boiler of the bio-mass Industries.

Screw feeder has wide range of application with conveying of pelletized materials in Industries. The aim of this research project is to develop 3D model of existing design of screw feeder and to analysis of design consideration by using three different axle-free screw feeders with performance of all four screws analysis using mass flow rate. This aim is divided into several objectives:

1. To identify the deformation occurring at existing screw feeder and comparing its results with modified axle free screw feeders.
2. To recognize the maximum stress occurring at existing screw feeder and to do result comparison with modified axle free screw feeders.
3. To classify the jamming occurring at two different hoppers and selecting the hopper with less jamming which is further assembled with all four screws. The jamming comparison of all four assemblies is done.
4. Mass flow rate for all the four screws are calculated for tool check.

In this research project four type of screw feeder is constructed using SOLIDWORKS with different dimension according to the design specifications and its CFD used for jamming analysis. ANSYS workbench used for stress and deformation simulation which uses the finite element method approach to both the designed screw feeders with which one can find whether the design suitable for industrial utilization.

This project consists of four different sections; names are followed by literature review, Analytical & simulation, result comparisons and conclusion. In literature review previous works on screw feeder is discussed based on the reference journals and the schematic diagram of research work is described. In Analytical & simulation section of thesis, the deformation and stress on the 4 different type of screw is been obtained using ANSYS workbench. The next sections are results comparisons and conclusion in which the obtained results are explained with the graphs. The ultimate statements are given at the end.

1. LITERATURE SURVEY

Screw feeder or conveyor is a component that uses a rotating helical screw blade called flights usually within a round and hollow tube, to move pelletized particle or fluids. The principle sort of screw conveyor was the Archimedes' screw, used since ancient times to pump irrigation water. Archimedes' screw, also called the Archimedean screw or screw pump, is a machine truly utilized for transferring water from a low-lying body of water into irrigation trench. Water is pumped by turning a screw-shaped surface inside a hollow pipe, from reference [16]

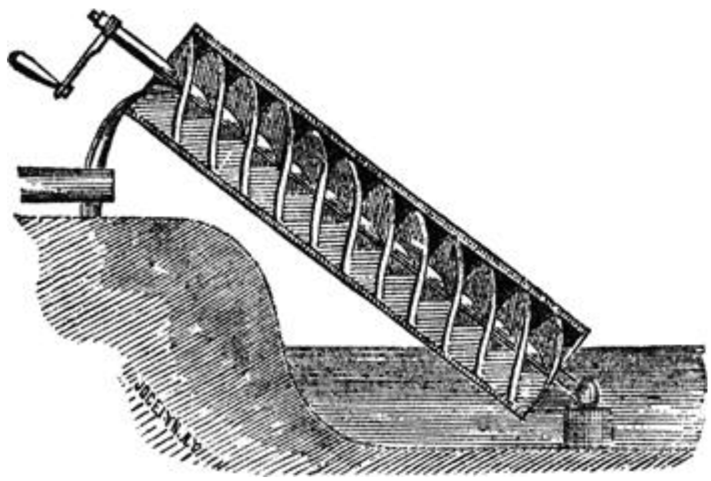


Figure 1.1. Archimedes screw, reference [16]

The screw is turned usually by a windmill or by manual labor. As the shaft turns, the bottom ends flights up a volume of water. This water will slide up in the spiral tube, until it finally pours out from the top of the tube and feeds the irrigation systems. The screw was used mostly for draining water out of mines or other areas of low lying water, from reference [16].

1.1 Screw feeder in biomass industries

The biomass in general refers to organic material from plants and animals including agriculture and civil waste products excluding food products. The biomass can be changed into distinctive forms of bio energy in variety of ways, from low tech to high.

Bio energy technologies are the processes and mechanisms that convert plant and animal matter into energy source. The energy generated from biomass is less harmful to environment and which can be transformed to gas & oil to generate electricity and heat. It can be converted into liquid fuels and used for transportation. The layout of bio mass industry is given below.

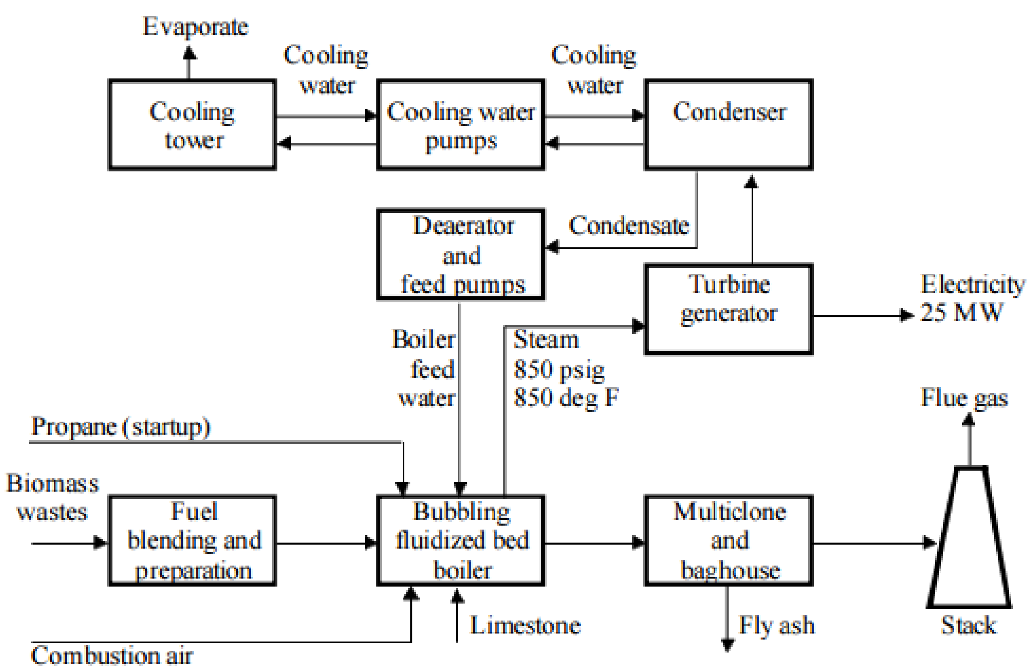


Figure 1.2 Layout of biomass plant, reference [17]

The screw feeders are used to transport the biomass products to Fuel blending and preparation which is further transferred fluidized bed combustion boiler by another screw feeder. The Fluidized bed combustion (FDC) is the combustion technology used burn solid fuels. FBC are capable for burning a variety of low-grade solid fuels, including most type of coal and wooden bio mass in a high efficiency without any expensive fuel separation, from reference [18].

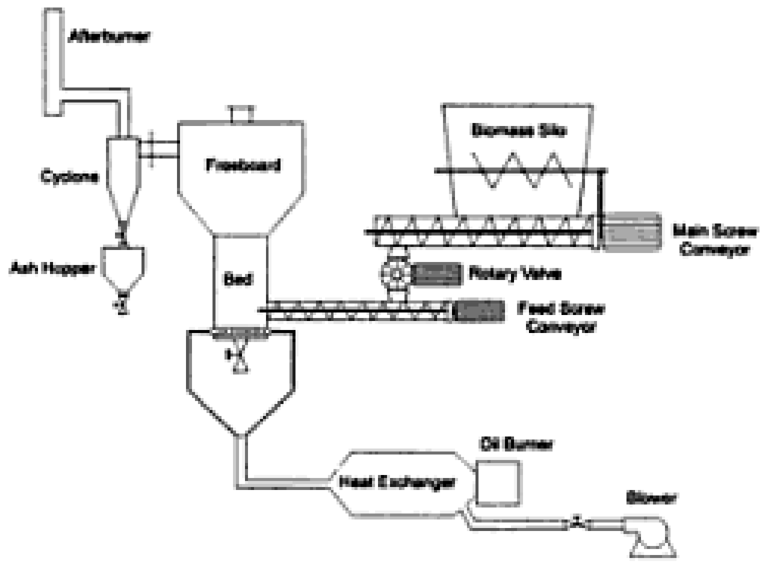


Figure 1.3 Screw feeders in Bio-mass gasification industry, reference [15]

1.2 Study of screw feeder

Jianjun Dai, John R. Grace developed a model for bio-mass screw feeder in which the bulk solid mechanics of a material element within the pocket surface is clearly stated out, reference [6]. The vertical stress exerted on the outlet of the hopper by the bulk material in the hopper is proportional to required torque. In their experiment they have used two screws with different screw diameter as screw-1 and different shaft diameter with constant screw diameter screw-2. The vertical stress and force acting on the flights of the screw feeder is compared. The interaction between the bulk solid materials is also explained using Mohr circle.

In biomass screw feeding with tapered and extended sections by Jianjun Dai, John R. Grace A methodology is presented to analyze the tapered and extended sections which are employed to improve plug seal to reactors in the biomass industry, reference [7]. The wall friction angle and internal friction angle is diffused in this part which is used as reference of calculation of force on the flights.

Roberts and Manjunath [8] have analyzed the volumetric characteristics and mechanics of screw feeders in relation to the bulk solid draw-down characteristics of the feed hopper. Distribution of throughput along screw and uniform draw-down patterns was investigated. Yu and Arnold proposed a theoretical model for torque requirements for single screw feeders. They assumed that the load imposed on a screw feeder by the bulk solids in the hopper is determined by the major consolidation stress.

Alan W. Roberts were carried out experimental investigation of Design and Performance evolution of screw conveyor, based on reference [5]. Screw conveyors with fully enclosed in cylindrical casings were used in experiment. The throughput, torque and power are significantly influenced by the vortex motion of the bulk solid being conveyed. The vortex motion, together with the degree of fill, govern the volumetric efficiency and, hence, the throughput. This, in turn, influences the torque, power and conveying efficiency. A theory is presented to predict the performance of screw conveyors of any specified geometry. The influence of the flow properties of the bulk material on the conveyor performance is given. Performance of screw conveyors is significantly influenced by the vortex motion of the bulk solid being conveyed. The flow properties of the bulk material being conveyed are shown to have a significant influence on the performance.

From Jianjun Dai, John R. Grace journals the properties of pelletized particle are tabulated.

Table 1.1 Properties of pelletized particle

Name of the specimen	**Particle size Range, mm**	**Bulk density Kg/m^3**	**Wall friction angle,(^{o})**	**Internal friction,(^{o})**	**Shape**
Wooden shavings	0.09 to 6.73	188	31.4	38	Irregular
Wood pellets	8 - 11	630	31.4	32	Cylinder
Ground hog fuel	0.09 – 2.8	150	31.8	45	Irregular

1.3 Challenges in existing screw feeders

Commonly faced problems by screw conveyors are pelletized particle density combined with the speed of the drive which causes screw to fail in shaft journals.

1.3.1 Operational parameter stresses

Frequently, certain methods of operating the screw feeder cause oddly high stresses in the screw. These stresses are primarily influenced by the following operating parameters

1.3.2 Different load conditions

Different stress magnitudes occur as a result of different load applications. Impact loads causes stresses that are two to three times higher than the "steady state" stresses that are present in the screw when it is operated at a slow, constant speed in a pelletized particle comprised of a homogenous material mixture as illustrated by reference journal by Improved conveyor performance by adjusting operating parameters to avoid loads and adhering to more rigorous inspections, conveyor downtime from wood screw failures becomes avoidable by Monica Shaw [9].

For example, a 20% increase in density results in a 20% increase in stress. Furthermore, changes in two or more operating parameters, such as filling conditions and material density, have an increasing effect as the stresses are added together, from reference journal [9].

Figure 1.4 Shows the excessive loads conditions frequently result in fatigue failures in the shaft, reference [9]

Figure 1.5 Shows the crack development at the end of shaft or weld section due to the stress and deflection, reference [9]

1.3.3 Operator faults

When the screw does not function as required, the first reaction by some personnel is to enlarge some of the screw's parts to improve performance and prevent future failures. Although increasing the applied horsepower or torque by increasing the motor size, gear ratio, shear pin diameter, or coupling bolt size may solve the problem, it decreases the screw's expected life by relocating the stress to a more crucial portion of the equipment based on the reference [9].

1.3.4 Shape of shaft

Stress magnitudes can be altered by changing the thickness or diameter of the shaft, but mostly do not change these dimensions because it requires a change in the unit's design and an alteration of the original equipment supplied by the manufacturer based on the reference [9].

1.4.1 Major advantage of shafted screw feeder

- ✓ The screw feeders are very compact and adaptable to congested locations. It does not have any return to similar to a belt or drag conveyor.
- ✓ Screw feeders are capable of handling a great variety of bulk material from slow-moving to free- flowing.

1.4.2 Major disadvantage of shafted screw feeder

- ✓ During the transportation of stick, wet and slow moving material in the screw feeder there will be loss in flow of pelletized particle at feeder outlet which happens due to pelletized particle sticking at the centre shaft of screw feeder which leads to jamming in the transportation.
- ✓ The most of screw feeder in the biomass industries is fixed only at one end and other is open to the furnace which causes the maximum stress at the end of the shafts and deformations occurs periodically. This happens due to weight of the screw feeder.

1.5 Axle-free screw feeder and its advantages

The present drawback in the screw feeder is overcome in this project by using axle-free screw feeder (shaft less). The bulk material discharge from hopper or filter presses can easily be metered or conveyed by Axle-free (shaft less) screw feeder based on the reference [10].

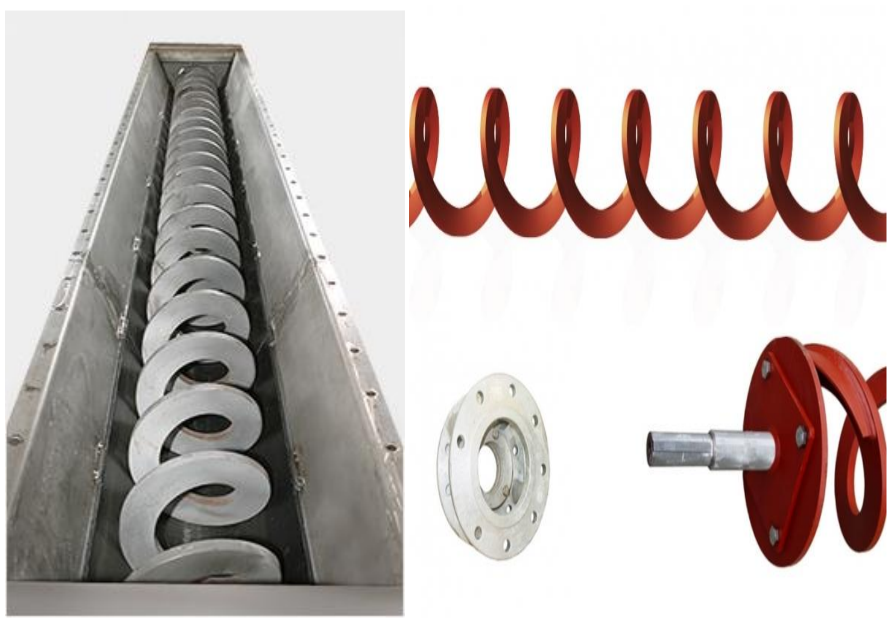
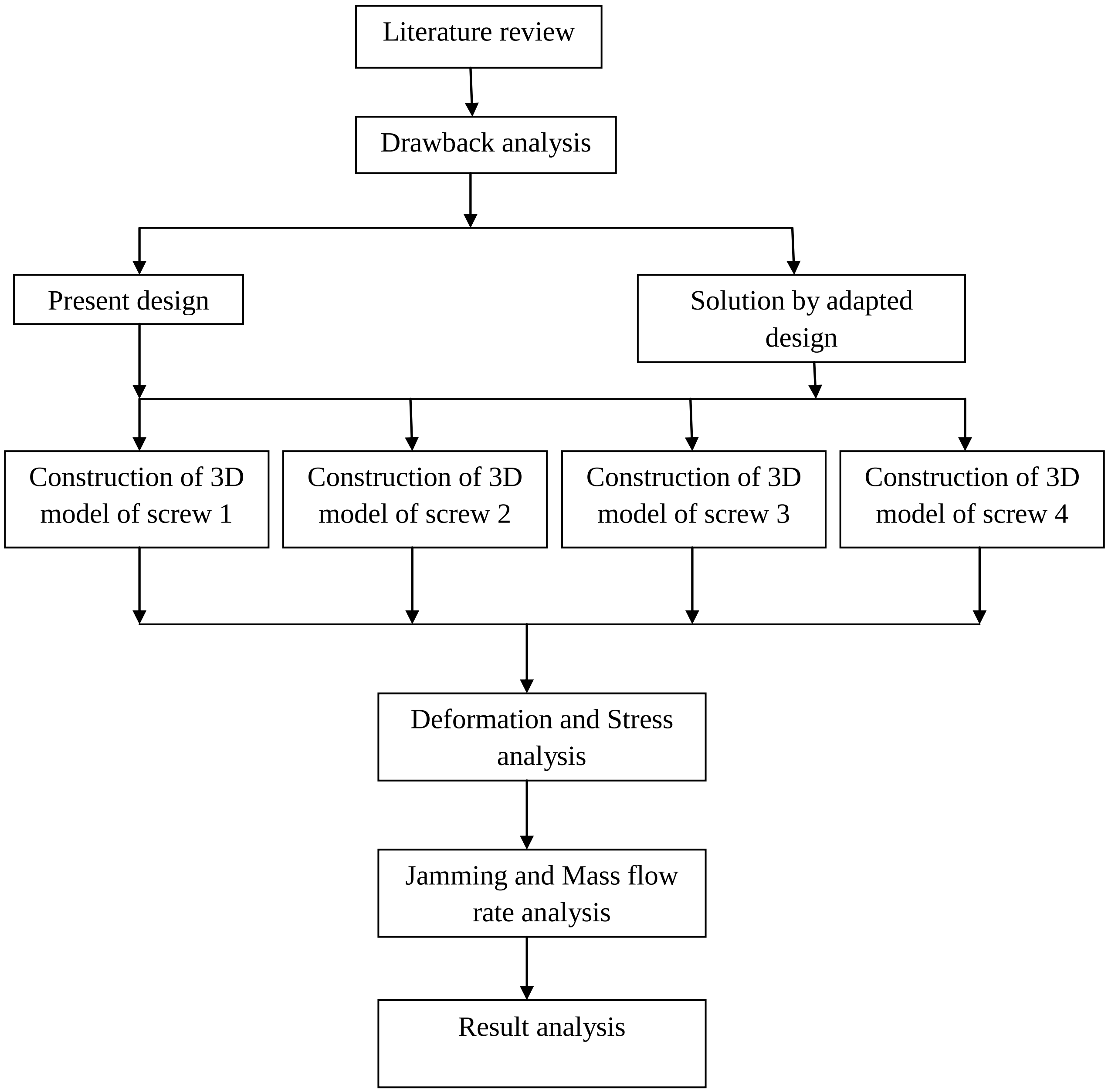


