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Campus Monterrey

Designing and Simulation of Pneumatic Conveying System for Fungus Materials

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Dedication

There are a few people without whom this research work might not have been completed, and to whom I am greatly indebted. I dedicate my work to my family and friends. I want to say a special thanks to my parents, Muhammad Arshad & Razia whose words always gave me motivation on all stages and push for tenacity ring in my ears.

My sister Zoya and my brother Ali have never left my side, gave me strength and are very special. My uncle Ansar Mehmood also supported me throughout the period and deserves humble thanks. I dedicate this work and give special thanks to Eleonora Sorrentino and Anna Maria Carella for being there for me throughout the entire program. I also dedicate this dissertation to my many friends for their endless love support and encouragement.

Acknowledgements

First of all, I must acknowledge my limitless thanks to almighty Allah. I am totally sure that this work would have never become truth, without his guidance.

I owe a deep debt of gratitude to the universities Politecnico di Torino and Tec de Monterrey for giving me a great opportunity to complete this research work.

I am grateful to my supervisor **Dr. Horacio Ahuett Garza**, who has been always generous and guided me throughout all the phases of the research work. I really appreciate his vast knowledge and skills in many areas.

I also want to say thanks to **Dr. Pedro Daniel Urbina Corona**, who supported me throughout all the period. Last but not least, deepest thanks to all people who took part in making this thesis real.

Not least of all, I owe so much to my whole family for their undying support, their unwavering belief that I can achieve so much. Unfortunately, I cannot thank everyone by name because it would take a lifetime but, I just want you all to know that you count so much. Had it not been for all your prayers and benedictions; were it not for your sincere love and help, I would never have completed this thesis. So thank you all.

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1. Introduction

A new category of self-growing, fibrous, natural composite materials with controlled physical properties that can be produced in large quantities and over wide areas, based on mycelium, the main body of fungi (Muhammad Haneef, 2017)[1]. Basically, Fungus Material (Mycelium) is easy to decompose and it doesn't make the pollution in the environment.

The ability of reproduction of the biological organisms remains unique in nature and is impossible to be duplicated by materials engineering. Introducing living biological systems in materials science and nanotechnology in order to accomplish materials from biological resources, developed in controlled ways is a strategy that is attracting significant research efforts (Dr., 2001).[2]

At present around 13 million tons of unicel are produced per year. The unicel is a high impact material against the environment, it is not recyclable, it is very toxic, and it takes about a thousand years to decompose.

Figure 1: Unicel Material

Fungus is a straw type material, composed of agricultural residues and fungal mycelium, a fungus that reacts chemically with agricultural waste to form a material very similar to unicel. Currently this material is being used for packaging bottles, furniture, electronics, etc. because it meets the same properties as the unicel, but it only takes 30 days to degrade once in direct contact with the earth and is not toxic.

The Purpose of using this material is to seek to promote this material and decrease more and more the use of the unicel and plastic base materials used in packaging or for different purposes. To achieve this, it seeks to automate the manufacturing process of Fungicel, since it is currently developed by hand.

The project is based on to develop a system for injection of fungus mycelium into different kinds of molds. It includes a total automated system, a process that will convey or transport the material until injection process into molds and a handling system that will remove the molds after filling stage.

A pneumatic conveying system will be used for conveying process and a handling system will be developed as well. The purpose of the project is to check and validate the system after initial design work, for this purpose a prototype also will be developed to check and validate the system.

1.1 Summary

Thousands of plastic factories are producing tons of plastic goods which are popularly used by the people because of their ease, cheapness and convenience. Due to non-biodegradable nature they cause hazardous negative impact on the environment. Disposal of plastic waste which is major cause of environment pollution becomes carcinogenic to human, birth defects, impaired immunity, endocrine disruption, development and reproductive effect (P. Pavani, 2014)[3].

There is an alternative material called Fungicel, which is a composite material of agricultural waste and a fungal mycelium. This material is shown as a substitute for the unicel and different plastic materials in different fields of application, especially in the packaging market. The main characteristic of the material is that when it comes into contact with the earth, it only takes 30 days to degrade and on the other hand unicel or plastic materials take thousands of years and are the major cause of the pollution.

Figure 2: Unicel vs. Mycelium Material

So, the purpose of this project is to automate the process of filling the molds with fungus material and develop a mechanism that allows the mold to put in the place of filling area and also remove them after injection process. In short, to meet the project requirements we need to build a machine which will convey the material, carry the molds until filling area and will remove the mold after filling.

For this purpose, for the material conveying until mold filling, a pneumatic conveying system will be designed. A mold handling system will be designed to automate the process which will put the mold on place and its removal as well.

This work has to be done in different steps.

1. Research;
2. Analysis;
3. Designing;
4. Simulations;
5. Prototyping;
6. Report Writing.

1.2 Research/background

Global environmental degradation issues of synthetic plastics in combination with the fossil depletion problems are the main reasons that push the materials-related research towards polymeric materials obtained from renewable resources (Ceseracciu, 2015)[4]. Intense research efforts are focusing on the development of polymeric materials from natural sources, such as cellulose, lignin, pectin from plants, proteins from plants and animals, polyesters from bacteria or plants etc. All materials those are sustainable, biocompatible and biodegradable with a wide variety of properties (Irimia-Vladu.M, 2014)[5].

The development of such materials needs usually difficult and complicated methods of processing of their bio sources, for their extraction, development and functionalization, that can be costly, time-consuming and with low production yield. For this reason these materials, although they could resolve various environmental problems, are still expensive and have very limited uses (E, 2013)[6].

A strategy to overcome these problems could be the development of composite biomaterials with properties controlled and tunable during their growth, which would be ready to use without the need of expensive and sophisticated processing methods. To materialize this strategy, mycelium is the best option, the vegetative lower part of fungi. Mycelium has been identified as the largest living organism on earth (a mycelium network occupies nearly 10 km^2 in Oregon's Blue Mountains) (Hawkswoth, 2001)[7].

It grows due to its symbiotic relationship with the materials that feed it, forming entangled networks of branching fibers (Bonafante, 2010)[8].

Mycelium is mainly composed of natural polymers as chitin, cellulose, proteins, etc., so it is a natural polymeric composite fibrous material. Due to its unique structure and composition we foresee the production of large amounts of mycelium-based materials. So far mycelia have been exploited principally by a US company that uses unprocessed biomass glued together by mycelia resulting into foamy structures (Zeller, 2012)[9].

To use the material for the research work it's important to know all the properties of the material. An injection system is needed to inject the material in molds in order to automate the whole process for the company. For the injection of the material, a pneumatic conveying system has been chosen.

Mycelium is a new developed material and it's the best alternative of unicel, to design some machine for this material, all design concepts are needed regarding to material properties. There is not such research work happened regarding to convey fungus material in a pneumatic conveying system but some related research can be helpful, for example the pneumatic conveying systems for dense or dilute materials. At least the design concepts of those systems would be helpful the regardless material used inside.

1.3. Objectives

The main purpose of this project is to design a machine for injection of the material into molds in order to create the different shapes of fungus mycelium for vast purposes. Since the project has different stages and the material used is very rare to use in this kind of methodology, it's very important to specify different objectives of the project.

Project has objectives, such as:

1. Specify the material properties according to design phase;
2. Mold specifications (design & dimensions);
3. Initial design of mold handling system;
4. CAD modeling of mold handling mechanism;
5. Initial study about different pneumatic conveying systems;
6. Design and experimental analysis of fungus material filling in the mold through pneumatic conveying system;
7. CFD Simulations;
8. Making prototype;
9. Prototype Testing;
10. Comparing the results.

2. Project Overview

This project is related to a specific problem, which is filling molds of different shapes with fungus material that is an alternative material of plastic and unicel. The material we are using for this purpose is a rare material, called fungus mycelium. The main goal is to make different packaging shapes for different goods by using this material. In this way, one can reduce the use of unicel and plastic material currently using in different fields. Currently there is no such process developed to fill the molds with fungus mycelium and most of the companies and start-ups use the manual process mostly by hands. Therefore, the main goal of the project is to develop a system, which will allow the molds to fill automatically.

For this purpose, a pneumatic conveying system will be used to convey the material, injecting in the mold and on the other hand, a mold handling mechanism will be designed to automate the process.

2.1. User Requirements

The purpose of the machine is to automate the whole system. According to project requirement the machine must be cost efficient and safety factors are also must be included.

After the automation of whole process, the project requirement is to fill 60 molds per hour, that's mean 1 mold/minute. In this way, an increase in production will happen, which cannot be reached by doing the process manually.

This project will be quite helpful to promote pollution free materials and will encourage the environmental health.

2.2. Problems

Fungus mycelium is a rare material which is introduced not so far ago for alternative of plastic and unicel materials. Even currently a lot of research is happening to introduce new forms of the fungus material.

In our case the fungus is mixed up with straw type residue from agricultural wastes. Since pneumatic conveying system has been decided to inject the material, it's a challenge to experiment the process through that system. Because the pneumatic conveying system is mostly use for bulky materials and non-bulky materials as well, for example, cement, coffee beans, sand etc.