Figure 1.6 Axle-free screw feeder, reference [10] & [13]

1.5.1 Advantage of using Axle-free screw feeder

- Ideal for handling sticky and sluggish bulk material.
- Conveying efficiency is improved when compared to shafted screw feeder.
- Less wear
- Maintenance is little bit less when compared to shafted screw feeder
- Handling of large objects up to trough diameter

1.6 Schematic diagram of research work



2. EXPERIMENTAL SETUP & ANALYSIS

The experimental design and complete setup is based on the reference of the journal “A Modal for biomass screw feeding” by Jianjun Dai and John R Grace [6]. The complete design of experiment setup is done on using SOLIDWORKS. The DC motor with 0.56 kW is constructed using SOLIDWORKS based on the reference journal [6]. Flange is constructed by SOLIDWORKS which is used coupling device to connect shafts in this machinery. Two connections are made by flange in this project, one is Motor-Speed reducer and another one is Speed reducer-screw feeder shaft. Flange is based on design standards [11]. A bearing is a machine element that constrains relative motion to only the desired motion and reduces friction between moving parts based on bearing definitions. The tapered bearing is used at the end of the shaft of screw feeder which construed based on design standards. ISO 355-2CD30-16, DE,NC,16.

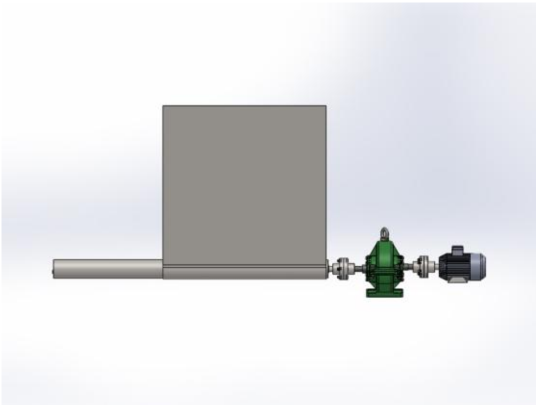


Figure 2.1 Full assembly side view with screw feeder

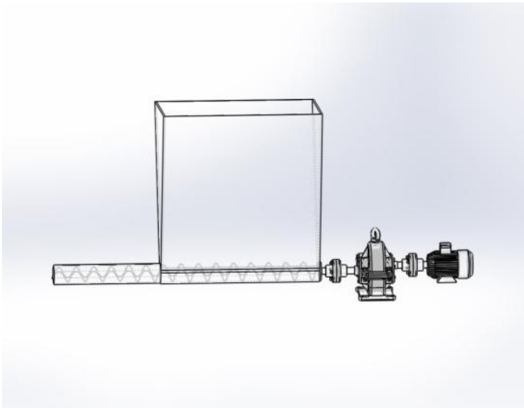


Figure 2.2 Wireframe view of screw feeder-hopper complete assembly

Different screw feeders are used in this project one of the screw feeder is with shaft based on the reading of pervious reference and others is axial free (shaft less) screw feeder, it is the new concept of implementing into the machinery.

2.1 Parameters of screw feeder and hopper

The Screw feeder is designed in SOLIDWORKS and the dimensions are tabulated in Table 1.

Figure 2.3 Isometric view of Designed Screw Feeder

Table 2.1 Screw dimensions

Parameter of Screw Feeder	Dimensions
Screw length	In Hopper length = 910mm In choke section= 610mm Total length of Screw= 1520 mm
Screw diameter, Do	100;90;80 (*1)
Shaft diameter, Ds	30 mm
Pitch,P	100
Flight Thickness	6.35
Clearance, c	1;6;11 (*1)
Material	316 SS

*1- For the length of first 800 mm of screw is 100 mm diameter with clearance as 1 mm. Next 300 mm of screw is 90 mm dia with clearance 6 mm. The last 420 of screw is 80 mm diameter with clearance 11mm.

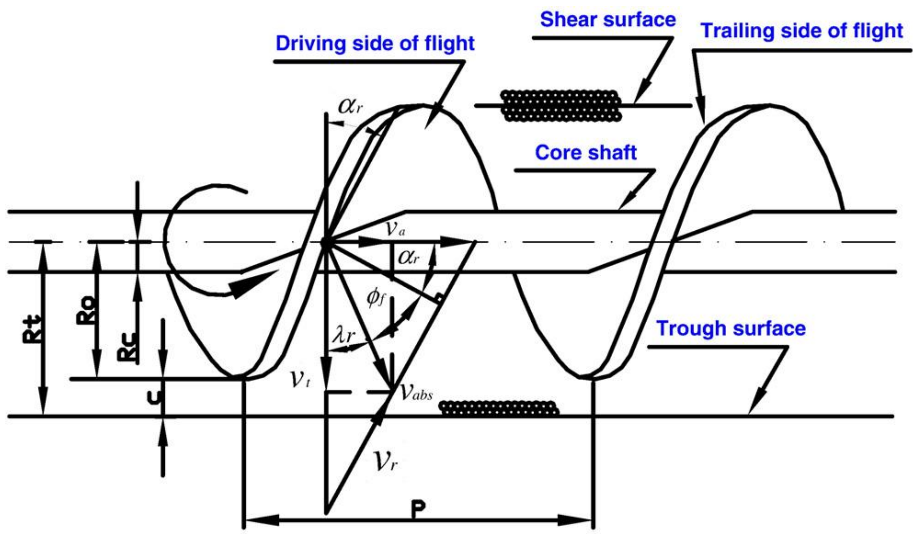


Figure 2.4 Screw feeder with dimensional parameters, reference [6]

The schematic diagram of Hopper

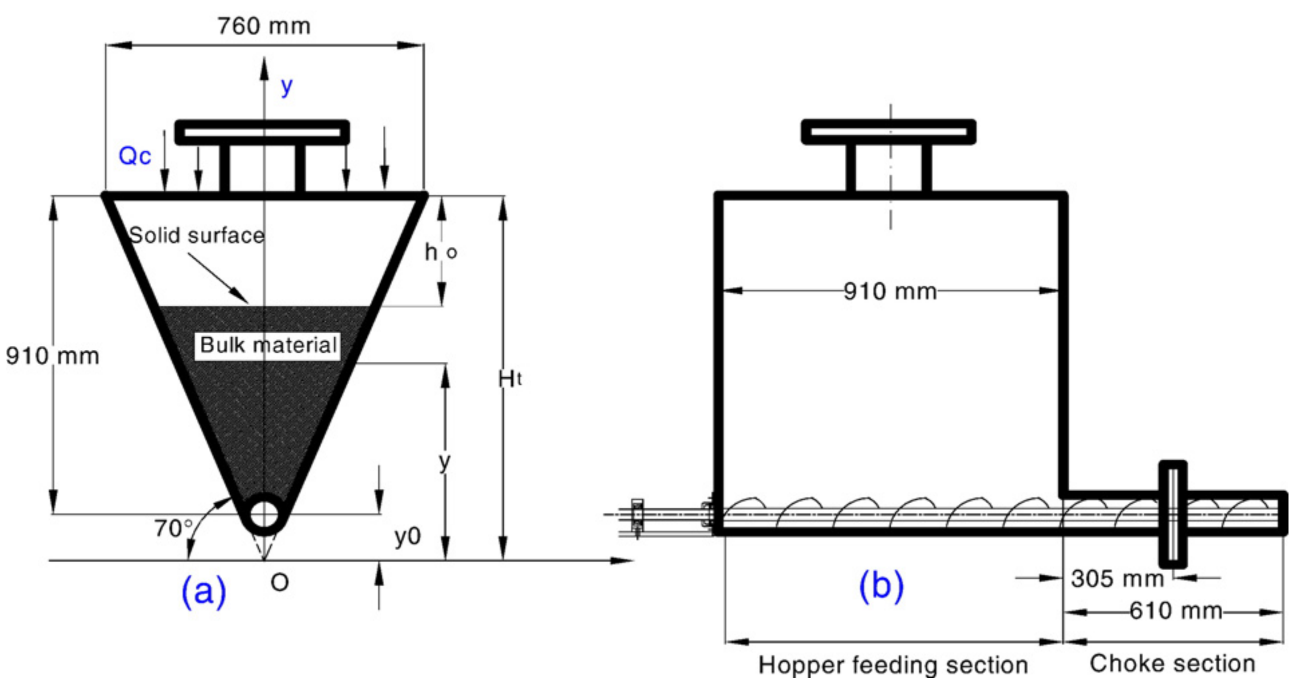


Figure 2.5 Front view and Side view of hopper, reference [6]

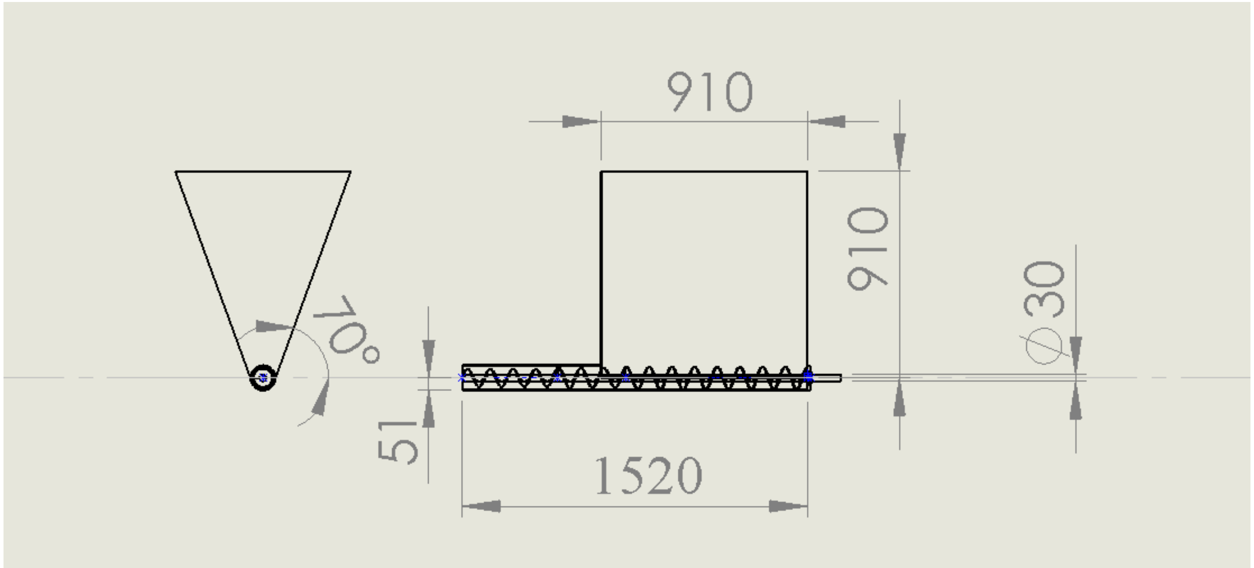


Figure 2.5 (b) Shows drawing of constructed model.

The hopper and Trough dimensions are given in Table 2.2 & Table 2.3.

Table 2.2 Hopper dimensions

Parameters of Hopper	Dimensions
Type	Wedge-shaped
Length	910 mm
Height	610 mm
Angle with horizontal axis	70^{o}
Material	Carbon steel

Table 2.3 Trough dimensions

Parameter of trough	Dimensions
Diameter, Dt	102 mm
Material	Carbon Steel

2.2 Wooden pellets

The analysis of the screw feeder is done based on the material to be transported. In this project the wood is consider to be transported in the screw feeder. The wood pellets are the one of the most common material used to transport biomass product. The property of screw feeder is given below.

Table 2.4 Property of Wooden pellets

Property of wood	Values
Bulk Density	630 Kg/m^3
Young Modulus	1.1E+09 Pa
Poisson Ratio	0.3
Bulk Modulus	9.1667E+08 Pa
Shear Modulus	4.2308E+08 Pa

2.3 Analysis of hopper-feeder

The analysis below consider on hopper, feeder and choke section. The capacity of screw feeder, stresses and forces calculations are done.

2.3.1 Capacity of Screw Feeder

The capacity of screw feeder can be determined by the formula derived by Siddhartha ray 2008 [2], Introduction to Material Handling. The screw diameter, pitch of screw, screw speed as a major role in the calculation of capacity of screw.

$$Q = V\gamma = \frac{\pi}{4}\, D^2\, S60n\phi\gamma C, ton/hr \qquad \text{Eqn (1)}$$

Q= Tonnage capacity, ton/hr

V= Volumetric capacity, m^3/hr.

D= Screw diameter, m

n = Speed, rpm

S= Screw pitch, m

γ = Bulk density, kg/m^3

C= Factor depending upon inclination of feeder.

ϕ = Flow ability of material, it depends upon the material.

Table 2.5 Flow ability of material

Material characteristics	Value of ϕ
Slow flowing abrasive	0.125
Slow flowing Mild abrasive	0.25
Free flowing mild abrasive	0.32
Free flowing non-abrasive	0.4

Therefore the capacity of shafted screw = 0.609 t/hr = 0.16 kg/s.

2.3.2 The Filling Condition

The filling condition in hopper h_o as show in Figure 2.5, is given as 0.3 m and 0.45 m it was formerly employed by the precious journals by "A Modal for biomass screw feeding" by Jianjun Dai and John R Grace. To find stress and force acting on screw feeder inside hopper can be calculated by the formula derived from the previous journals.

$$\sigma_V = q\rho_b g L_h B, N/m^2 \qquad \text{Eqn (2)}$$

σ_v = Vertical stress, N/m^2

$\rho_b = 630 kg/m^3$, Bulk density

q = Surcharge factor = 1.04

B = hopper outlet width, mm

L_h= Length the particle filled in Hopper condition.

G= Standard earth gravity, m/s^2

Under filling condition, once the flow is initiated the stress field is generated in the hopper. This stress field is generated throughout the hopper. The surcharge factor is involved in the calculation of vertical stress acting on the screw feeder due to stress on the upper part of the pelletized material. The surcharge factor (q_f) can be calculated by the formula which is given below based on the reference [1].

$$q_f = \left(\frac{\pi}{4}\right)^m \frac{Y\,(1+\sin\delta)}{2\,(X-1)\sin\alpha} \qquad (3)$$

Where X and Y,

$$X = \frac{\sin\delta}{1-\sin\alpha}\left[\frac{\sin(2\beta+\alpha)}{\sin\alpha} + 1\right] \quad (4)$$

$$Y = \frac{(\alpha+\beta)\sin\alpha + \sin\beta\sin(\alpha+\beta)}{(1-\sin\delta)(\sin(\alpha+\beta)^2)} \quad (5)$$

m, Hopper factor=1 (for axis symmetric flow)

δ, Effective angle of internal friction

α, Hopper angle.