Until now, there is no pneumatic conveying system experimented for this kind of material. It's really important to recognize material properties to make the simulation of injection process of the mold. Autodesk CFD will be used for this purpose.

The second important thing is to introduce a mechanism that can make the mold handling automated. For this purpose, different kind of mechanism was discussed and appropriate one will be chosen according to the requirements.

2.3. Literature and Patent Review

The main part of the project is experimenting the transportation of fungus mycelium through pneumatic conveying system and injecting the material in the mold.

Pneumatic conveying appears to have been in existence for well 100 years. It is said that pneumatic conveying took off with the invention of the Roots Blower by the Roots brothers, Philander and Francis, in Indiana in 1859, Roll (1931). At that time the blowers were used in supercharging in the internal combustion engine and first being employed in blast furnaces to help with the melting of iron. Undoubtly compressors did exist before this so that high pressure air could be obtained to utilize in the pneumatic conveying operation. Vacuum conveying was also possible about the same time frame (Klinzing G. E., 2017)[10].

The vacuum pump is attributed to the Romans and later in the 13th century the Arabs were using suction pumps. The pumps surfaced in the Europe in the 15th century. The first vacuum pump is attributed to Otto von Guericke in 1654[10].

The earliest technical exploration into pneumatic conveying occurred in Germany by Gasterstadt (1924) at the Technische Hoshschule Dresden. The work is reported in German Engineering journal, VDI. The work reported a linear behavior of the pressure drop in a straight section of the pipe with solid flow rate. The flow was dilute in nature. This concept was used by Cabrejos and Klinzing (1992) to develop a flow meter for measuring the solids flow rates with a system of transducers and valve to explore the full range of experimental conditions. Using the data from a large conveying system the linearity of the system pressure drop with the solids flow rate was constructed by baker (Klinzing G. E., 2017).

3. Pneumatic conveying systems

A pneumatic conveying system is a process by which bulk materials of almost any type are transferred or injected using a gas flow as the conveying medium from one or more sources to one or more destinations. Air is the most commonly used gas but may not be selected for use with reactive materials and/or where there is a threat of dust explosions.

3.1. Overview

Pneumatic conveying, while having been practiced for a long time and having many advantages, has some precautions that must be noted to have a trouble-free environment for the system. The flow patterns that are seen for the gas and solid systems are different than those for a single-phase operation. This difference is the cause of many problems with loss in down time and damage to equipment. Many developments have occurred over the past several years with the newer computer-based applications opening tremendous potential for the practitioner. Artificial intelligence can eliminate many of the common pitfalls in operations and designs. Some exciting newer measurement concepts permit nonintrusive applications to be applied to pneumatic conveying (Klinzing G. , 2001)[11].

3.2. Types of pneumatic conveying systems

There are several methods of transporting materials using pneumatic conveying. In general, but there are three main categories: dilute phase, dense phase, and air conveying.

3.2.1. Dense phase

In dense-phase an air pulse is used to drag a slug or a batch of material from one location to another location. In dense-phase material is carried by high pressure, low velocity and high product to air ratio. This process is used mostly to convey bulk material. This process mostly used to convey the materials through long distances. Almost any kind of material can be conveyed by this method.

3.2.2. Dilute-phase

Conveying is the process in which material is conveyed or carried from one place to another place by maintaining a sufficient airstream velocity. Dilute phase is a continuous type process and during the process high velocity, low pressure and low product to air ratio has to b e used. In this process, material is suspended in the air because of high velocity of the air or gas. Short distance conveying is recommended through this process, but also long distances can be applicable. It is better to not use abrasive materials in dilute phase because the high velocities can damage the material properties.

3.3. Design concepts and considerations for dilute phase system

Material used in the project is fungus material, which is the mixture of fungus and straws residuals from agricultural wastes. Since it is not a bulky material and it is also a light material, the dilute phase pneumatic conveying system will be used for the project. Before designing the system, there are different kind of considerations and design concepts that are important to discuss. After defining those design aspects and parameters, design calculations will be done in next stages of the project.

The design and selection of pneumatic conveying system involves different parameters such as conveying velocities and conveying distance. Conveying velocity is depending on the material properties and distance. There are two main relationships from where we can start:

- Conveying distance is directly proportional to conveying pressure;
- Conveying distance is inversely proportional to conveying capacity.

Now the other important parameters will be discussed shortly to understand the system design before starting the system calculations.

3.3.1. Pressure volume relationship

Air will be used to convey the material and filling the mold. Air will behave as compressible travelling through the length of the pipes. The pressure drop will happen since the volumetric flow rate will go up. To control the air, a basic thermodynamics equation can be used:

$$\frac{P_1}{T_1}V_1 = \frac{P_2}{T_2}V_2$$

Where:

- P is the pressure of the air;
- T is the temperature in the pipeline;
- V is the volume rate of the air;
- Subscript 1 and 2 shows the different points in the pipeline.

In our case, we assume that the temperature will be constant throw the pipeline so the new equation will be:

$$P_1 V_2 = P_2 V_2$$

By looking to this equation, we can see that those pressure and volume flow rates are inversely proportional. A pressure drop will happen through the pipeline and on the other hand volume flow rate will increase through the conveying process, which means the velocity will be continuously increasing as well.

3.3.2. Air volume relationship with velocity

For any kind of material, there is a minimum velocity need to convey the material. As we discussed before, in dilute phase system the material is suspended in the air because of the velocity of the air. And the air flow rate or the volume of the air is dependent on the area of the pipeline. The relationship between velocity and air volume can be derived by this equation:

$$V = \rho * A * v$$

Where:

- V = Volume flow rate of the air (m^3/min);
- ρ = Density of the air (Kg/m^3);
- A = Area of the pipe (m^2);
- v = conveying velocity (m/min).

After simply solving the equation, one can get the velocity easily.

3.3.3. Material velocity

Air Velocity is very important factor in dilute phase pneumatic conveying systems. Because in dilute phase systems, conveying materials are always conveyed through air and are suspended in the air. Mostly the air velocity is greater than the velocity of the air so there is always a drag force. It is not easy to calculate the velocity of the material particles and it's a complex problem. Since the material is conveyed in a suspended condition through air, air velocity is always used for the design purposes rather than the velocity of the material. But there are some considerations which can be useful to understand the velocity of the material as well.

- Slip ratio is really helpful to understand the velocity of particles with respect to velocity of the air. Basically it's the ratio between two velocities, which is velocity of the particles divided by the velocity of the air which is conveying the material. In horizontal pipelines the material velocity is 80% of the air velocity. And in this case, the slip ratio will be 0.8.
- And in vertical pipelines this ratio is considered 0.7.

There are different kinds of velocities, some of them are important to discuss:

Air inlet velocity

It is the velocity where the material enters into the pipeline. It is the lowest velocity at this point in the system. In vacuum systems it's referred to free air velocity at the inlet point.

Minimum conveying velocity

Minimum conveying velocity is the velocity which can be used to convey any kind of material through pipeline. It is the lowest air velocity that can be achieved in a dilute phase system without chocking or settling down of the material on the bottom of the pipeline.

3.3.4. System pressure drop

Pressure drop is quite important indicator for the designing of pneumatic conveying system. It also shows the system resistance; the more will be the system resistance the pressure drop will be more as well.

Following equation is useful to calculate the resistance of the system:

$$\frac{F}{A} = f * \rho * v^2 / 2 \quad \text{.................. (1)}$$

Where:

- F = friction force;
- A = Area of acting friction force;
- f = Friction factor coefficient;
- ρ = density of the material;
- v = Velocity of the material.

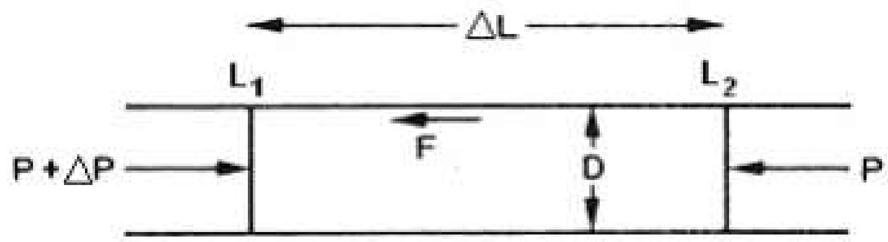

Figure 3: Energy Balance over a length of pipe

Considering the energy balance between L1 and L2, since the material velocity is less than the air velocity there will be a drag force and the total force required to overcome that drag force will be supplied by a pressure force making a pressure drop ΔP along the length of the pipe.

The pressure force is:

$$\Delta P * Area\ of\ the\ pipe = \Delta \mathrm{P} * \mathrm{pi} * \frac{D^2}{4}$$

Friction force is:

$$= F/A * pi * D * \Delta L$$

Hence, from equation (1)

$$= (f * \rho * \frac{v^2}{2}) * pi * D * \Delta \mathrm{L}$$

Equating friction force and pressure drop:

$$\Delta P = 4 * \left(f * \rho * {v^2}/{2}\right) \times {\Delta L}/{D}$$

From the equation of pressure drop one can see that:

- Pressure drop is directly proportional to the square of velocity, the more will be the pressure drop more will be the velocity.