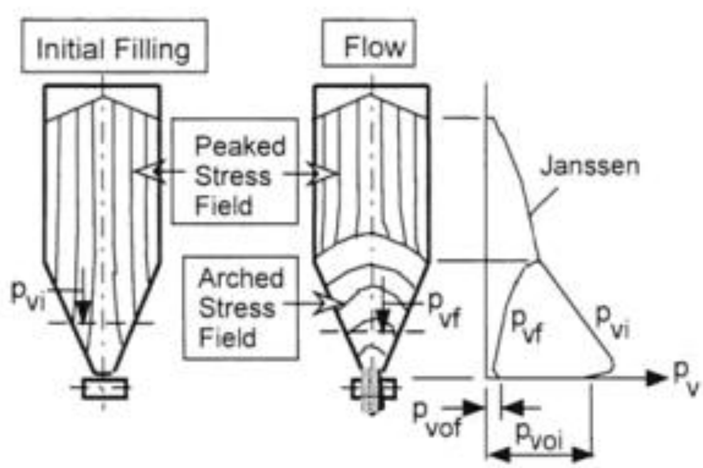


Figure 2.6 Stress Field, reference [12]

The vertical stress calculation are made according to the equation (2) for the both filling condition and the results are tabulated

Table 2.6 Vertical stresses

	Hopper Level	Values
Vertical stress inside hopper, σ_v	0.3	1683.5 N/m^2
	0.45	2195 N/m^2

The vertical stress acts only the shaft part which is inside the hopper. The remaining part in trough will be subjected to have only axial stress.

2.4 FORCES ACTING ON SCREW FEEDER

The force acting on the screw feeder is illustrated by Figure given below.

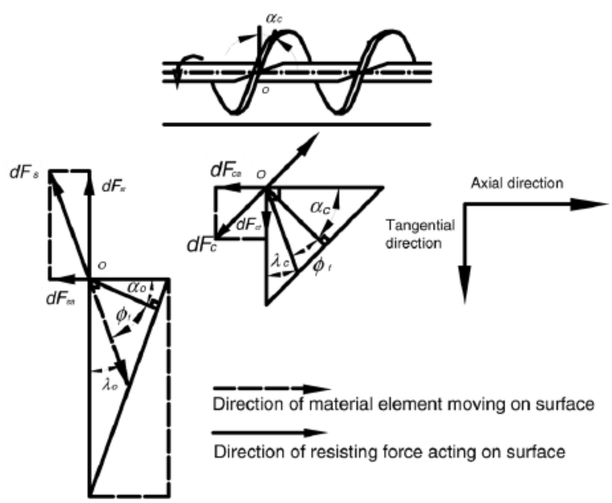


Figure 2.7 Force acting on the flight, reference [6]

The Force acting on flight of screw feeder is product of equivalent friction co-efficient of bulk solids it is taken from reference journal, A modal of biomass screw feeding by Jianjun Dai, John R Grace.

2.4.1 Force on driving slide of flight

To calculate the force on driving slide of flight additional factor such as force on trailing surface and trough surface is taken into account. The friction force on the trailing side resists the forward motion of pelletized particle but it helps to rotate material inside the pocket section. Pelletized particle moves forward due to connect on the driving slide of the screw feeder. The Figure 2.8 shows the resisting force acting on the trailing side of the screw flights. Figure 2.9 shows driving force on the material. The force acting trailing flight are derived in equation (6) & (7)

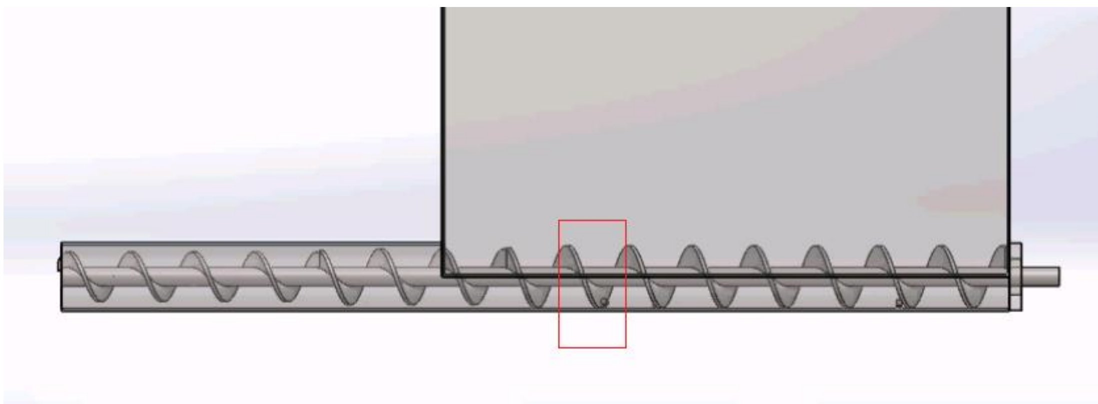


Figure 2.8 Resisting force acting on the pelletized material

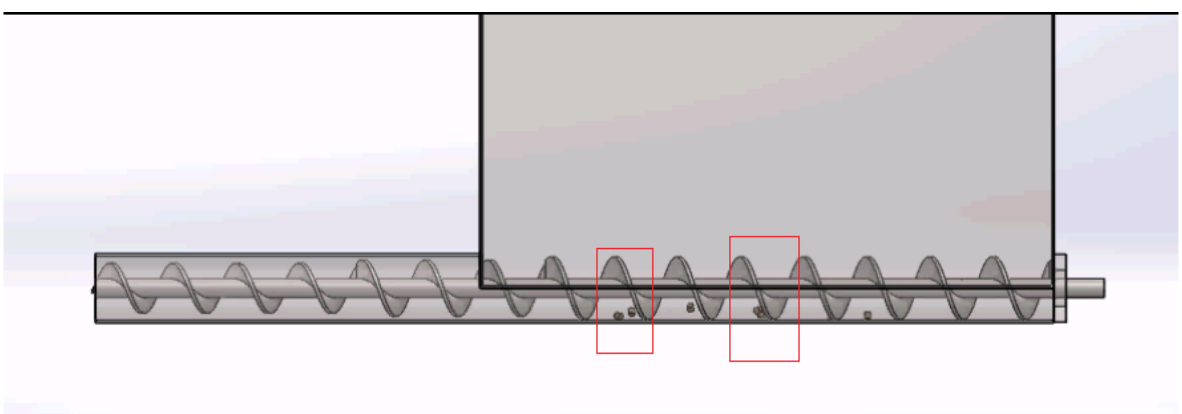


Figure 2.9 Driving force acting on the pelletized material

$$F_{ts} = K_{ts}\sigma_v D_o^2 \quad (6)$$

$$K_{ts} = [\frac{\pi\mu}{4} (1 - c_d^2) - \frac{c_p}{2}(1 - c_d)] \quad (7)$$

The pelletized particle subjected to have frictional force on the inside surface of trough. The axial resisting on the screw flight is given by equation (12) & (13).

$$F_{to} = K_{to}\sigma_v D_o^2 \quad (8)$$

$$K_{to} = \frac{\pi c_t (c_t - c_d)}{8} \cos(\alpha + \phi) \quad (9)$$

Where $c_t = \frac{2R_t}{D_o}$, Ratio of trough to screw diameter

$c_d = \frac{D_C}{D_o}$, Ratio of core shaft diameter to screw diameter

$c_p = \frac{P}{D_o}$, Ratio of pitch to screw diameter

Therefore the force acting on the driving flight of screw feeder is given by equation (10) & (11).

$$F_{dt} = K_{dt}\, \sigma_v\, D_o^2 \quad (10)$$

$$K_{dt} = \frac{4\,(K_{to} + K_{ts})}{\pi\,(1 - C_d^2)} \quad (11)$$

Table 2.7 Force on flights of all four screws

Hopper Level, m	Force acting on flights of screw 1, N	Force acting on flight of screw 2, N	Force acting on flights of screw 3, N	Force acting on flights of screw 4, N
0.3	173.5	89.2	79.46	70.14
0.45	269.1	178.4	144.9	127.68

The deformation of the screw feeder is simulated using workbench. The results of Maximum stress, total deformation and deflection through Y- axis are taken

2.5 Simulations for shafted screw feeder, screw 1

The simulation is done using ANSYS workbench. Only screw and trough part is taken into account. At first the shafted screw feeder (SCREW 1) taken deformation and stress analysis.

2.5.1 Total deformation for screw 1

The vertical stress and pressure on driving side of the flights is applied on the shafts of the Screw-1 with fixed support at one end. The simulated results and values are tabulated below.

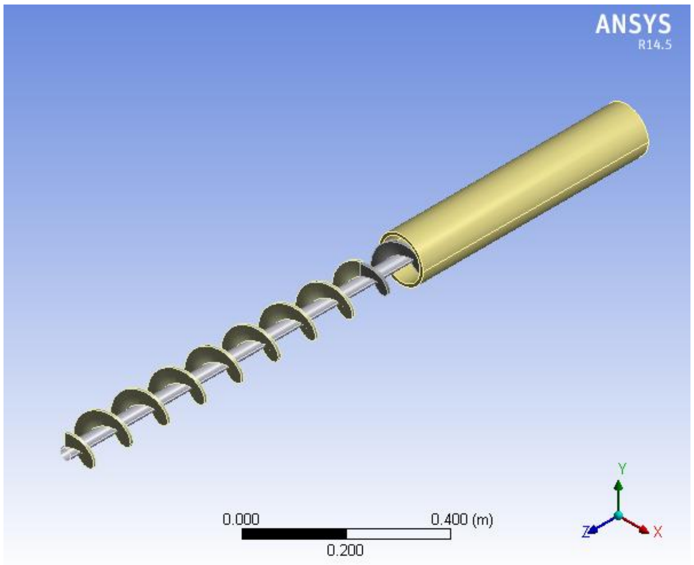


Figure 2.10 Screw 1 with trough in ANSYS workbench

With respect to two filling condition 0.3m and 0.45m of hopper the pressure values are given. At first the total deformation of about the filling condition is given below. The total deformation of screw 1 is shown in next page.

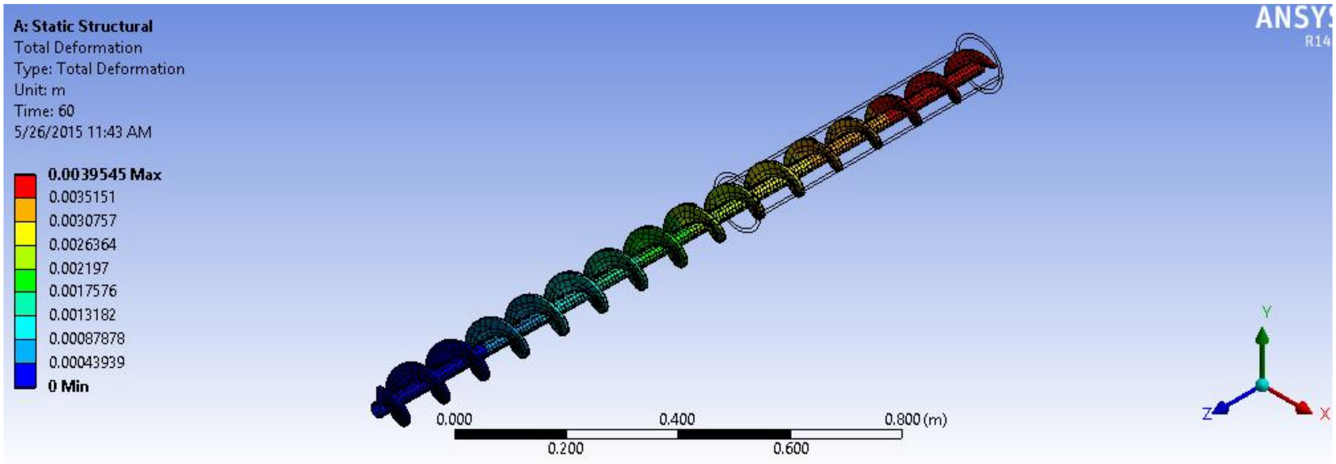


Figure 2.11 Wireframe view of hopper level 0.3m

The Figure 2.11 shows the result of total deformation for screw 1 with filling level 0.3m. The below image 2.12 shows the total deformation for filling level 0.45m.

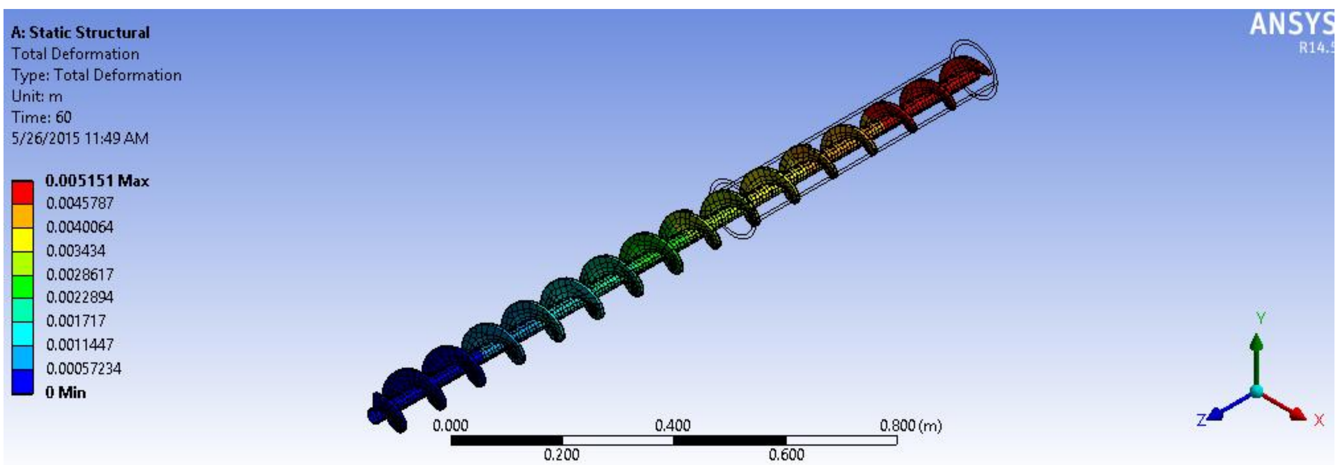


Figure 2.12 Wireframe view of Total deformation for hopper level 0.45

The values from the above simulated results are tabulated.

Table 2.8 Total deformation of SCREW 1

Shafted screw feeder Total Deformation	Hopper level, mm	Maximum, mm
	300	3.9
	450	5.2

2.5.2 Maximum Principal Stress for screw-1

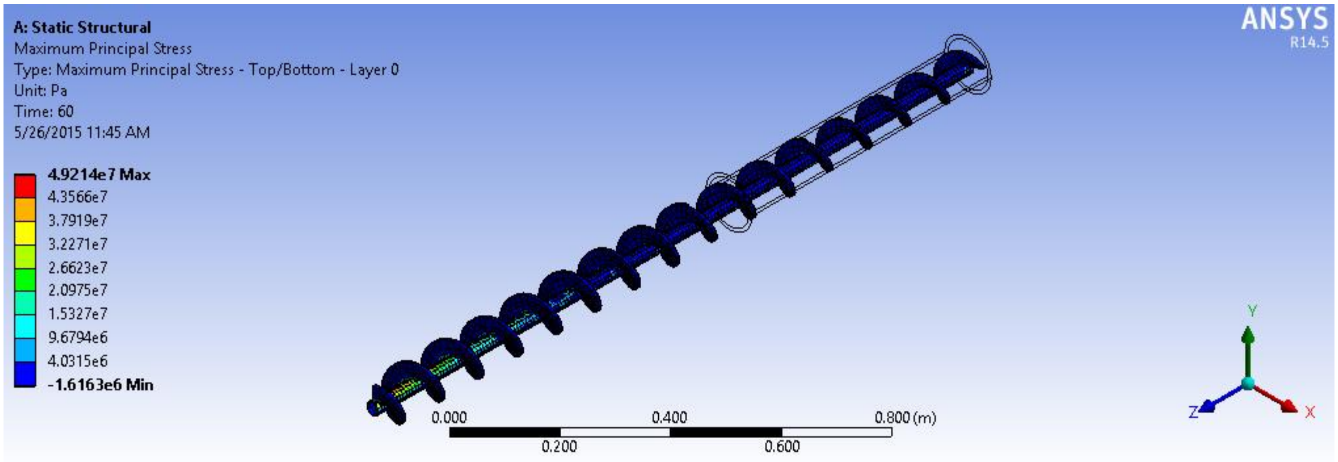


Figure2.13 Wireframe view of Maximum Principal Stress for 0.3m

The Figure 2.13 shows the result of Maximum principal stress for screw 1 with filling level 0.3m. The below image 2.14 shows the Maximum principal stress for filling level 0.45m.