- Pressure drop is directly proportional to the length of the pipe; the longer will be the pipeline more pressure drop will occur.
- Pressure drop is inversely proportional to the pipe diameter, bigger will be the diameter of the pipe, less pressure drop will happen in the pipeline.

Pressure drop is also depending on the length and the shape of the pipeline. Number of bends, horizontal and vertical branches of the pipeline also affects the pressure drop and has to be considering initially in the design phase.

3.3.5. Minimum conveying velocity

There is always a minimum velocity which allows the material to be conveyed and not settled down in the bottom of the pipeline. This minimum conveying velocity should have a proper magnitude, because if it will be too low material will stick or settled down in the pipe; on the other hand, the higher velocities increase the pressure drop in the pipeline.

Minimum conveying velocity and flow rate of the air is closely related to material characteristics. Particle size, density, shape and mean size: they all have a direct effect on minimum conveying velocity, pressure drop and air flow rate. Moisture content is a property that can cause conveying problems in the bends and valves.

3.3.6. Mode of conveying

The first thing for designing the pneumatic conveying system is to look for mood of conveying. It means which system is more suitable to convey the selected type of material. Since the material is closer to our case for conveying fungus mycelium is close loop system, the most ideal mode for conveying is dilute phase conveying. For dilute phase conveying the important variable to consider is the "solid loading ratio" (Akhil Raj P, 2017)[12].

3.3.7. Solid loading ratio

Solids loading ratio or phase density, is a useful parameter in helping to visualize the flow. It is the ratio of the mass flow rate of the material conveyed divided by the mass flow rate of the air used to convey the material. It is expressed in a dimensionless form. In dilute phase system it is preferred ratio of solid to air is 2:1 (Akhil Raj P, 2017).

3.3.8. Conveying capacity

The more will be the distance the less will be the capacity to convey and vice versa. In our case, the conveying distance isn't that much so the system will allow conveying the more material.

3.3.9. Conveying pressure

Conveying pressure is directly proportional to conveying distance, the more is the distance to convey the material, and the more pressure is needed to make sure the conveying process completion.

4. Design Phase

This is an initial design of the system that is going to be developed in this project work. This system design has many complexities; the main complex problem is material properties. The purpose of the project is to build a system through which the molds of fungus mycelium will be filled. This material would be a good alternative of plastic and unicel material and helpful to control the pollution.

First of all, the design components were developed and built in Solid works and NX. Design determines the shape or geometry of the model or assembly. It also expresses numeric parameters, such as line lengths or circle diameters, or geometric parameters.

So, to design the system, many initial designs were discussed with coordinator Dr. Ahuett. The best solution has been decided to convey the material through a dilute phase pneumatic conveying system and inject inside the mold. Air will be used as gas in conveying process.

Finally, the system was selected which includes different components. The material will be placed inside a mixer which will mix the material through a motor supply. A vacuum will be used in the bottom which will suck the material from the mixer and material will be conveyed through pneumatic conveying pipeline and finally inject in the mold. To remove the excessive material from the box and placed it again in the mixer a cyclone separator will be used, that will separate the material from air and material will go again inside the mixer.

A pneumatic conveying system never has been used to convey this kind of material before. But the main problem is the injection process because it is hard to control the material trajectory and filling process inside the mold through air.

The system will consist several components:

- Horizontal pipe sections
- Vertical pipe sections
- Bends 90°
- Y pipe component
- Suction Pump
- Cyclone separator
- Box for the mold
- Base of the system
- Inlet Bucket or mixer
- Motor for the mixer

This design is initial stage of the project and will be used for the further research in the future. To test the material in the system, a prototype will be made and will be discussed in the next chapter. In short, system components will be discussed in this chapter. Mostly, the results will be based on prototype experiments so it would be easy to modify the system components and design after prototype experiments and results.

4.1. Design of the pipeline

To convey the material from the initial to final point, a pipeline is required with specific length and diameter, considering the all conditions and concepts discussed above. This design phase is a theoretical part for the designing of dilute phase pneumatic conveying system for our project purpose for injection the material in the mold.

To validate our system and check the injection process a prototype will be made. And also, the simulations will be made regarding to that prototype in order to compare the results.

All the design parameters and calculations are selected by using the standard design calculations from the book of David Mills “Pneumatic conveying system design guide”.

For the pipeline designing, to convey the fungus material from initial point to final point, we will use some horizontal and vertical parts as well.

4.2. Pipeline length

Pipeline length must be considered in terms of its orientation, and account must be taken of the individual lengths of horizontal, vertically up and vertically down sections (Mills, 2004)[13].

In our project the material will not be conveyed from so long distance, so a suitable length will be required. There are several vertical and horizontal sections are included in the overall length of the pipeline.

Section Number	Pipeline component	Orientation	Length in centimeters
1	Pipe	Vertical	11
2	90 degree Bend	Vertical to horizontal	
3	Pipe	Horizontal	73
4	90 degree Bend	Horizontal to vertical	
5	Pipe	Vertical	35
6	Pipe (Y section)	Vertical with two bends	

Table 1: Pipeline data from inlet to injection point

This length of the pipeline will be used to convey the material from inlet bucket to the injection point, in the mold.

During the injection process of the mold, material will fall through the air pressure in the mold. The mold is placed inside a box to close the circuit from the atmosphere. There will be excessive material left inside the box after filling and removing the mold every time. So, this excessive material has to be removed and delivered to the initial point from where material conveying process has been started. For this purpose, another section of the pipeline will be used, which will convey the material from the box until the mixer.

Section Number	Pipeline component	Orientation	Length in centimeters
7	90 degree Bend	Vertical to horizontal	
8	Pipe	Horizontal	
9	Pipe	Horizontal	
10	90 degree Bend	Horizontal to vertical	
11	Pipe	Vertical	35
12	Pipe (Y section)	Vertical with two bends	

Table 2: Pipeline component data and dimensions from injection to inlet

The overall pipeline length is 5.05 meters, which includes different horizontal and vertical sections. There are 5 bends used in the system and all the bends are 90 degrees.

4.3. Mathematical Model

After selecting the length of the pipeline, a mathematical model has been made to compare the results with experiments, which will be made after this part. These calculations involve in model have different parameters such as velocity, volumetric flow rate; Mass flow rate, Solid loading ratio, Pressure at inlet, pressure at outlet, and total pressure drop in pipeline.

Different formulas were use in this mathematical model to calculate the desire values for the system.
All the formulas used in this model are taken from the book "Design guide for pneumatic conveying" by David Mills.

$$\mathfrak{m} = \frac{2.74 P_1 C_1 d^2}{T_1} \; Kg/_{s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Equation (1) shows the mass flow rate of the air:

Where:

- P = pressure;
- C = velocity of the air;
- d = diameter of the pipeline.

$$Power = 165\mathfrak{m} \ln\left(\frac{P_4}{P_3}\right) KW \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Equation (2) shows the power required for the system run.

Where:

- $\mathfrak{m}$ = mass flow rate of the air;
- $\frac{P_4}{P_3}$ = the pressure fraction of the pressure at inlet and outlet points.

$$\nabla P = \left(\frac{4fL}{d} + \sum K\right) \times \frac{\rho\, C^2}{2}\ {}^{N}/_{m^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Equation (3) shows the change in pressure or pressure drop across the pipeline.

Where:

- ∇P = pressure drop;
- f = friction coefficient;
- L = overall length of the pipeline;
- K = coefficient that shows the sum of losses;
- ρ = density of the material;
- C = velocity of the air.

Based on these formulas, a mathematical model has been made in excel file.

Material Data		
Material	**values**	**Units**
Volumetric flow (theoretical)	150 0.0025	L/min m^3/sec
Density	150	Kg/m^3

Table 3: Material data

Parameters	Values	units
Pipe length	5.05	meter
Diameter (assumed)	0.05	meter
Delta pressure	0.05123869	bar
Temperature	298	K
Air velocity	20	m/s
bends	4	
Y constant	3.718	
R constant	8.314	

Air density	1.225	Kg/m^3
K	1.9	

Table 4: Design parameters

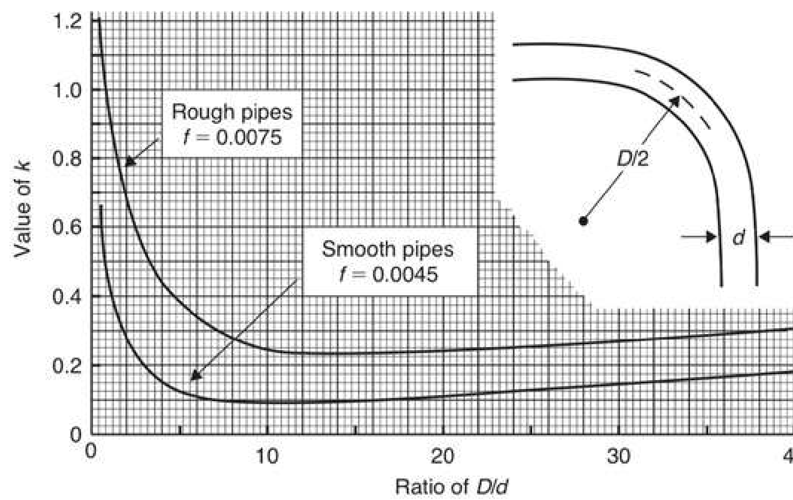

Figure 4: Head loss for 90 degree radius bend

Figure 4 shows the head loss for the 90-degree bends. We are using 4 bends in the system and they are all 90-degree bends. As shown in the figure, different values can be selected depending on the roughness of the pipe. For rough pipes coefficient of friction is 0.0075 and on the other hand for smooth pipes it is 0.0045. K is the sum of head losses in the pipeline and in horizontal axis the is ration between external and internal diameter of the pipeline.