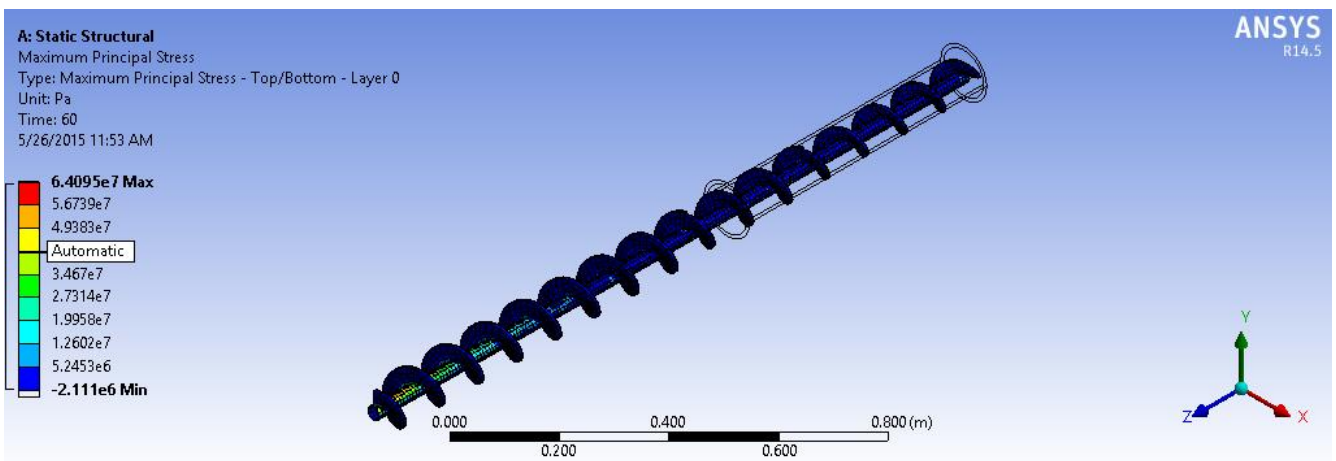


Figure 2.14 Wireframe view of Maximum Principal Stress 0.45

Table 2.8 (a) Maximum Principal Stress for SCREW 1

Shafted screw feeder Maximum principal stress	Hopper level, m	Maximum, MPa
	0.3	49.214
	0.45	64.095

2.6 Simulation for axial free screw feeder , Screw-2

The Axial free screw feeder SCREW-2 as same diameter with respect to SCREW 1 but it is shaft free connected to one end as show in the Figure.

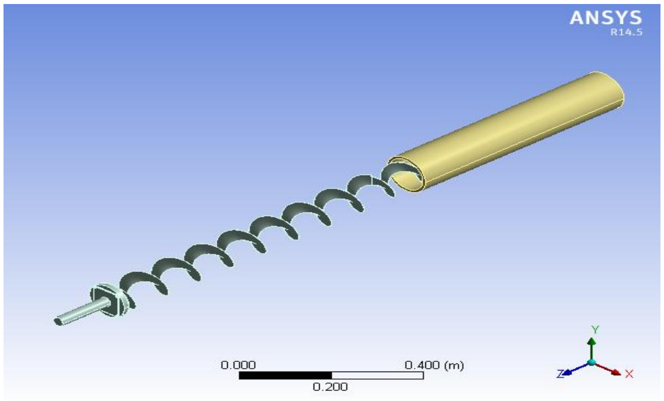


Figure 2.15 Axial free Screw Feeder with different diameter

2.6.1 Total deformation for axial free screw feeder SCREW-2

Based on design of existing shafted screw feeder proposed by John Dai, Same screw diameter is used but without the centre shaft is created.

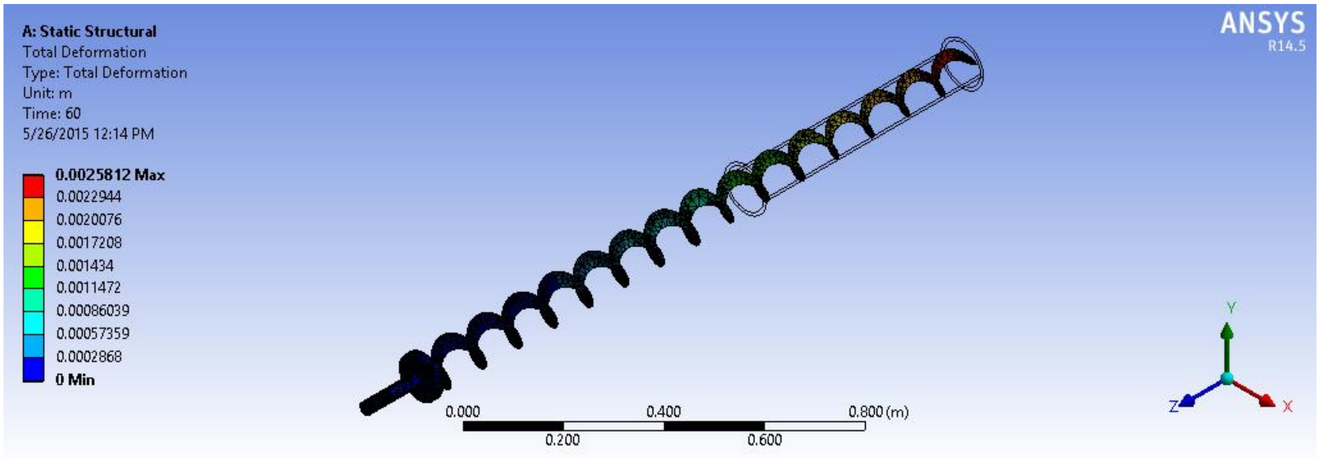


Figure 2.16 Wireframe view of axial free screw feeder with different diameter SCREW 2, 0.3m

The Figure 2.16 shows the result of total deformation for screw 2 with filling level 0.3m. The below image 2.17 shows the total deformation for filling level 0.45m.

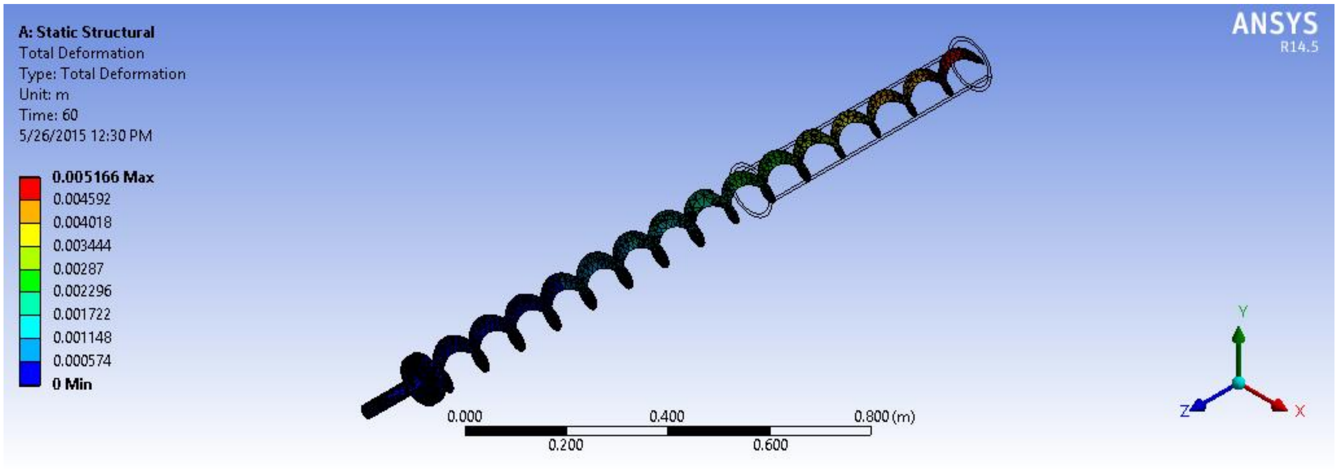


Figure 2.17 Wireframe view of axial free screw feeder with different diameter SCREW 2, 0.45m

Table 2.9 Total deformation of SCREW 2

Axial free screw feeder, SCREW-2 Total deformation	Hopper level, mm	Maximum, mm
	300	2.5
	450	5.1

2.6.2 Maximum principal stress for screw 2

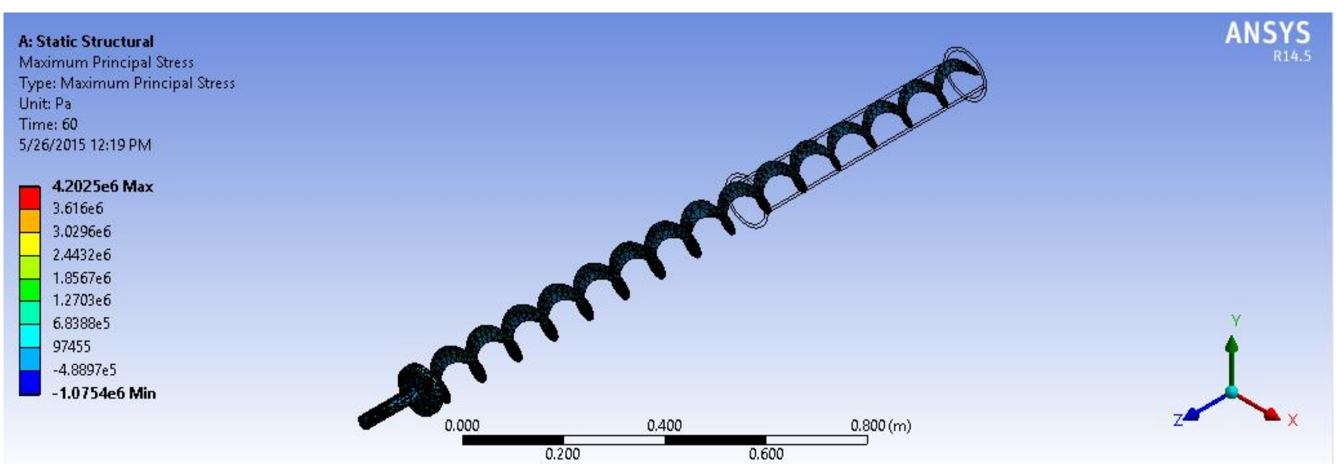


Figure.2.18 Wireframe view of Maximum Principal Stress for filling condition 0.3m

The Figure 2.18 shows the result of Maximum principal stress for screw 2 with filling level 0.3m. The below image 2.19 shows the Maximum principal stress for filling level 0.45m

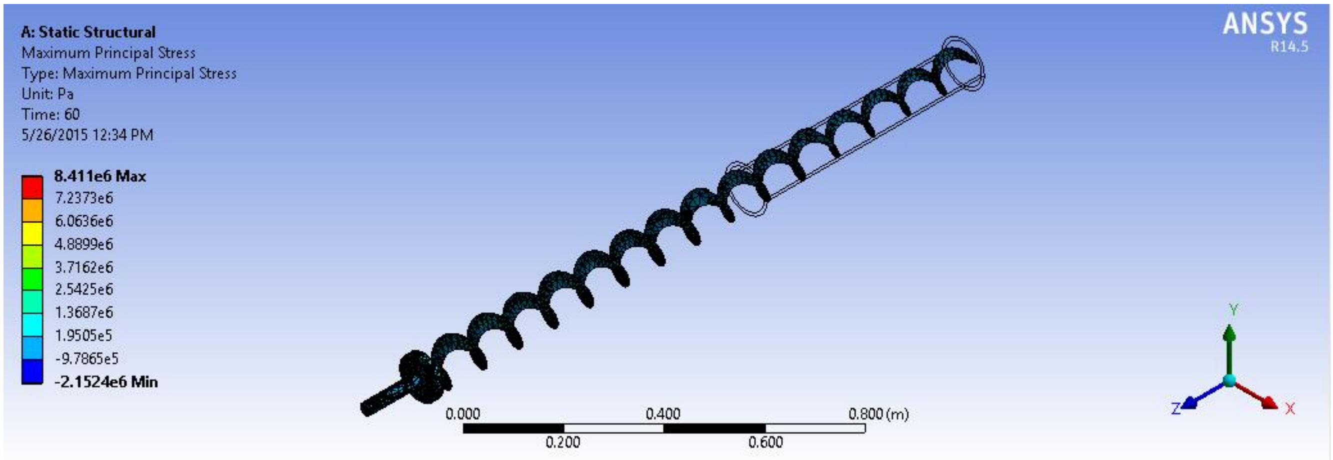


Figure 2.19 Wireframe view of Maximum Principal Stress for filling condition 0.45m

Table 2.9 (a) Maximum Principal Stress for SCREW 2

Axial free screw feeder with different diameter (SCREW-2) Maximum Principal Stress	Hopper level, m	Maximum, MPa
	0.3	4.202
	0.45	8.411

2.7 Axial free screw feeder with standard diameter, Screw 3

Now the research is carried out by applying standard diameter of axial free screw feeder to existing assembly. Two screws with 90 mm and 80 mm are used, Screw 3 is with diameter of 90 mm and Screw 4 is with of diameter 80 mm. At first, SCREW- 3 is analyzed with two filling conditions 0.3m and 0.45m.

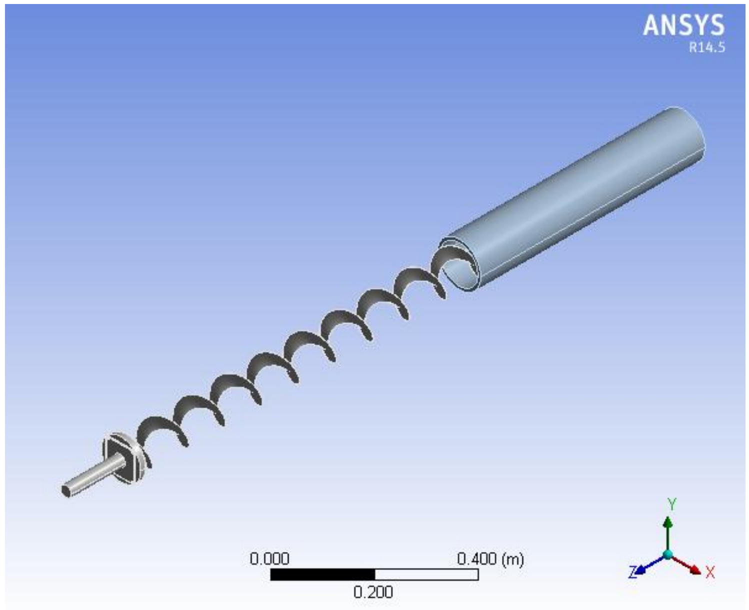


Figure 2.20 Axial-Free screw feeder with 90 mm diameter, SCREW-3.

2.7.1 Total deformation of axial free screw feeder with 90mm diameter, SCREW-3:

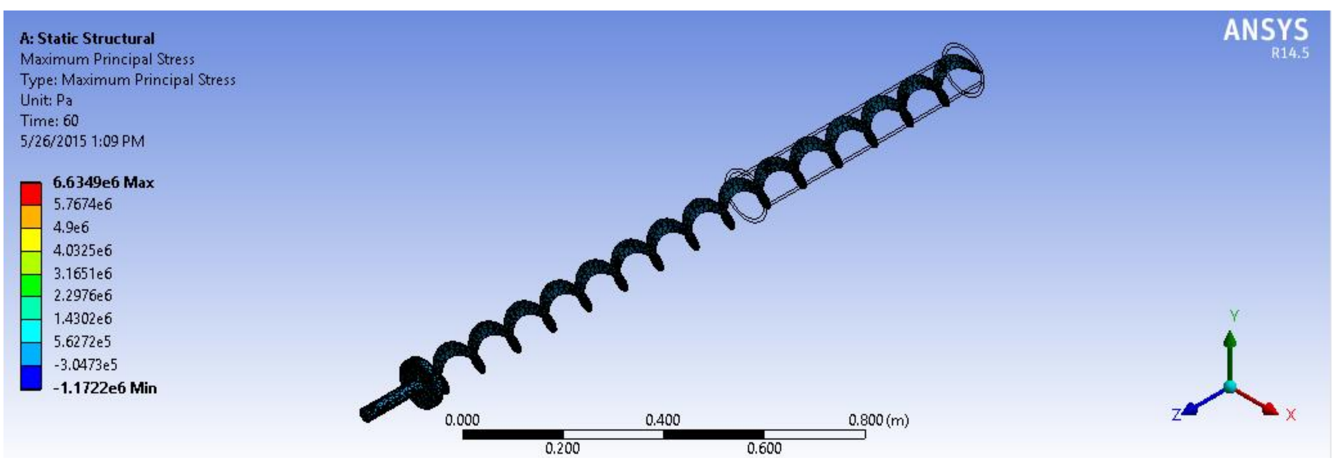


Figure.2.21 Wireframe model hopper level 0.3m, Screw-3

The Figure 2.21 shows the simulated result of total deformation for screw 3 with filling level 0.3m. The below image 2.22 shows the total deformation for filling level 0.45m.

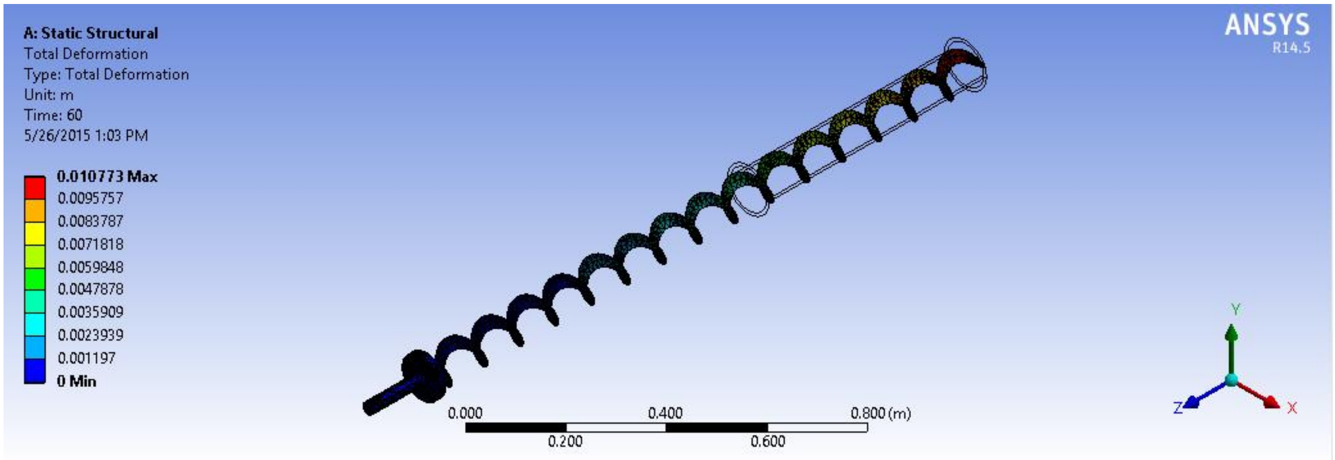


Figure 2.22 Wireframe view of total deformation for hopper level 0.45m, Screw-3

Table 2.10 Total deformation of SCREW 3

Axial free screw feeder , SCREW-3 Total deformation	Hopper level, mm	Maximum, mm
	300	5.82
	450	10.77

2.7.2 Maximum Principal Stress for hopper level for Screw 3:

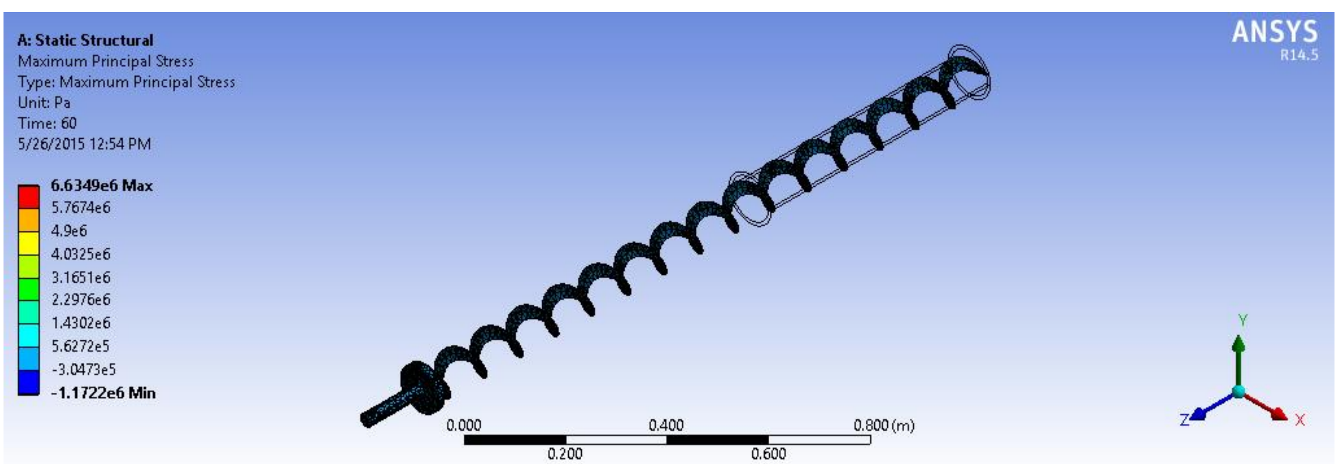


Figure 2.23 Wireframe view of Maximum Principal Stress with hopper level 0.3m, Screw-3

The Figure 2.23 shows the simulated result of Maximum principal stress for screw 3 with filling level 0.3m. The below image 2.24 shows the Maximum principal stress for filling level 0.45m.

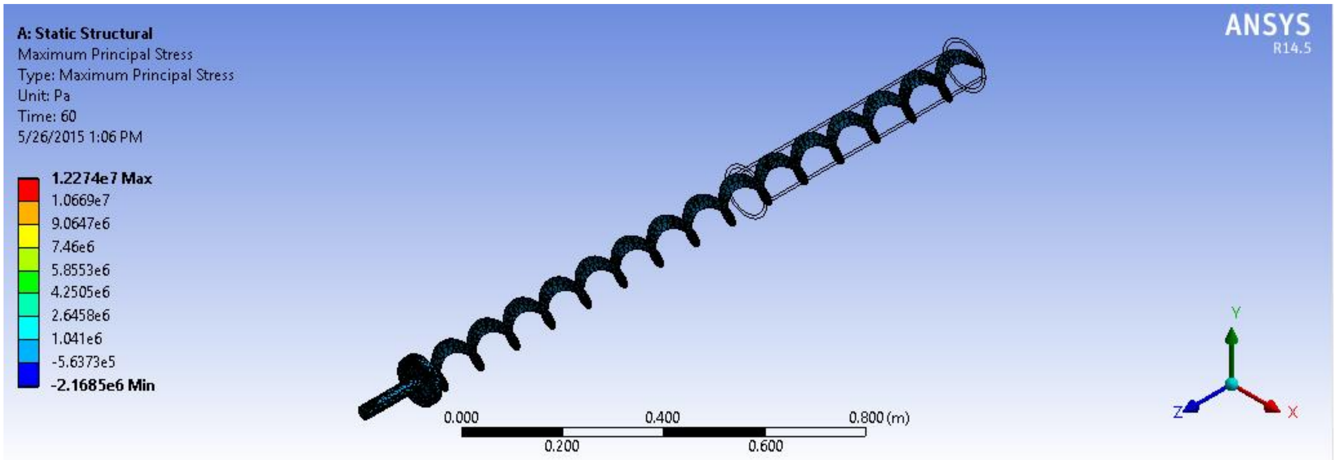


Figure 2.24 Wire frame view of Maximum Principal Stress with hopper level 0.45m, Screw-3

Table 2.10 (a) Maximum Principal Stress for SCREW 3

Axial free screw feeder , SCREW-3 Maximum Principal Stress	Hopper level, mm	Maximum, MPa
	0.3	6.634
	0.45	12.27

2.8 Axial free screw feeder with 80 mm diameter, Screw 4

Now the research is carried out with another screw feeder with screw diameter 80mm based on standard diameter specifications.

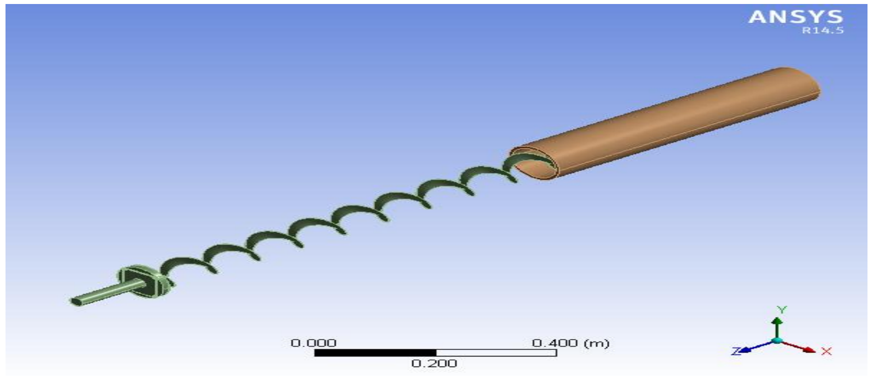


Figure 2.25 Axial-Free screw feeder with 80 mm diameter, SCREW- 4.

2.8.1 Total deformation of axial free screw feeder with 80 mm diameter

The Figure below Figure 2.26 shows the total deformation of axial free screw feeder with 80 mm diameter with hopper level 0.3m.

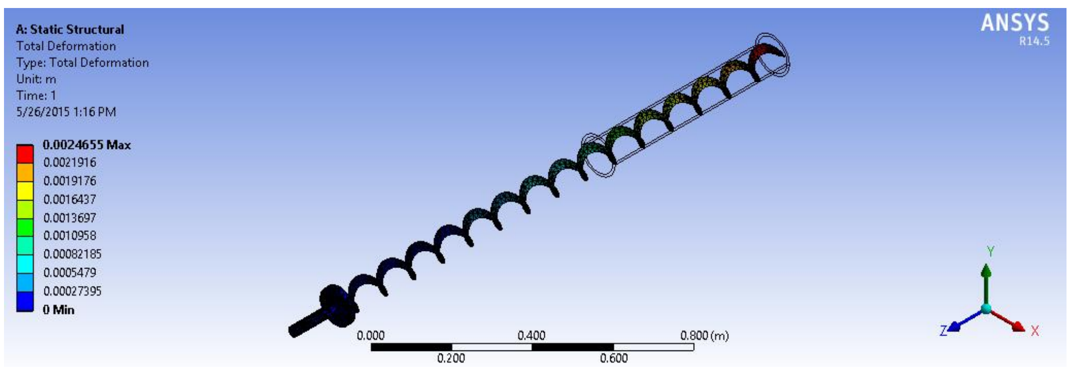


Figure 2.26 Wireframe model for hopper level 0.3m, Screw- 4

The Figure below 2.27 shows the directional deformation of axial free screw feeder with 80 mm diameter with hopper level 0.45m.

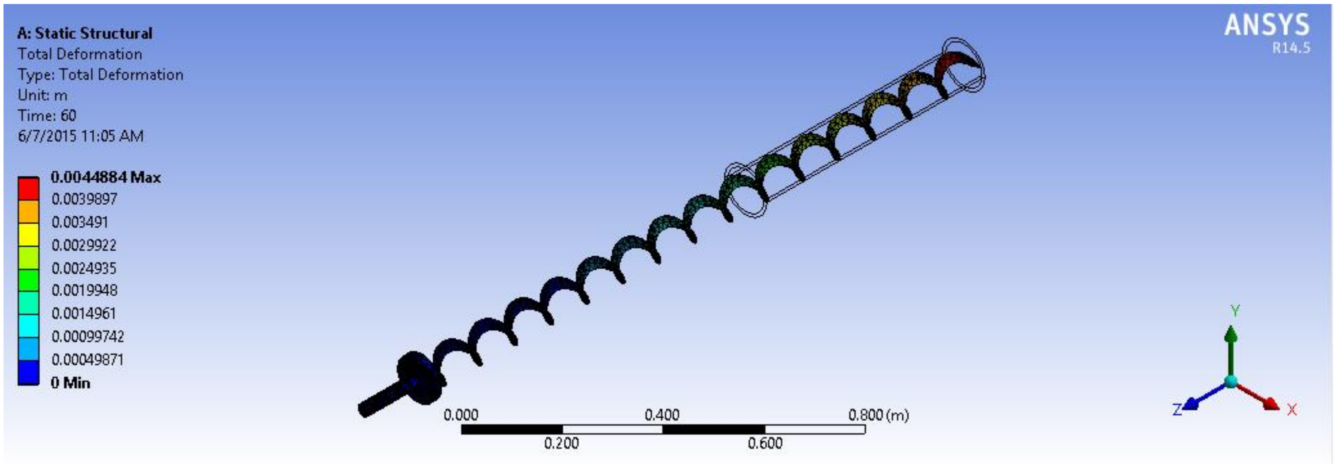


Figure.2.27 Wireframe view of total deformation hopper level, 0.45m

Table 2.11 Total deformation of SCREW 4

Axial free	Hopper level, mm	Maximum, mm
screw feeder 80mm dia	300	2.47
Total deformation	450	4.48

2.8.2 Maximum principal stress for axial free screw feeder with 80mm

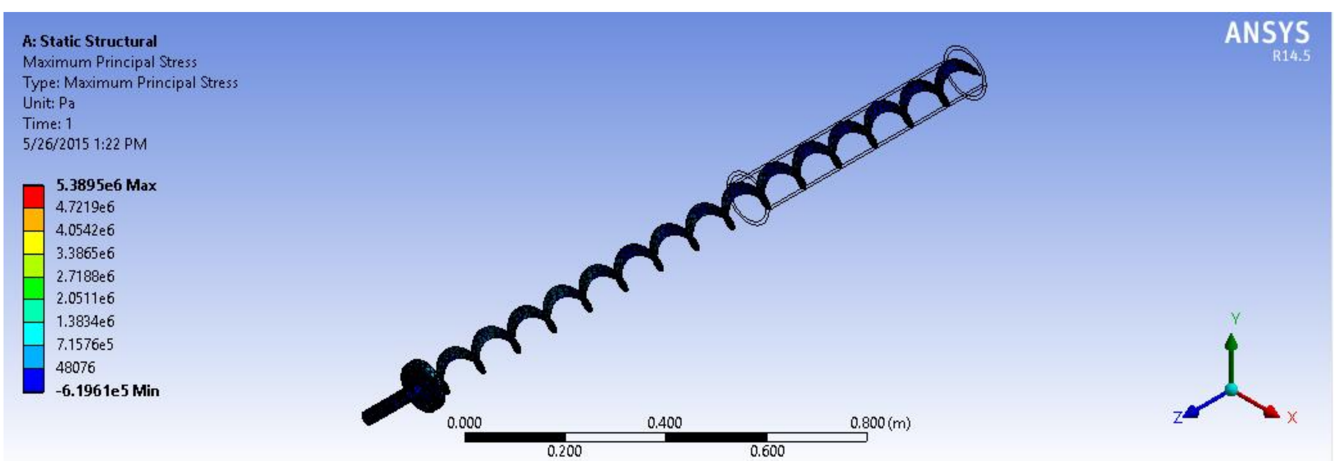


Figure 2.28 Wireframe view of Maximum principal stress for 0.3m, Screw-4

The Figure 2.28 shows the simulated result of Maximum principal stress for screw 3 with filling level 0.3m. The below image 2.29 shows the Maximum principal stress for filling level 0.45m.

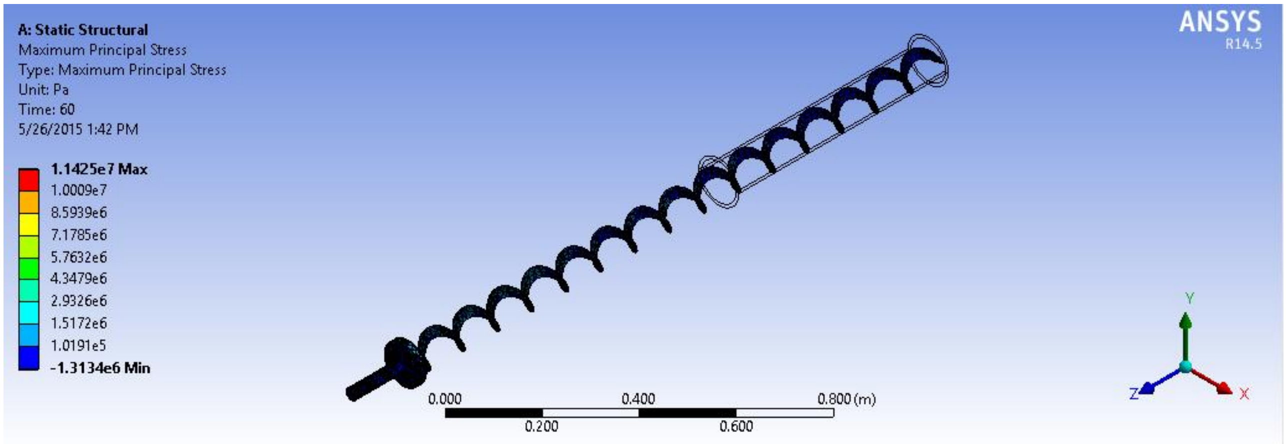


Figure 2.29 shows the Wireframe model Maximum principal stress for 0.45m, Screw-4

Table 2.11 (a) Maximum Principal Stress for SCREW 4

Axial free	Hopper level, m	Maximum, MPa
screw feeder 80mm dia	0.3	5.389
Maximum principal	0.45	11.425

3.9. Analysis of jamming using CFD

The jamming occurs in the place where the trough part and hopper part is joined. If trough part is higher and if base of the hopper part is lower to it then the jamming of pelletized particle occurs. The design change of hopper is done after analyzing in both motion analysis and CFD of SOLIDWORKS.