Parameters	Values	Units
Mass flow rate of the material	0.375 1.35	Kg/s Ton/h
Mass flow rate air	0.0331614	Kg/s
Power	0.35846982 0.48070803	KW HP
Loading ratio	3.14120223	

Table 5: material parameters

2							
3	**Material**		**Unidad**		Flujo másico materi	0.375	kg/s
4	Flujo Volumétricc	150	L/min			1.35	tonne/hr
5		0.0025	m^3/s				
6					Flujo másico aire	0.0331614	kg/s
7	Densidad	150	kg/m^3				
8							
9	**Parámetros**				Potencia	0.3584698	kW
10	Longitud tubos	5.05	m			0.480708	HP
11	Diámetro	0.05	m				
12	Delta Presión	0.0512387	bar				
13	Temperatura	298	K		loading ratio	3.1412022	
14	Velocidad Aire	15	m/s				
15	#Codos 90°	4					
16	Constant Y	3.718					
17	Sumatoria K	1.9					
18	Constante R	8.314					
19	densidad aire	1.225	kg/m3				
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29							

$$\dot{m}_a = \frac{2.74 p_1 C_1 d^2}{T_1} \text{ kg/s}$$

$$\text{Power} = 165 \dot{m}_a \ln\left(\frac{p_4}{p_3}\right) \text{ kW}$$

$$\Delta p_a = \left(\frac{4fL}{d} + \Sigma k\right) \times \frac{\rho C^2}{2} \text{ N/m}^2$$

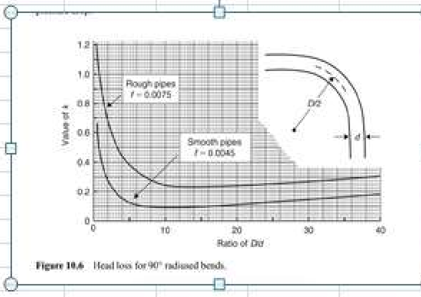


Figure 5: Mathematical model

In figure 6, Mathematical model has been created in the excel file. This mathematical model is the initial step for design phase of the system, that can lead to the more efficient and accurate design. The purpose of this model is to compare the results of the system with the prototype which will be made to validate the system. And some changes can be made in the system on the basis of results by comparing experimental and mathematical values. The excel file will be attached in the end of the document.

4.4. Calculation of the diameter of pipeline

To calculate the diameter of the pipeline we need density of the material, air density and velocity.

$$Density\ of\ the\ material = \ 150\ kg/m^3$$

$$Density\ of\ the\ air = 1.2\frac{kg}{m^3}$$

$$Mass\ flow\ rate\ required\ (Theoratical) = \ 0.375\ \ kg/s$$

Velocity assumed in the pipeline was 20 m/s.

This ratio expresses the mass flow rate of the material conveyed divided by the air mass flow rate that convey the material (Mills, Solid loading ratio, 2004)[14].

$$\varphi = \frac{\mathfrak{m}_m}{3.6m_{air}}$$

In this case, the sold loading ratio has been calculated in mathematical model (Table 5: material parameters).

which is φ=3.14120223

So, we can say:

$$\mathfrak{m} = \rho \times A \times v = 0.375 \ {}^{kg}/_{s}$$

$$\mathfrak{m} = \Phi \times \rho \times A \times v$$

$$0.375 = 3.14120223 \times 1.2 \times \pi/4 \times D^2 \times v$$

Thus, $D^2 = \frac{0.375\times4}{3.14120223(1.2\times20\times\pi)} = 0.060663m = 2.3858inche$

So, we will consider the diameter of our pipeline 2 inches or 0.05 meter.

4.5. Material of the pipe

Material of the pipeline is really important for the system durability and long-run. Since, our material which is a fungus material is not bulky and sharp, a suitable material can be used for the pipeline sections.

In any case, steel is the most common material that use in pneumatic conveying pipelines. Hence, there are many other suitable materials that can be used regarding to conveying material properties.

Different materials need to be conveyed in a good way and that can only be achieved by controlling conveying conditions (Mills, Pipeline material and material degradation, 2004) [15].

4.6. Bends

Bends are necessary components are any kind of pneumatic conveying system. It allows the materials to change its direction depending on the flow direction and the final destination of the material conveyed. But bends also cause different problems in pneumatic conveying systems.

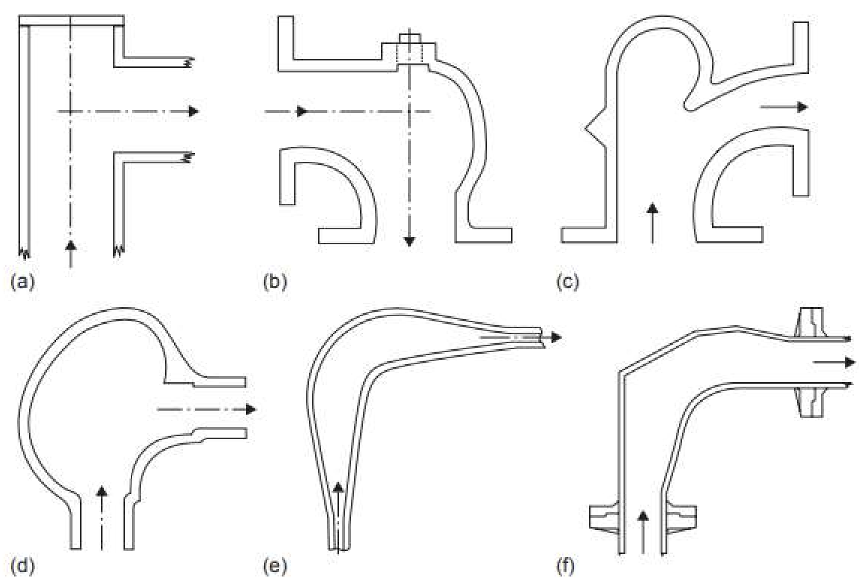


Figure 6: some special bends developed for pneumatic conveying systems: (a) the blind tee, (b) the booth bend, (c) the vortices ell, (d) the flow bow, (e) the expanded bend and, (f) the gamma bend

Each bend will add some resistance to the system and hence to the conveying air pressure required. If the conveying material is abrasive an ordinary steel bend fail within 2 hours. An abrupt change in direction will add to the problem of fines generation with friable materials, and angel hairs will be generated in long radius bends with many synthetic materials. Different bends are available to minimize each problem mention above. Mostly, bends have constant bore or constant radius, as with conventional bends.

There is another group of bends which is developed to control different situation of flow and different problems as well. These bores neither have constant bore nor constant radius. Some of these bends are shown in the Figure 24.

To use that kind of bends, some care has to be taken into account, they must be suitable for the material being conveyed and the pressure drop across the pipeline (Mills, Bends, 2004)[16].

4.7. Head losses in the pipeline

Losses happen in the pipeline for different reasons and they interrupt the flow of material. They also disturb the pressure drop and conveying velocity of the material. To calculate the losses in our system, we divide the pipeline in two sections. (1) Mixer to injection system and (2) injection system to cyclone separator.

<u>Head losses from Mixer to injection box pipeline section:</u>

To calculate the head loss, the formula is taken from the book "Pneumatic conveying design guide" by David Mills.

$$h_f = \frac{4flv^2}{2gD}$$

Where:

- $h_f = frictional\ losses$
- F = friction factor
- l =length of the pipeline
- v =velocity of the material

Horizontal length of the pipeline in this part is 0.73m and vertical length of the pipeline is 0.46m.

So, total length is $L = 0.73 + 0.46 = 1.19m$

From Moody's chart, frictional factor 4f is taken 0.04.

Thus, $h_f = \frac{0.04 \times 1.19 \times 20^2}{2 \times 9.81 \times 0.05} = 19.408766\ m\ of\ fungus\ material$

Bend losses in pipeline=$number\ of\ bends \times 0.5^2 \times {v^2}/{2g}$

$$= 2 \times 0.5^2 \times \frac{20^2}{2 \times 9.81} = 10.19\ m\ of\ fungus\ material$$

Total head loss= $19.408766 + 10.19 = 29.60237\ m\ of\ fungus\ material$

Equivalent head of air ,$h_{air} = \frac{\rho_{fungus\ material}}{\rho_{air}} \times total\ head\ loss$

$$= \frac{150(\text{Table 3}) \times 29.60237}{1.2(\text{Table 3})} = 3700.2974\ m\ of\ air$$

<u>Head losses from injection outlet to cyclone pipeline section</u>

This is second section of our pipeline system, which goes from injection bucket to cyclone separator. The same process will be applied to calculate the losses in this section as well.

$$h_f = \frac{4flv^2}{2gD}$$

Horizontal length of the pipeline in this part is 1.8783m and vertical length of the pipeline is 2.3m.