Using CFD of SOLIDWORKS the jamming found in the hopper design by analyzing the pressure of the pelletized particle in the hopper. The images of the analysis are given below.

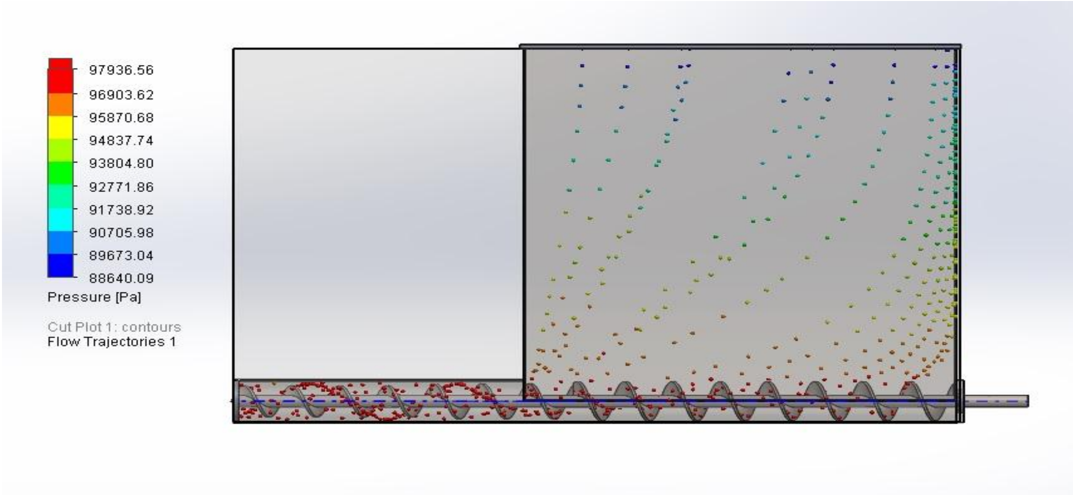


Figure 2.30 Pressure of particles in hopper 1 with Screw 1 Assembly

The above Figure 2.30 shows the pressure on pelletized particles in hopper. For hopper 2, the same assembly is made with Screw 1 which is shown in Figure 2.31 and pressure values are simulated using CFD of SOLIDWORKS.

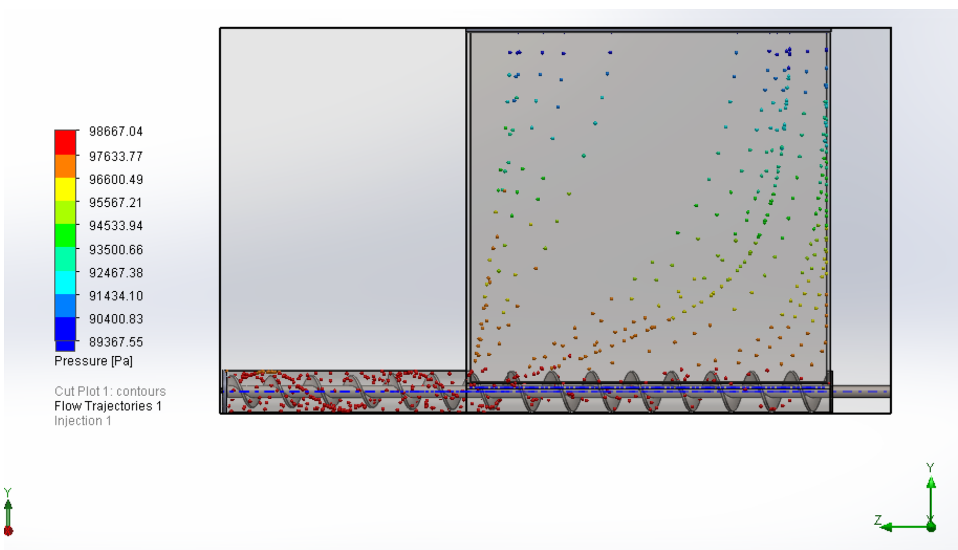


Figure 2.31 Pressure of particles in hopper 2 with screw 1 Assembly

The hopper 1 pressure values are high in hopper 2 when compared to hopper 1 which means the jamming is occurring at hopper 2.

Now, the two different hoppers are analyzed with motion analysis of SOLIDWORKS. The images of analysis are given below.

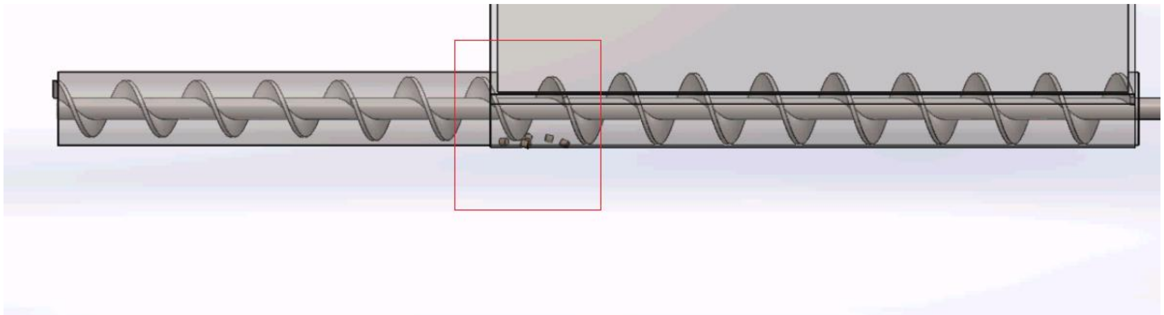


Figure 2.32 Jamming in the hopper-2

The Figure 2.32 shows the jamming occurring at the hopper which is highlighted in red border. This is rectified by design solution of having trough and hopper bases at same height which show in the below image.

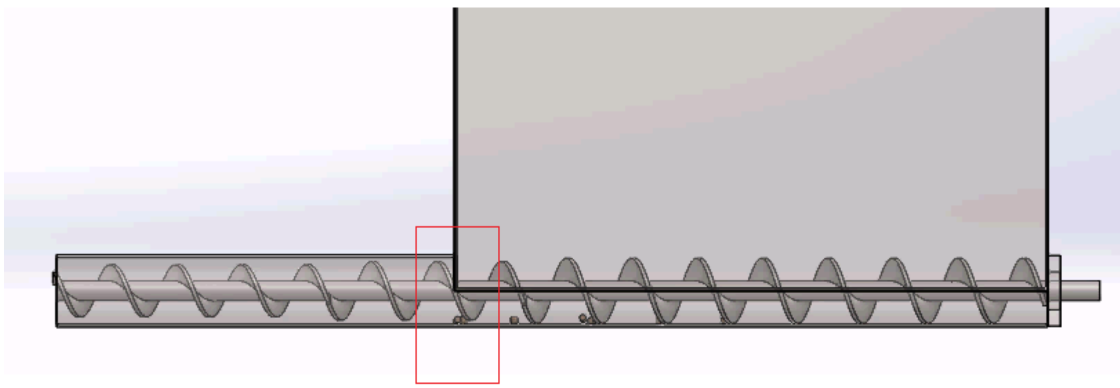


Figure 2.33 Jamming-Free hopper-1

The Figure 2.33 shows the free flow of pelletized particle at the point where trough and hopper is connected.

Now the research carried out with particle analysis of all four screw feeders with hopper 1 (jamming-free hopper). The screw feeders are assembled in hopper 1 designed using SOLIDWORKS. Flow analysis of SOLIDWORKS helps to find velocity and pressure of pelletized particle transported.

Since the screw 1 with hopper 1 is already analyzed in the above section of this research project. Now for rest of the screws such as SCREW-2, SCREW-3 and SCREW-4 the pressure values are analyzed using CFD.

For shaft less screw with different diameter (SCREW 2) the obtained velocity and pressure are show in Figure 2.34.

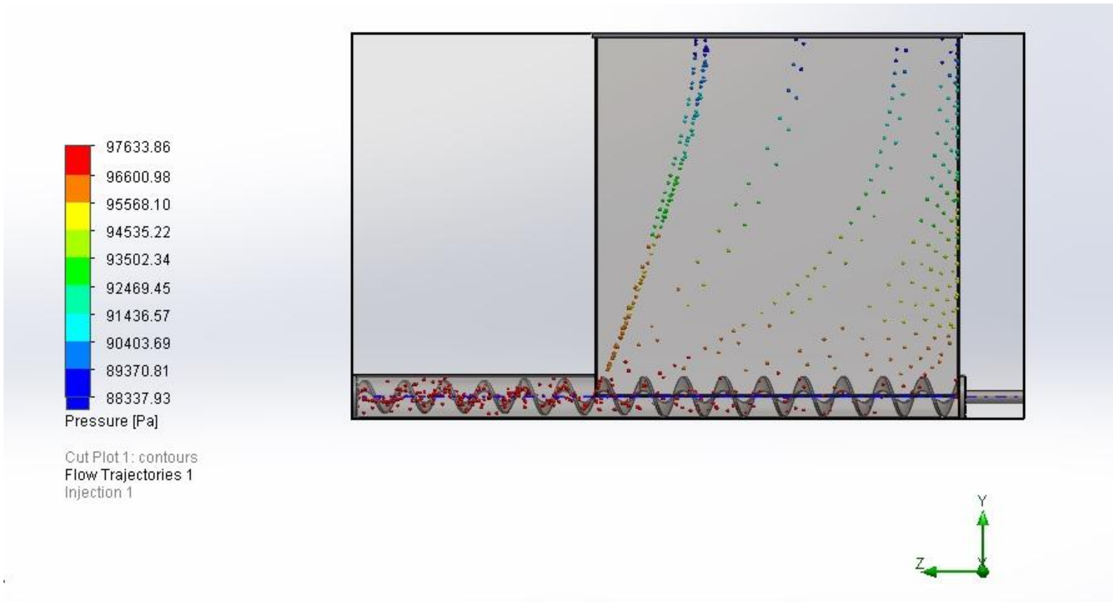


Figure 2.34 Pressure of particles in Screw 2 Assembly

For shaft less screw with diameter of 90 mm (SCREW 3) the obtained pressure are show in Figure 2.35.

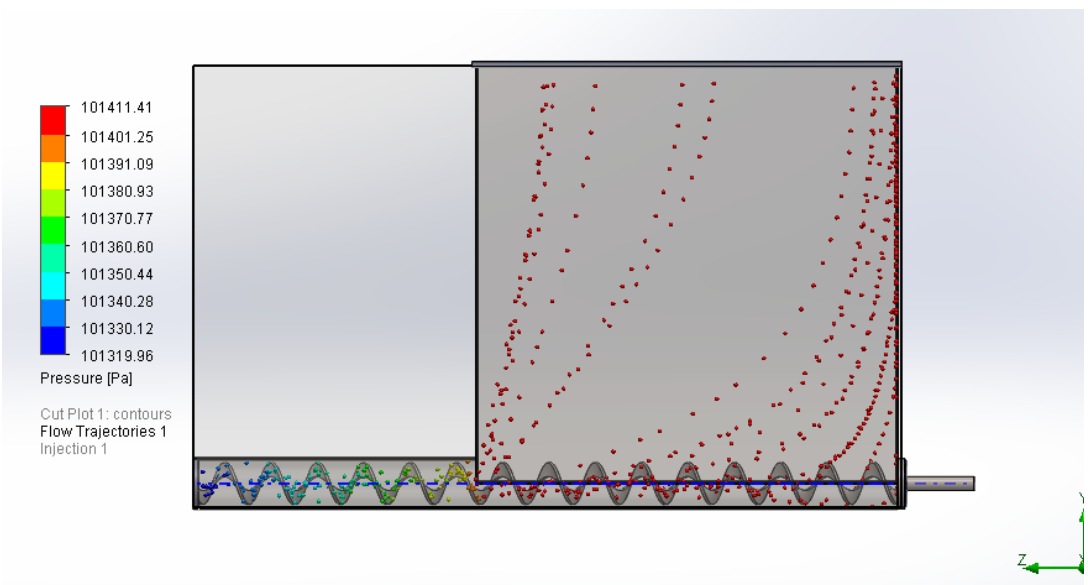


Figure 2.35 Pressure of particles in Screw 3 Assembly

For shaft less screw with diameter of 80 mm (SCREW 4) the obtained velocity and pressure are show in Figure 2.36

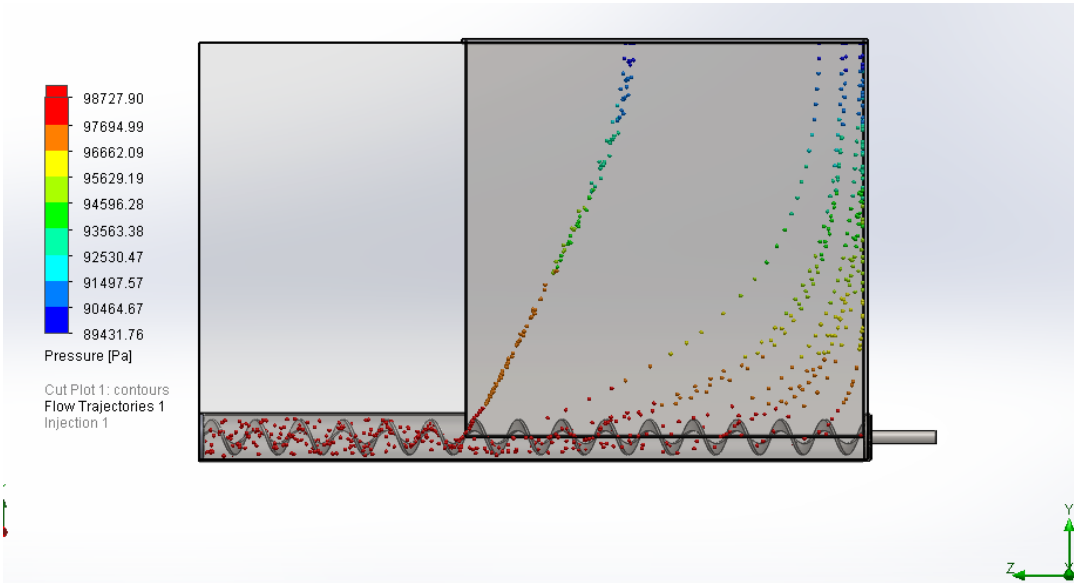


Figure 2.36 Pressure of particles in Screw 4 Assembly

3.10 Analysis of mass flow rate using CFD

The mass flow rate of the feeder can be easily found by finding out velocity of the particles transported in the equipment and implementing it on equation (12).

$$M = \rho V A, kg/s \quad (12)$$

ρ= Buk density kg/m^3

V= Velocity of the particles, m/s

A = Flow area, m^2

The existing mass flow rate from the screw feeder through the trough section is 0.16 kg/s which are obtained from the equation (1). Now the velocity of the pelletized particle inside the assembly of all four screws with hopper 1 is analyzed using CFD. The Screw 1 and hopper assembly is taken at first; the velocity of pelletized particle in it is given in Figure 2.37 only the trough part is show in the Figure for clear appearance.

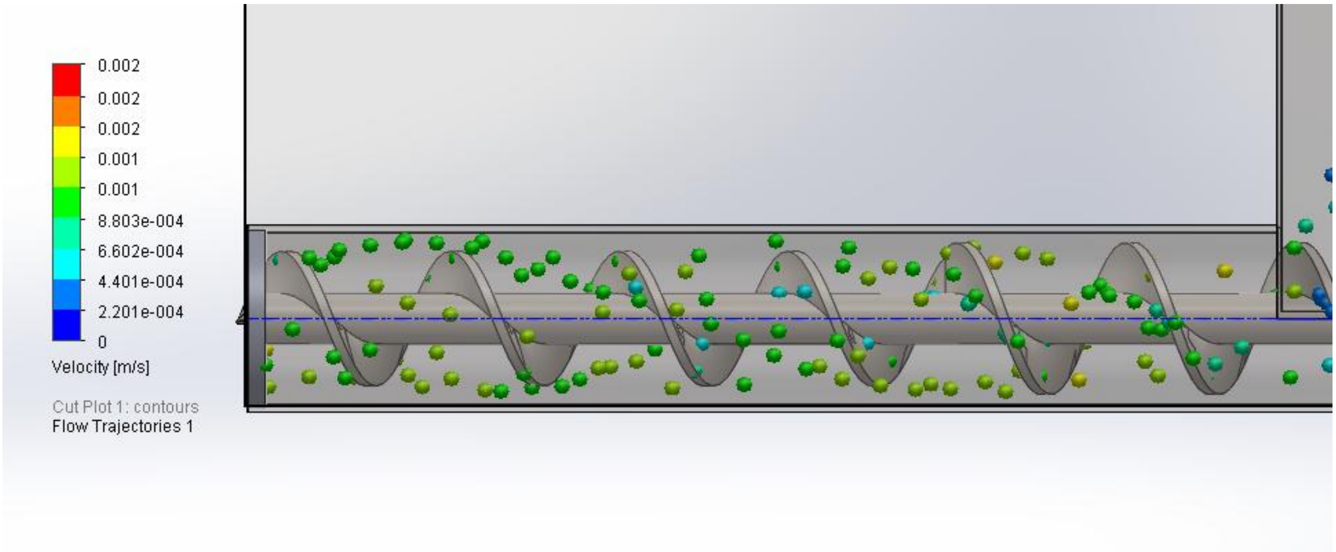


Figure 2.37 shows the velocity of the particles in the screw 1 and hopper 1 assembly.

From the simulation, the velocity of particles at outlet of trough surface is 0.0011 m/s by substituting the value of velocity in equation (12) the obtained mass flow rate is 0.15 kg/s which is closer to the calculated value.

Now the same setup of CFD is applied for Screw 2, Screw 3 and Screw 4 with hopper 1 in the assembly. The Figure 2.38 below shows the simulated results of velocity in Screw 2 assembly.

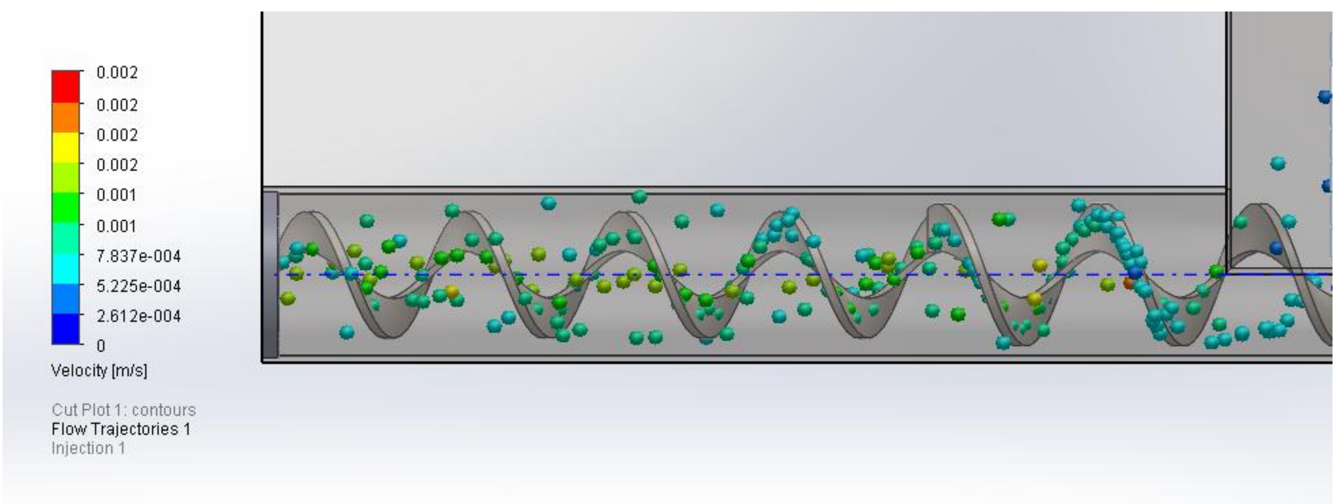


Figure 2.38 shows the velocity of the particles in the screw 2 and hopper 1 assembly.

From the simulation of screw 2, the velocity of particles at outlet of trough surface is 0.0011 m/s which values are equal to screw 1 due to the same screw diameter by substituting the value of velocity in equation (12) the obtained mass flow rate is 0.15 kg/s which is closer to the calculated value 0.16 kg/s.

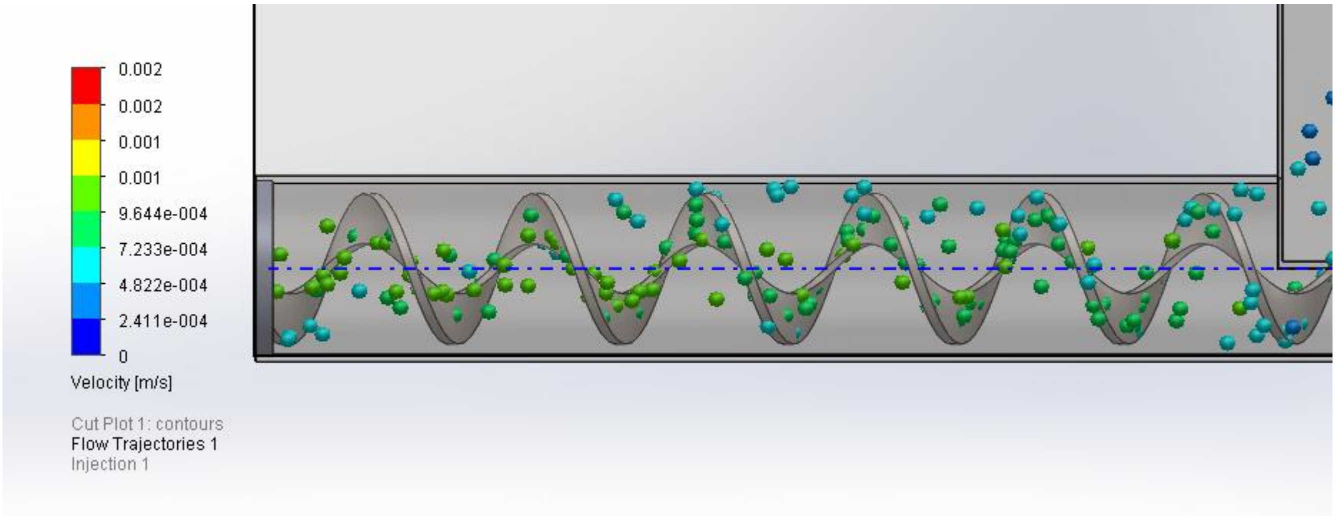


Figure 2.39 shows the velocity of the particle in the screw 3 and hopper 1 assembly.

From the simulation of screw 3 shown in Figure 2.39, the velocity of particles at outlet of trough surface is 9.644e-004 m/s by substituting the value of velocity in equation (12) the obtained mass flow rate is 0.12 kg/s which is not closer to the calculated value 0.16 kg/s. Therefore the Screw 3 will not convey required amount of mass flow.

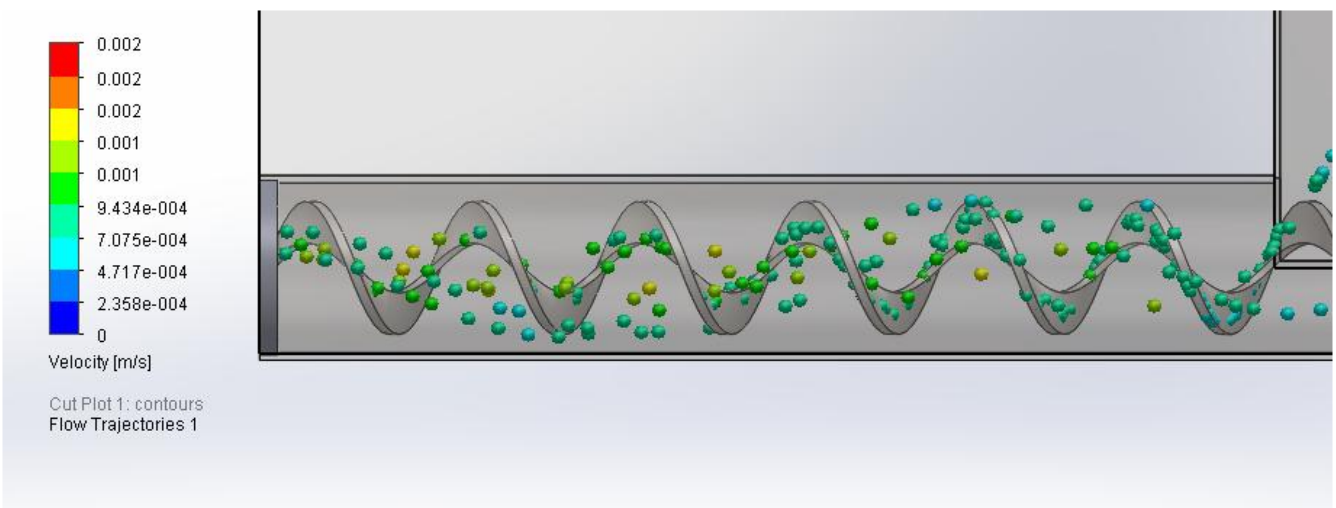


Figure 2.40 shows the velocity of the particle in the screw 4 and hopper 1 assembly.

From the simulation of screw 4 shown in Figure 2.40, the velocity of particles at outlet of trough surface is 0.00102 m/s by substituting the value of velocity in equation (12) the obtained mass flow rate is 0.14 kg/s which is closer to the calculated value 0.16 kg/s.

3. RESULT

The simulated results from ANSYS WORKBENCH are tabulated and variations are found through the graph. There four different types of Screw feeders are used in this project. The names of each screw are listed out below.

SCREW 1 - Shafted screw feeder with different screw diameter.

SCREW 2 – Axial free (shaft less screw feeder with different screw diameter),

SCREW 3 – Axial free screw feeder with standard diameter 90mm.

SCREW 4- Axial free screw feeder with standard diameter 80mm.

3.1 Result analysis on Total deformation of the screw feeders for all the screws:

This section denotes the total deformation of screw feeders. From the table 2.8, 2.9, 2.10 and 2.11 the Figure 3.1 & Figure 3.2 is plotted.

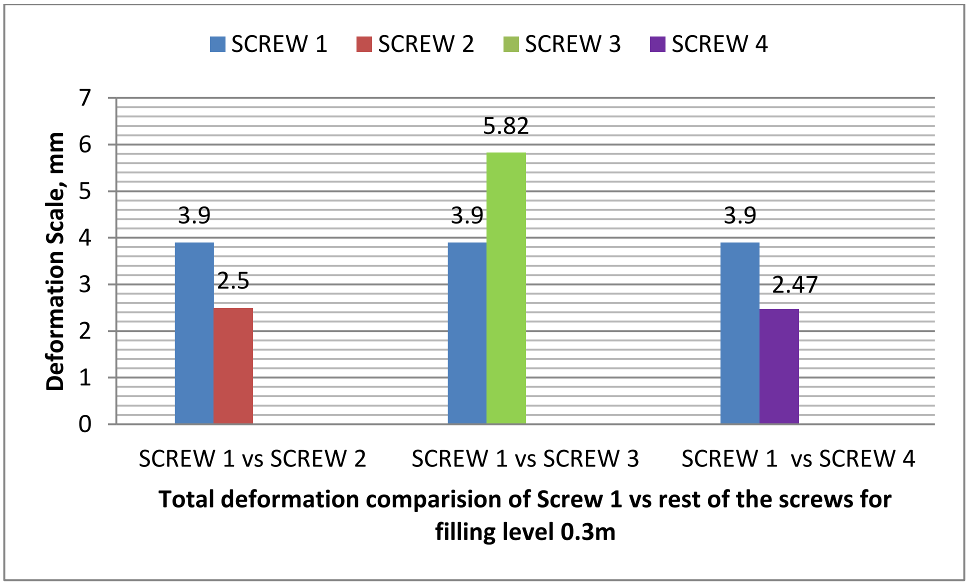


Figure 3.1 Total deformations of all screw feeders for filling level 0.3m

From the Figure 3.1, it shows that screw 2 and screw 4 have lesser deformation value when compared to screw 1. In screw 2 the deformation of screw 1 is reduced by 1.4 mm and in screw 4 deformations is reduced by 1.43 mm.

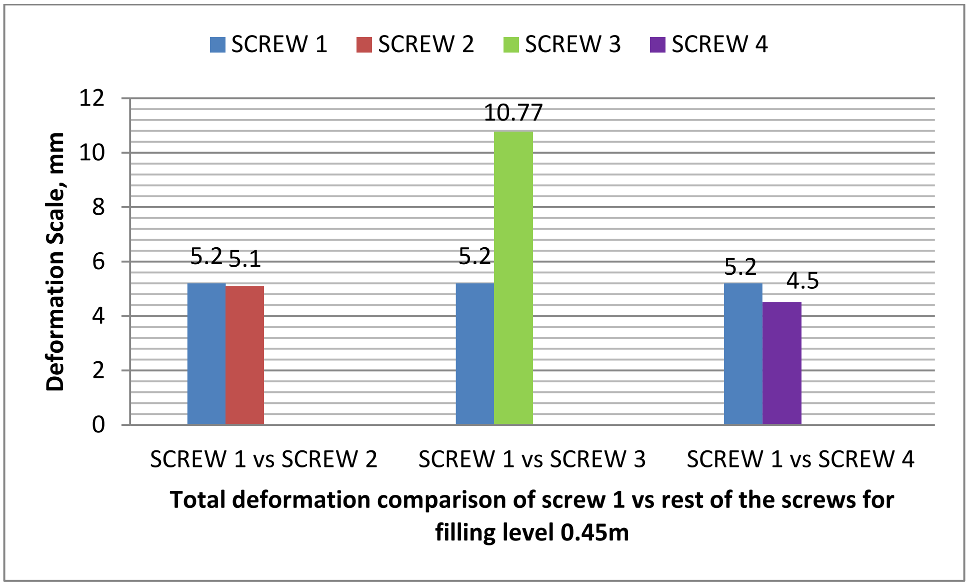


Figure 3.2 Total deformations of all screw feeders for filling level 0.45m

From the Figure 3.2, the screw 2 has 1 mm lesser deformation when compared to screw 1. The screw 4 has same level deformation with screw 1.

3.2 Result analysis on Maximum principal stress for all the screws

This section denotes the Maximum principal stress on all screw feeders. From the tables 2.8 (b), 2.9 (b), 2.10 (b) and 2.11 (b) the Figure 3.3 and 3.4 are plotted.

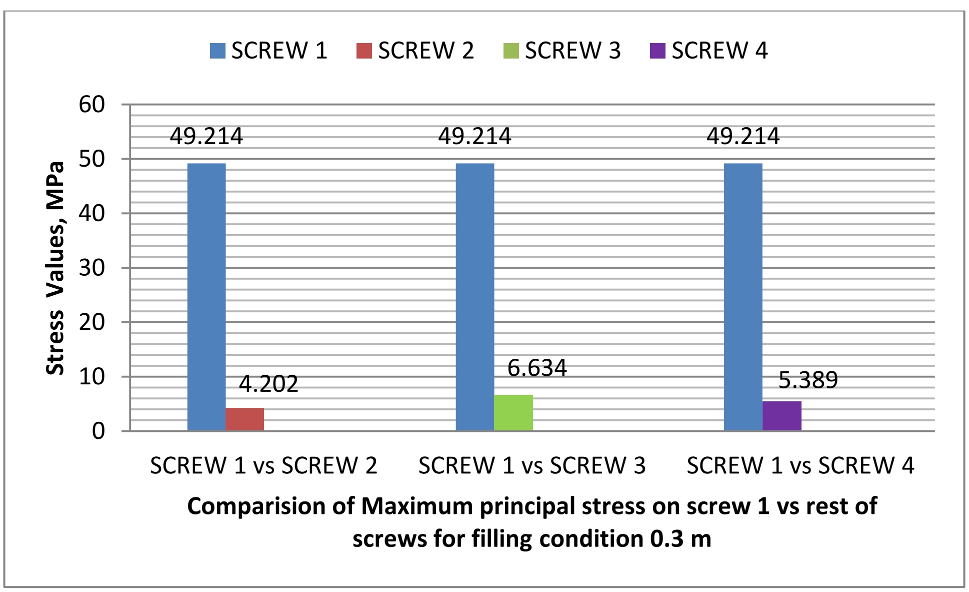


Figure 3.3 Maximum Principle stresses of all screw feeders for filling level 0.3m

The yield strength of stainless steel (SS 316) is 172.37 MPa. From the figure 3.3, all the four screw are below the yield strength of stainless steel. The stress value of SCREW- 2 is minimum when compared to all other screws.