So, total length is $L = 1.8783 + 2.3 = 4.1783m$

From Moody's chart, frictional factor 4f is taken 0.04.

Thus, $h_f = \frac{0.04 \times 4.1783 \times 20^2}{2 \times 9.81 \times 0.05} = 68.1476\ m\ of\ fungus\ material$

As we can see that the head friction losses are quite large comparing to first section. The reason is the flow of the material, because in first section the material was flowing downwards and in this section material has to flow upwards in a long vertical section as well.

Bend losses in pipeline=$number\ of\ bends \times 0.5^2 \times {v^2}/{2g}$

$$3 \times 0.5^2 \times \frac{20^2}{2 \times 9.81} = 15.29\ m\ of\ fungus\ material$$

Total head loss= $68.1476 + 15.29 = 83{,}4376\ m\ of\ fungus\ material$

Equivalent head of air ,$h_{air} = \frac{\rho_{fungus\,material}}{\rho_{air}} \times total\ head\ loss$

$$= \frac{150(\text{Table 3}) \times 83.4376}{1.2(\text{Table 3})} = 10429.7\ m\ of\ air$$

4.8. Design of the blower

To design the blower, we need to know the air discharge through the blower (Akhil Raj P A. J., 2017)[17].

$$Air\ discharge\ from\ bower = Cross\ section\ area \times velocity\ of\ air$$

$$Area\ of\ pipe = {}^{\pi}/_{4} \times D^2 = {}^{\pi}/_{4} \times 0.05^2 = 0.0019625m^2$$

Air velocity=20 m/s

So, the discharge will be= $area\ of\ the\ pipe \times velocity\ of\ air$

$$Discharge = 0.0019625 \times 20 = 0.03925\ {}^{m^3}/_{s}$$

4.9. Power needed

Power needed for the system can be calculated from two different methods, by using the pressure drop and second way is to use the total head losses in the system

Using pressure drop:

To calculate the power needed for the system, pressure drop must be calculated first.

$$Power = 165 m_a \ln\left(\frac{P_4}{P_3}\right) KW$$

- $m_a = mass\ flow\ rate\ of\ the\ air$
- $P_4 = pressure\ drop\ of\ air\ in\ pipeline$

- $P_3 = pressure\ at\ inlet$

P_4 can be calculated from following formula:

$$\nabla P_a = P_4 = \left(\frac{4fL}{d} + \sum k\right) \times \frac{\rho C^2}{2}\ ^{N}/_{m^2}$$

Where:

- $f = friction\ f = 0.0045$ (Figure 4: Head loss for 90 degree radius bend)

- L =o verall length of the pipe= 5.05 m

- D = diameter of pipe $= 0.05m$

$$\sum k = sum\ of\ losses = 1.9$$

To see the estimation go: Figure 4: Head loss for 90 degree radius bend

$$\rho = density\ of\ the\ air = 1.225\ \frac{kg}{m^3}$$

$$C = velocity\ of\ the\ air = 20\ ^{m}/_{s}$$

Thus, the $\nabla P_a = 0.098441\ bar$

Pressure P_3 at inlet of the pipeline was measured in the fluid lab and will be considered in the formula for power estimation:

Figure 7: Inlet pressure measurement

A manometer with mercury was used to take the value at the inlet of the pipe and was measured as 1.013 bar.

Thus, by having all values to calculate the power needed using the following formula.

$$Power = 165 m_a \ln\left(\frac{P_4}{P_3}\right) KW$$

Thus,

$$Power = 0.80853237\ KW$$
$$= 1.08424191\ HP$$

<u>Using head losses in the system</u>

Power needed at inlet of the vacuum is the product of density of material, volumetric flow rate, gravitational acceleration and total head loss by material (Akhil Raj P A. J., Power required, 2017) [18].

Therefore, $P = \rho \times Q \times g \times H$

Volumetric flow rate=Q= $\frac{m}{\rho} = \frac{0.375}{150} = 0.0025\, m^3/_s$ (Table 3: Material data)

Thus, $P = 150 \times 0.0025 \times 9.81 \times 83.4376$ [1]=$0.30694607\ KW$

Considering the safety factor of 1.5, the power needed will be:

$$P = 0.30694607 \times 1.5 = 0.4604191 KW$$

Let's consider the power calculated by head losses in the system that is $0.4604191 KW$ KW.

4.10. Material velocity

Mass flow rate of the material (needed) = 0.375 kg/s

Volumetric flow rate, Q= $\frac{m}{\rho} = \frac{0.375}{150} = 0.0025\, m^3/_s$ (Table 3: Material data)

Pipe area (cross-sectional)= $\pi/_4 \times D^2$

$$= \pi/_4 \times 0.05^2 = 0.0019625 m^2$$

Discharge is $Q = A \times v$

Where v is the velocity of the material, $v = \frac{Q}{A}$

$$= \frac{0.0025}{0.0019625} = 1.27388535\, m/_s$$

[1] Head loses 83.4376 was calculated in the section head losses in the pipeline.

[2] The coefficient of restitution is the ratio of the final to initial relative velocity between two objects after the

4.11. RPM of the motor

Velocity of air must be determined that rotor of motor must have to meet system requirements.

We know that, $v = \frac{\pi \times D \times N}{60}$

Where N is the RPM of the motor and the D is the diameter of pipe.

Therefore, $N = \frac{60 \times 20}{\pi \times 0.05} = 7643.31rpm \sim 8000rpm$

Cyclone separator

A cyclone separator is a device, which causes separation of solids and gas with the help of centrifugal force. The material that has to be separated can be in solid or liquid form, i.e. droplets, which are classified regarding to their size, shape, and density. The cyclone uses the energy obtained from the fluid pressure gradient to create rotational fluid motion. This rotational motion causes the dispersed phase to separate relatively fast due to strong acting forces.[19]

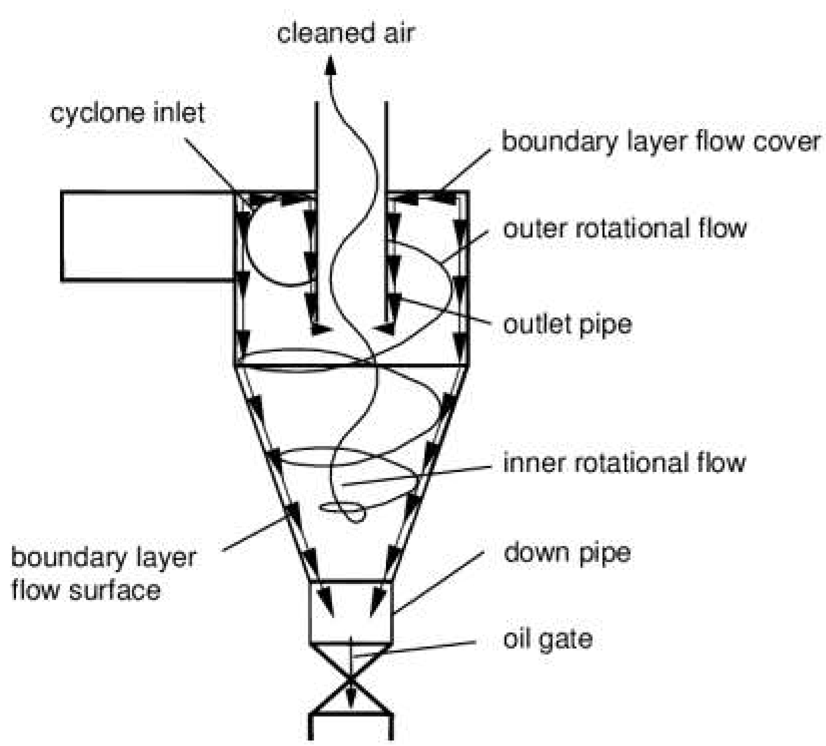


Figure 8: working principle of cyclone separator [20]

As shown in the Figure (26), there are different parameters which explain how a cyclone separator works.

5. CFD Simulations

In this chapter, a brief introduction of CFD simulation will be given. The working methodology of Autodesk CFD will be discussed according to project purpose and criteria. To validate the design, different kind of scenarios has been created with different geometry and parameters. In all simulations, working conditions (parameters) has been changed to see the results and how material flow inside the pipeline and fill the mold. The main purpose of simulations was to visualize the injection process of the mold in initial stage before reaching to the final design. On the basis of these simulations, a prototype will be made to compare the simulations and experimental results, which can help to reach the final design of the system.

5.1 Introduction

CFD is stand for computational fluid dynamics. In CFD applied mathematics, physics and computational software are used to visualize in order to see how liquid or liquid flows. Computational fluid dynamics is based on Navier-stokes equations. These equations tell that how velocity, pressure, temperature, and density of a moving fluid are related (Rouse, 2014).
CFD has wide applications in the areas of fluid and heat transfer within the aerospace and nuclear industries backed by the availability of powerful supercomputers. It has expanded into other industries such as the chemical and petrochemical industries. It is only in recent years that it has been applied to the food industry, with a limited variety of food-related problems being investigated (Scott, 2008)[21].

Computational fluid dynamics has become a very useful tool for engineers. CFD simulations describe in details that how products and processes work, and allow new designs to be developed even before prototypes have been made. It is also used for problem solving and optimization purposes. CFD became more useful since there are more powerful computers has been developed. Low cost, better accuracy and short lead time allows CFD to compete with building physical prototypes, i.e. ´virtual prototyping. There is many commercial software are available and they are easy to use with many default settings, so an unexperienced user can also obtain results for easy problems. Since no model is universal, user has to optimize that which model is better for particular design. This is really important because results obtained from the simulations often help to make decisions that what prototype and process has to be built (BENGT ANDERSSON, 2012)[22].

5.2 Applications

Single phase laminar flow can be simulated accurately, and most single phase turbulent flows the simulations are reliable. But many systems in engineering are very complex and the results obtained might not be so accurate. However, there are design equations can be useful for limited range of processes. CFD simulations can be really helpful when no accurate predictions are possible.

For example, to get flow visualization of the material, and on the basis of these results one can do small change in parameters and can observe that what will change buy changing these parameters. CFD simulation without proper knowledge can be a very uncertain tool.

The normal CFD software have many default settings and will always give results from the solver, but to have good and reliable results the design and model must be selected with logical methodology. A converged solution displays the results of the specific chosen model with the given mesh; however, it does not reveal the truth. Without proper understanding of the CFD program and the modelling theory behind it, CFD can become limited to ‘colorful fluid display’ (Bengt Andersson, 2012)[23].

In most of the CFD packages different options can be available which can deal with CAD drawing, meshing, flow simulations and post processing. To solve a model, there are many steps required, as illustrated in the figure

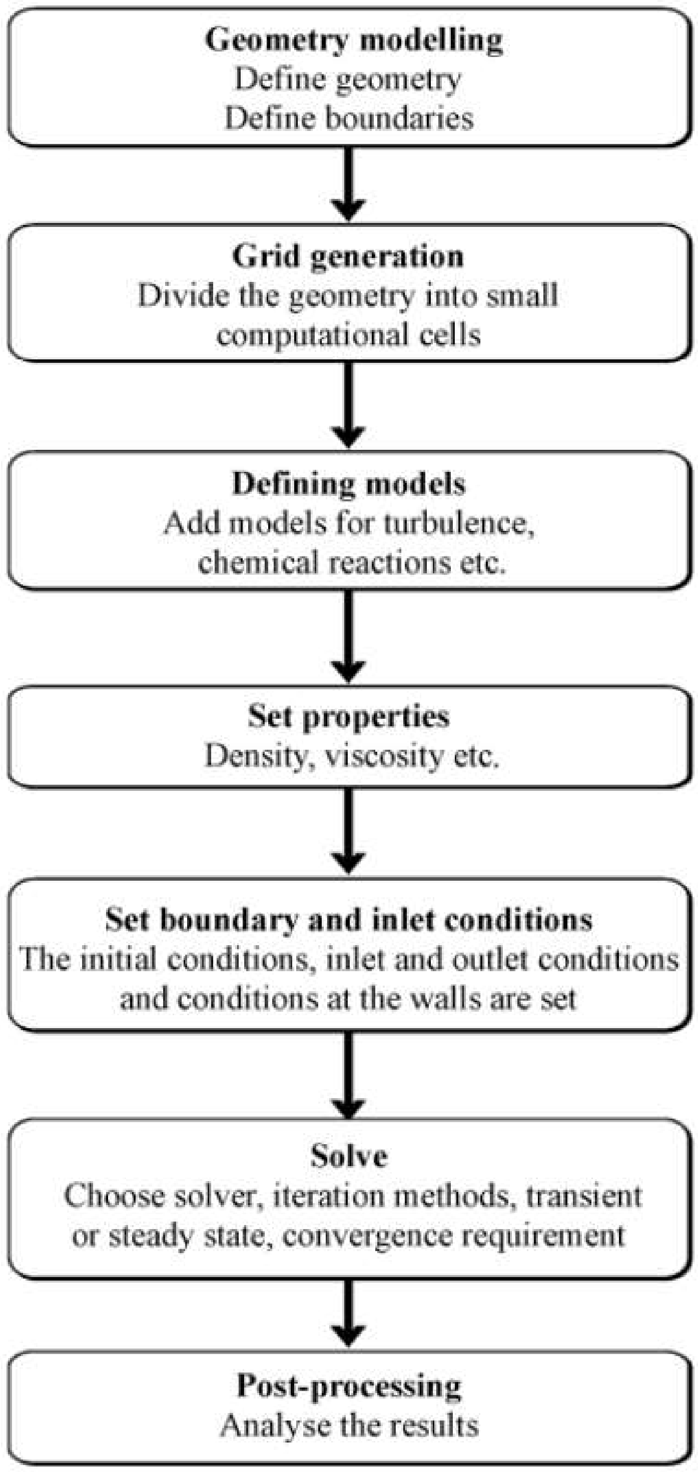


Figure 9: Steps in CFD simulation (BENGT ANDERSSON, 2012, pág. 5)

5.3. Autodesk CFD

For flow simulations purposes, there are different CFD packages are available in the market for example Flow simulator, Simflow, ANSYS, Autodesk CFD etc. Since, the material used in project is not a fluid but a solid kind of material, the best option of using a software for simulation purpose was Autodesk CFD. Because most of the other packages are used for fluid flow simulations and not for massed particles. In CFD 2018/2019, there is an option to optimize the flow and trajectory of massed particles as well.

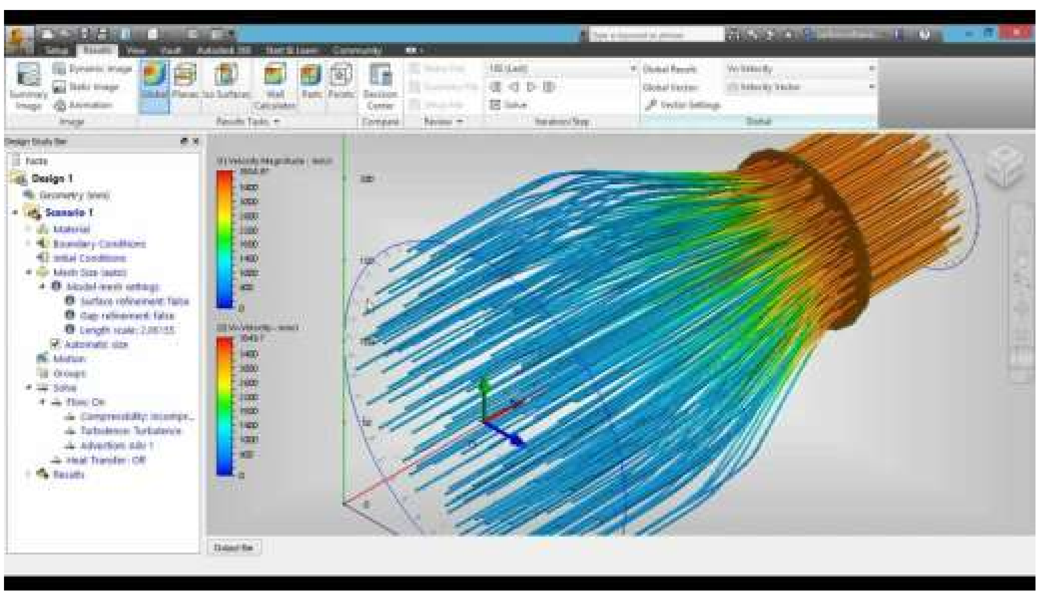


Figure 10: Particles trajectory

To optimize the injection process, different simulation scenarios has been created with the help of Autodesk CFD. The material used in the project is a fungus material and a newly developed material, which is never used in an injection process though pneumatic conveying system. For this concern, it is very important to make simulation of the process before making a prototype. The main purpose of making these simulations is to understand the flow path and trajectory of the material and how it can fill into the mold. As shown in the Figure (10), there is simulation made with particle trajectory and one can see easily understand the flow of particles with specific geometry.

Simulations are very important in any kind of engineering project, because different decision can be made on the basis of the simulation results. Hence, it can be costly to build a prototype without knowing the visual result in advance or the simulations because one can change the parameters and then can change the geometry or design on the basis of the results obtained.

For the project, CFD Autodesk was the best option, because there is a tool that is called "massed particles" and it converts the trajectory of particles to different densities of particles. Since, it is more complex to simulate the massed particles than just a simple fluid flow. Material used in project is a new material and properties, the goal of the simulations to analyze and understand the concept that how injection of the material works through pneumatic conveying system.

For this purpose, different scenarios have been simulated. In this section, a deep explanation will be given about how each scenario has been simulated and the results will be also discussed according to design parameters.

In first scenario, a deep overview will be given about simulation process and how it works. Hence, in the next scenario only the results and important facts will be discussed.