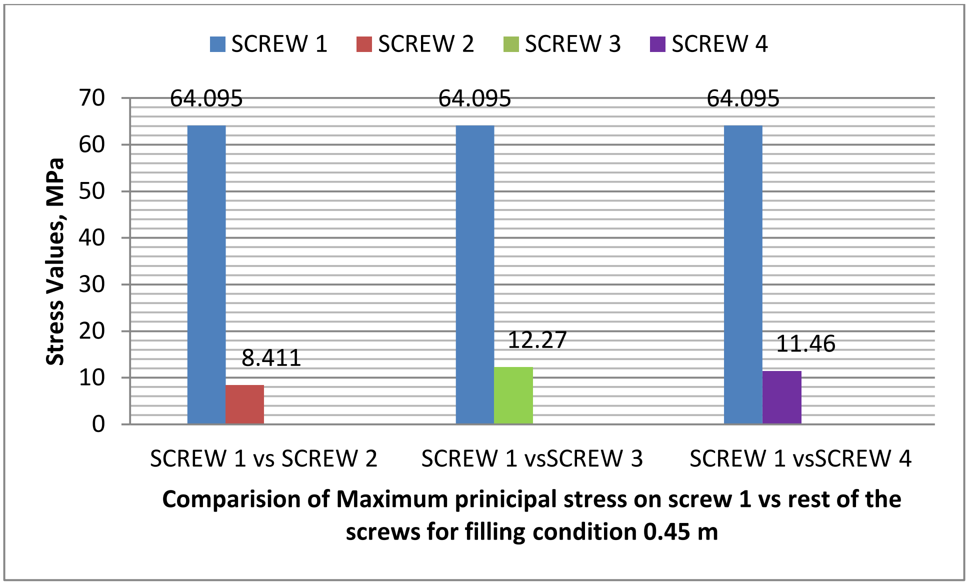


Figure 3.4 Maximum Principle stresses of all screw feeders for filling level 0.3m

From Figure 3.4, the maximum stress for hopper level 0.45 is denoted. All the four screws are below the yield strength of stainless steel. The stress value of SCREW- 2 is minimum when compared to all other screws.

3.3 Result on pressure analysis of pelletized particle in hopper

As discussed pressure analysis of pelletized particle (wooden pellet) is done in with two different hoppers with assembly Screw 1 the existing design. From simulated results of analysis of jamming using CFD the Figure 3.5 is plotted.

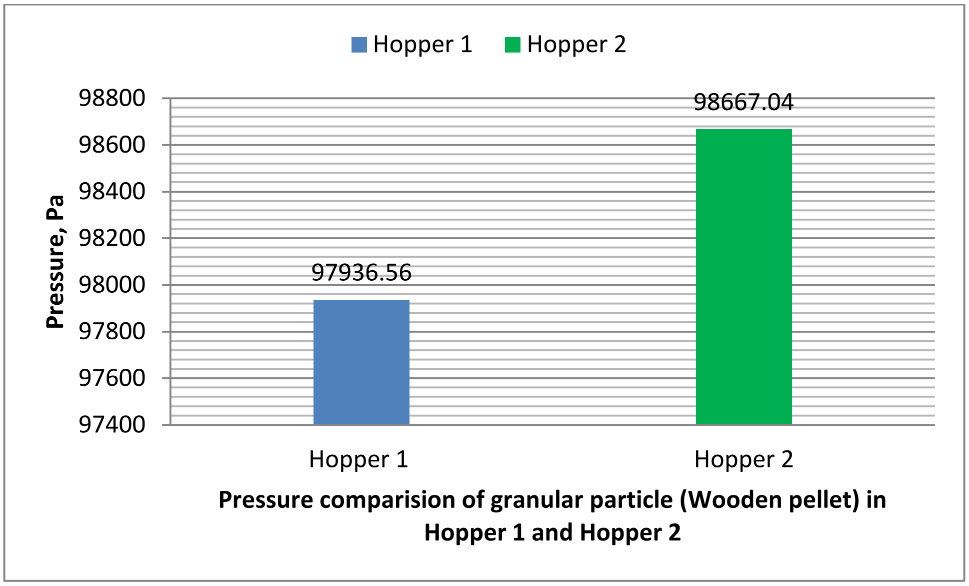


Figure 3.5 Pressure comparison of pelletized particle (wooden pellet) in Hopper 1 and Hopper 2

From Figure 3.5, the pressure in pelletized particle is high on Hopper 2 therefore Hopper 1 design is used to analysis of pressure in pelletized particles using all fours in hoper 1 as assembly. From the simulation results all four assembly the Figure 3.6 is plotted.

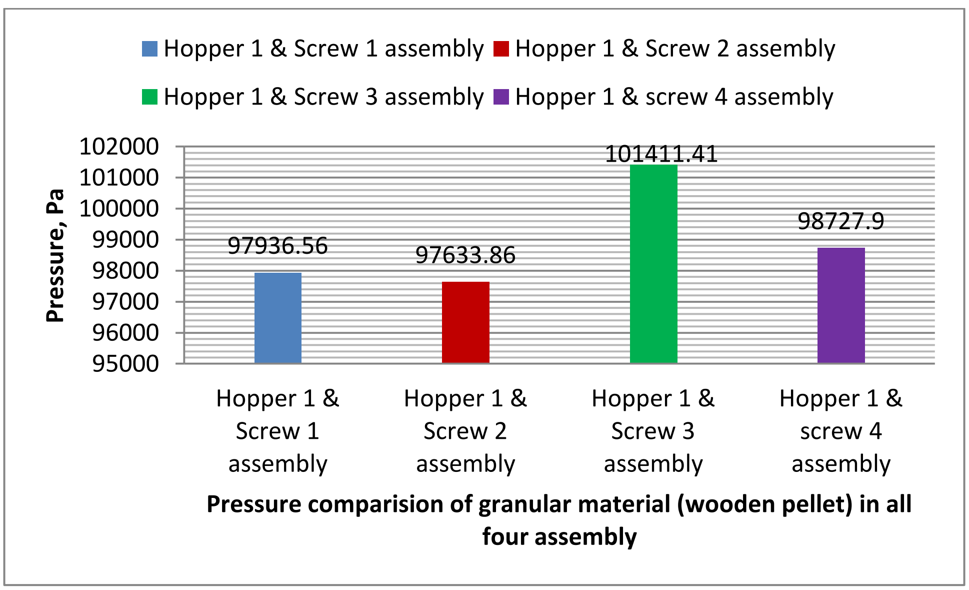


Figure 3.6 Pressure comparison of pelletized particle (wooden pellet) in all four assemblies

From Figure 3.6, the pressure in pelletized particle is low on screw 2 and very high on screw 3 assemblies. Pressure on pelletized particles on screw 4 is little high when compared screw 1 assembly.

3.4 Result on analysis of Mass flow rate in all four screws

The Mass flow rate analysis on all screws is done by using three different pelletized particles with different bulk density at varying speeds. The Figure 3.7 shows the mass flow rate of screw 1 and the Figure 3.8 shows the mass flow rate of screw 2.

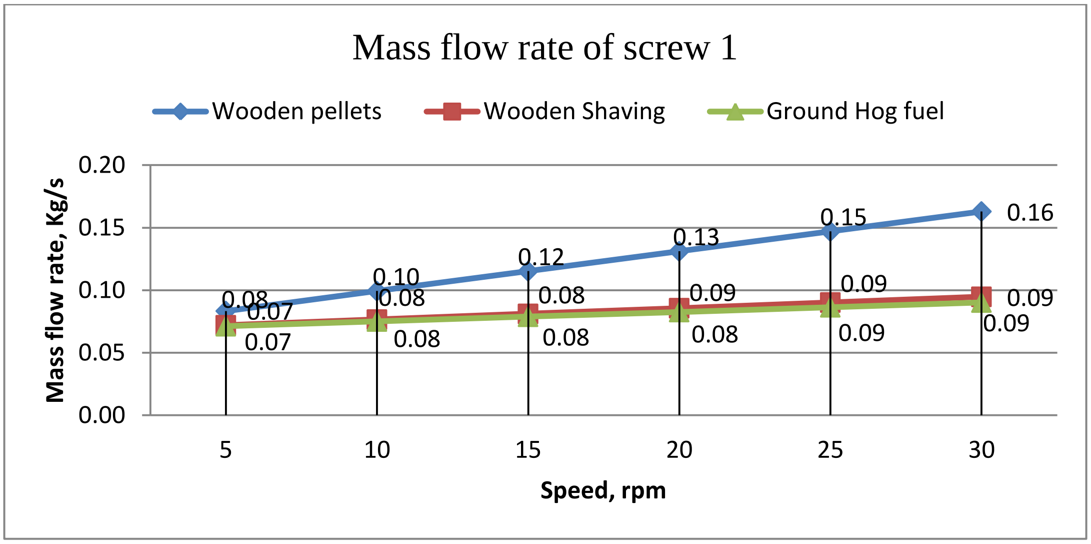


Figure 3.7 Mass flow rates of Screw 1

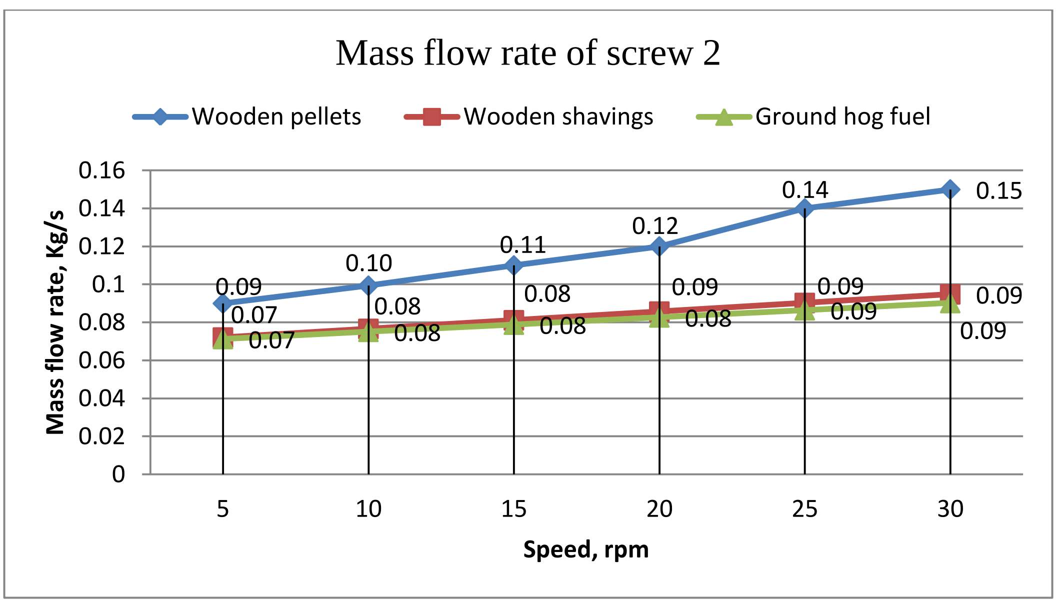


Figure 3.8 Mass flow rate of Screw 2

Now the mass flow rate of screw 3 is shown in the figure 3.9 with same three pelletized materials such as wooden pellets, wooden shaving and Ground hog fuel.

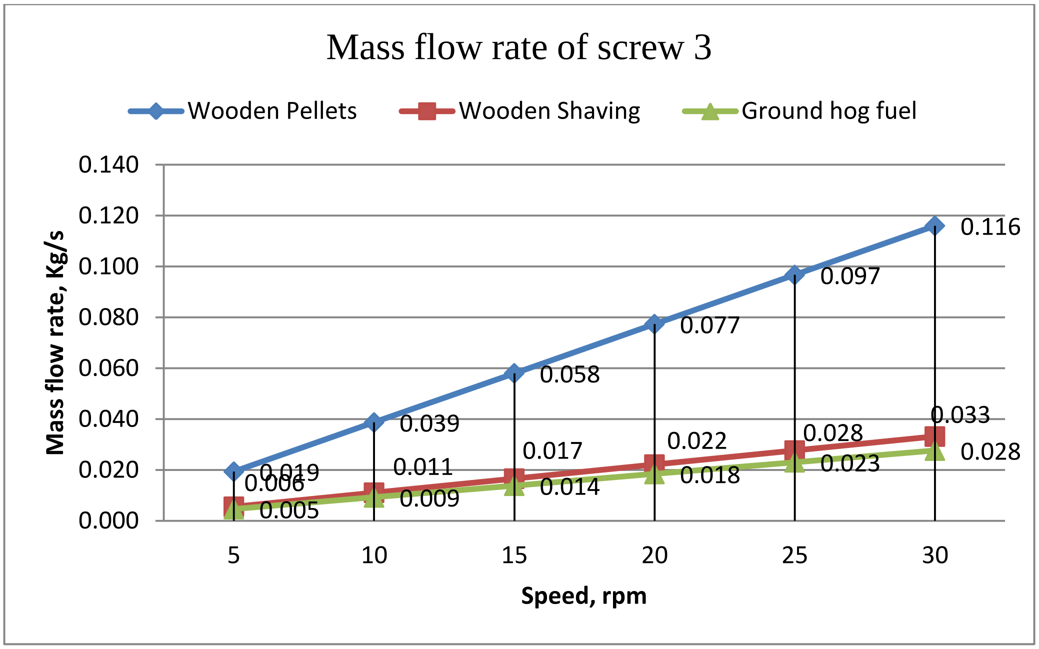


Figure 3.9 Mass flow rate of Screw 3

The final part of the research shows the mass flow rate of screw 4 in figure 3.10.

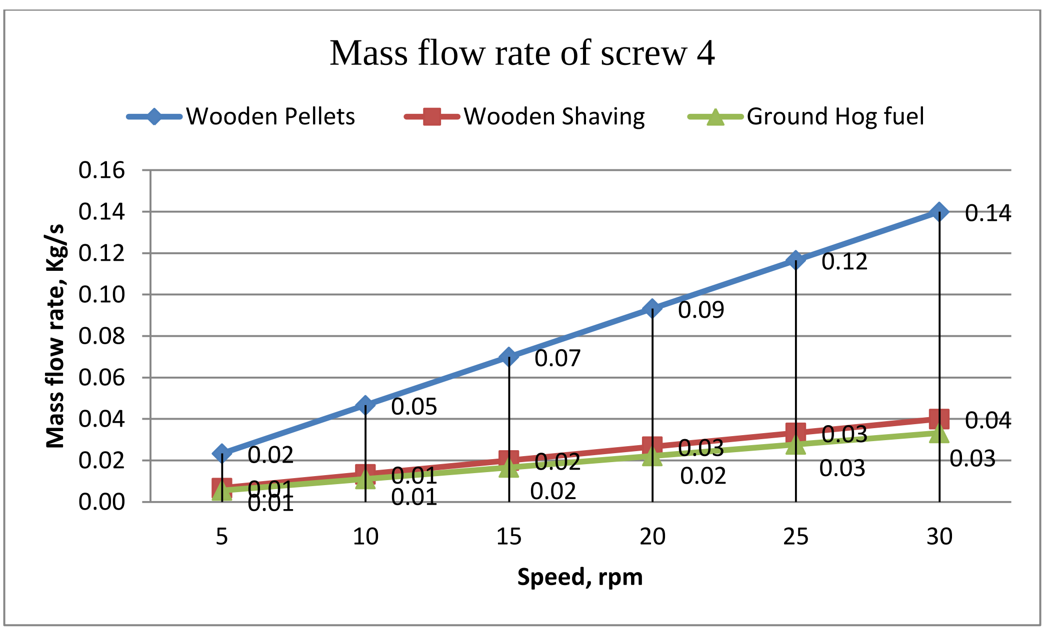


Figure 3.10 Mass flow rate of Screw 4

CONCLUSIONS

The design calculations, modeling and analysis were done for all the four screw feeders. The modeling of the screw feeders are constructed using SOLIDWORKS 2013. The stress and deformation analysis are done using ANSYS workbench 14.5. The Jamming analyses are done using SOLIDWORKS computational fluid dynamics and mass flow rate is checked for all four screws.

1. The Screw-1 is constructed with the typical specifications and its simulation values are perfectly satisfying the model conditions. From the deformation result of the research, the total deformation occurring at Screw-1 is in permissible limit to the hopper. The total deformation occurred in screw-2 is 1.4mm less when compared to Screw 1. The Screw- 3 as higher deformation values than screw 1 which will be unsuitable for existing hopper design. The Screw-4 also has similar less deformation when compared to Screw 1.
2. From the result of Maximum principle stress, the maximum stress occurring at all four screws are below the yield strength therefore the design is safe. In comparison, the stress value in Screw- 2 is 56MPa less when compared to screw-1. The Screw-4 also has less stress value which is reduced up to 53MPa.
3. From the result of jamming analysis, the pressure of pelletized particles in hopper 1 is lesser than hopper 2 therefore the possibility of jamming is less in hopper 1. The chances of jamming with all four screws with hopper 1 assembly are analyzed. From the results of the assembly, it shows that Screw 2 assembly has lesser pressure values of pelletized particle in the hopper 1 when compared to Screw 1 – hopper 1 assembly. The screw 4 has little high pressure in pelletized particle with hopper 1 assembly when compared to Screw 1- Hopper 1 assembly.
4. The mass flow rate are calculated and plotted for all four screws when comparing the result, Screw 2 have equal mass flow rate to screw 1. The Screw 4 have closer mass flow rate to Screw 1.

From this research, the modified design Screw 4 will be suitable for existing hopper with some tapered design at trough part and the modified design Screw 2 will be directly suitable for existing hopper 1 which has 7.3 Kg lesser weight when compared to Screw 1, less deformation, less stress values and similar performance to the screw 1.

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