5.4. Methodology

To get the best result, a good methodology has to be followed up. In order to simulate any kind of CAD model, a sequence of steps must be followed to reach the best results. Best methodology and steps will be discussed in this section, which were proved best for the project simulation purpose.

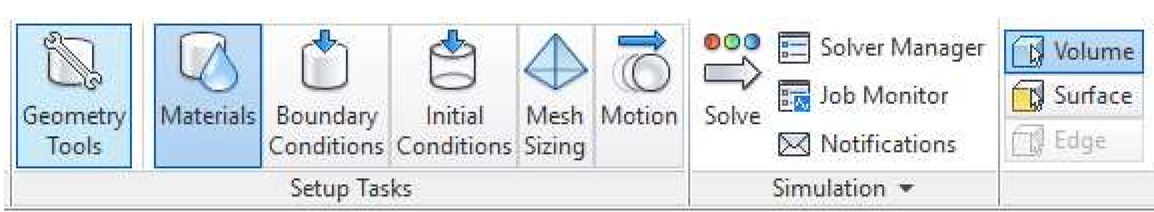


Figure 11: Setup tool bar

There are different setup tasks that are shown above in figure 11. To solve any kind of model, this sequence has to be followed.

Geometry tools

Basically, geometry tools allow to modify the original CAD model according to the best outcome, in which one can get the best result and can avoid the problems in solving the model.

There were 4 main geometry tools that were used in almost all CAD models of the project.

1	**Edge Merging**	**Connect edges that share a vertex with an inflection less than a specified tolerance**
2	Small object Removal	Remove very small surfaces and edges that are typically too small to see, but can greatly affect meshing.
3	Void fill creation	Fill an internal cavity with a mesh able volume to simulate the flow.
4	External Volume Creation	Immerse the model in a flow volume to simulate external flow.

Table 6: Geometry Tools [24]

These tools must be applied before applying any other tool on the model.

Material assigning

After merging the small edges and surfaces which can create problems in meshing and solving the model, material has to be assigned to each and every part of the model. Without assigning the material the mesh can't be completed and system cannot be solved. There are different materials available to use in the program.

Boundary Conditions

Boundary conditions connect the simulation model with its surroundings. Without them, the simulation is not defined, and in most cases cannot proceed. Most boundary conditions can be defined as either steady-state or transient. Steady-state boundary conditions persist throughout the simulation.[25]

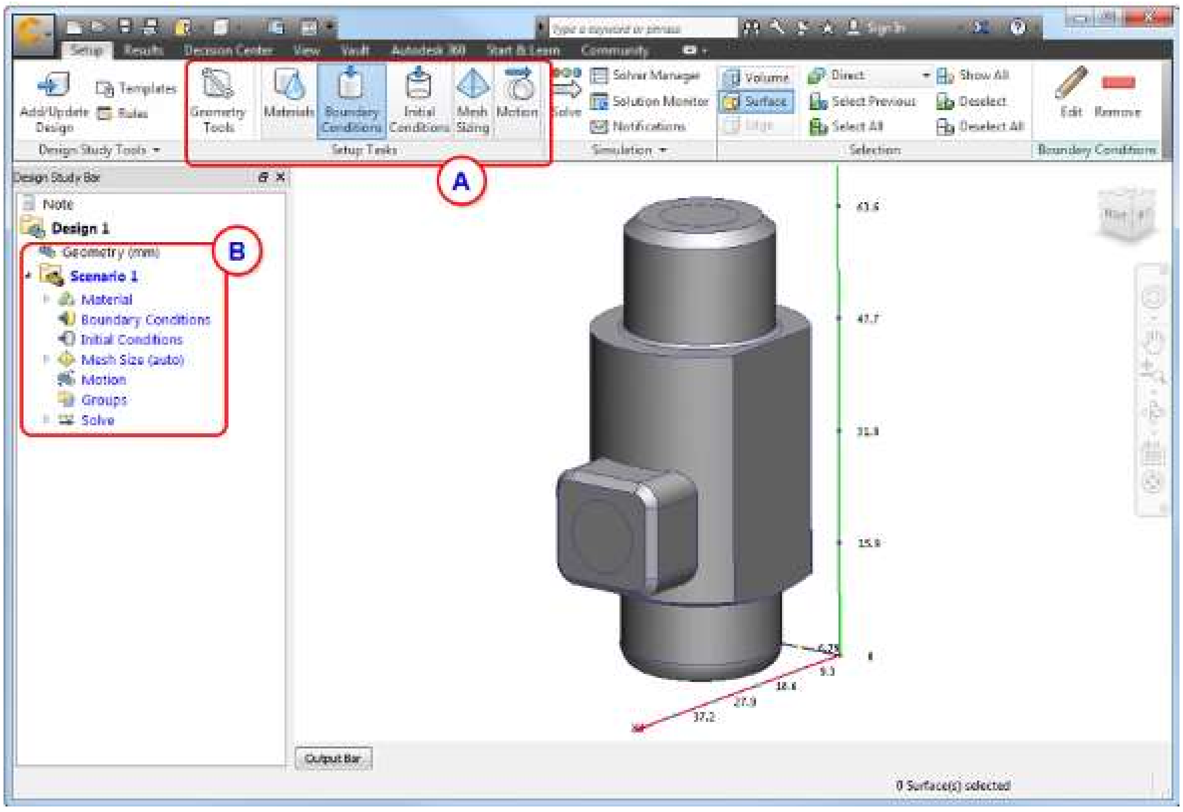


Figure 12: Boundary conditions

Boundary conditions are mostly applied on inlet and outlet surfaces, as shown in the figure 12 above, different boundary conditions have been assigned to the specific model.

Initial conditions

Comparing to boundary conditions, initial conditions can be only assigned at the start of the analysis. Mostly they are used for transient analysis.

There are several initial conditions that can be assigned to model:

- Velocity;
- Pressure;
- Temperature;
- Scalar;
- Humidity;
- Quality;
- Height of fluid

Mesh sizing

the geometry is broken up into small pieces called elements. The corner of each element is a node. The calculation is performed at the nodes. These elements and nodes make up the mesh. (Autodesk knowledge network, 2018)
There were two main meshing options most used, one is manual mesh and the other is called automatic mesh.

Massed Particle Traces

This tool is the most important for the simulation purpose, because it can trace the massed particles flow accurately. Since the material used in our project is not a fluid but a solid particle, this tool will be highly useful for the analyzing of the flow.

5.5. Scenario 1 (with 1 inlet)

To make the final prototype for the system, simulation testing was the first step. One can understand initially by analyzing the simulation and can avoid different design problems which can occur after making the prototype without simulating. As it is known, to make the prototype the material and different instruments are needed and changing every time the design of the prototype can be very costly.

To make flow simulation, a Cad design or model is always required. Since, the most of the concern is related to injection process and flow in the pipeline, a CAD model has been created on Solidworks for scenario 1.

CAD model

A CAD model were made initially for the simulation, to see the flow and injection process in the mold.

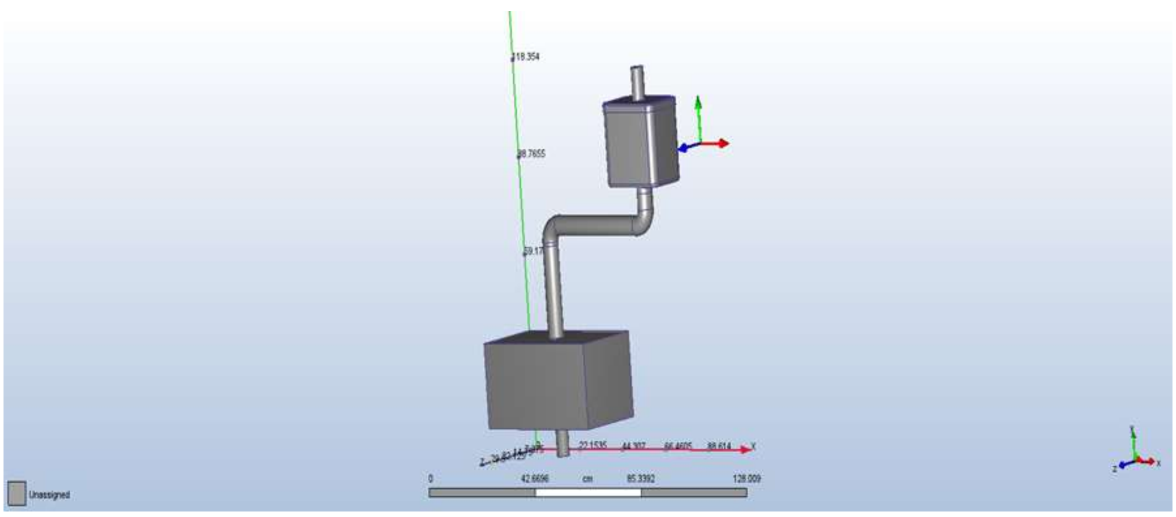
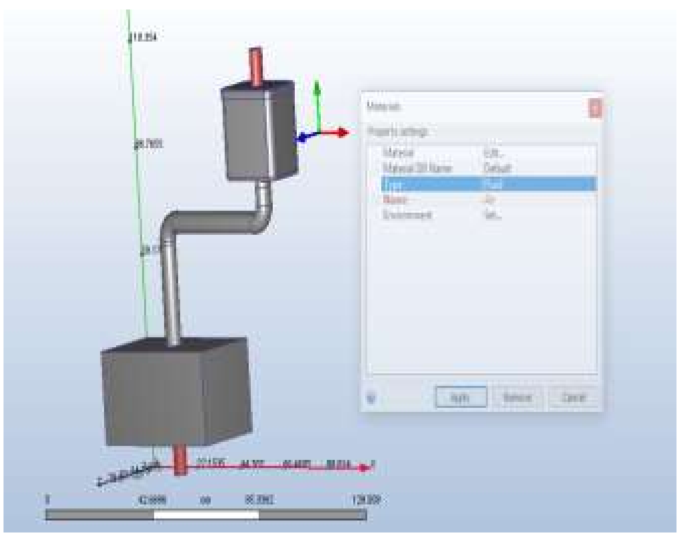


Figure 13: Design model

The box on the top was created as mixer, from where material will start flowing and will come through the pipes in the box shown in figure. Inside the box downside, there is a mold placed to analyses the injection process of the material inside the mold. And how the excessive material goes out from the box.

Material assigning

In the prototype building, PVC pipes has been selected. So, in the simulation the same material has been applied to the pipes. The material for the mold was acrylic, which was the most suitable.



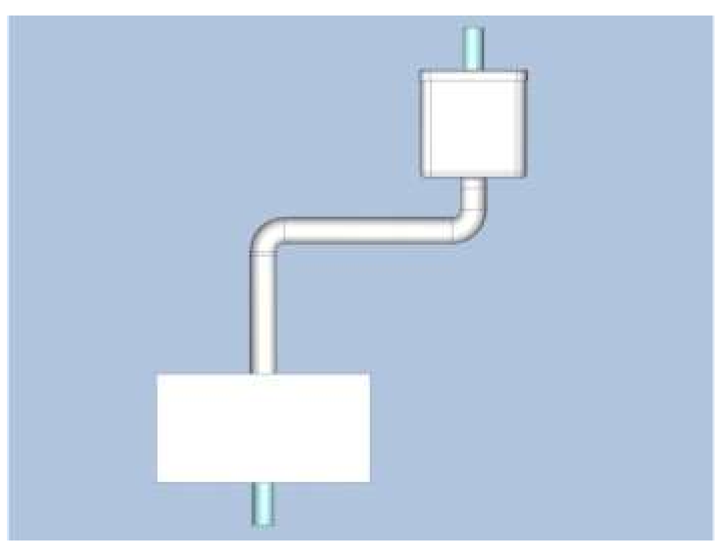


Figure 14: material assigning

The two red pipes shown in the figure above are the inlet and the outlet of the system. In the original design of pneumatic conveying system, air has been selected as conveying gas. So, to assign the boundary conditions for the system, air has been assigned to the inlet and outlet of the material.

Boundary conditions

After assigning the material, the boundary conditions have been applied to the inlet and outlet of the model.

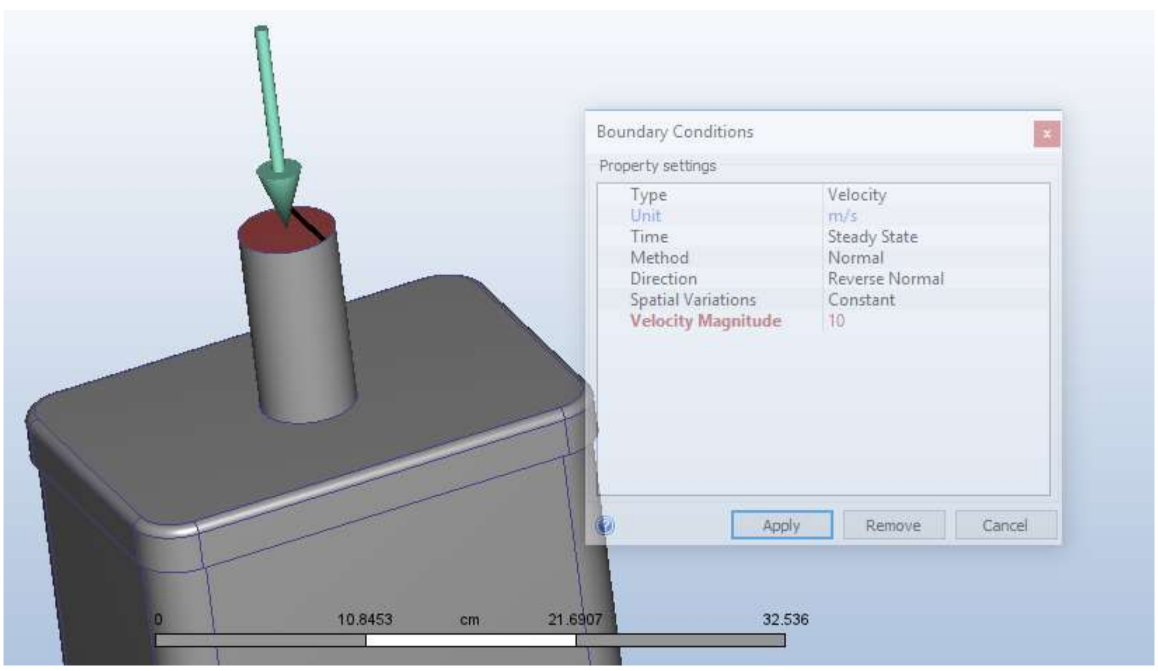


Figure 15: boundary conditions

TYPE	ASSINGNED TO
Velocity Normal(10 m/s)	Surface:159
Temperature(298 Kelvin)	Surface:159
Pressure(0 bar Gage)	Surface:162

Table 7: Boundary conditions

Velocity was applied as first inlet condition, which was 10 m/s assumed. The temperature has been set as second boundary condition, which was 298 kelvins.

As the pressure drop was unknown in the system, the only best possibility is to apply the 0 bar pressure at the outlet of the flow. So, system can automatically calculate the pressure drop according to the flow conditions.

Meshing

For the meshing, an automatic mesh has been used in the software. To have the good result, geometry tools must be used before doing the automatic mesh to avoid certain problems.

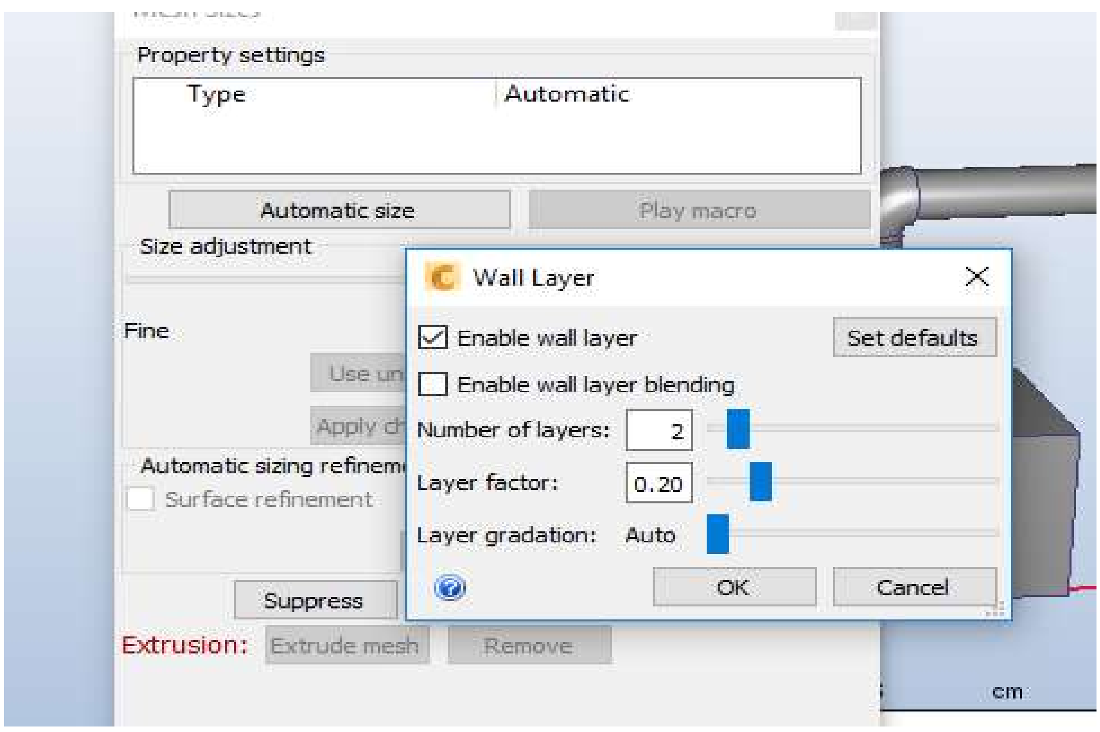


Figure 16: Wall factor

2 numbers of layer were chosen with a layer factor of 0.20. because the design has a lot of connecting points and elements where material must have to flow.

In the figure below, the meshing on the edges can be shown according to selected parameters.

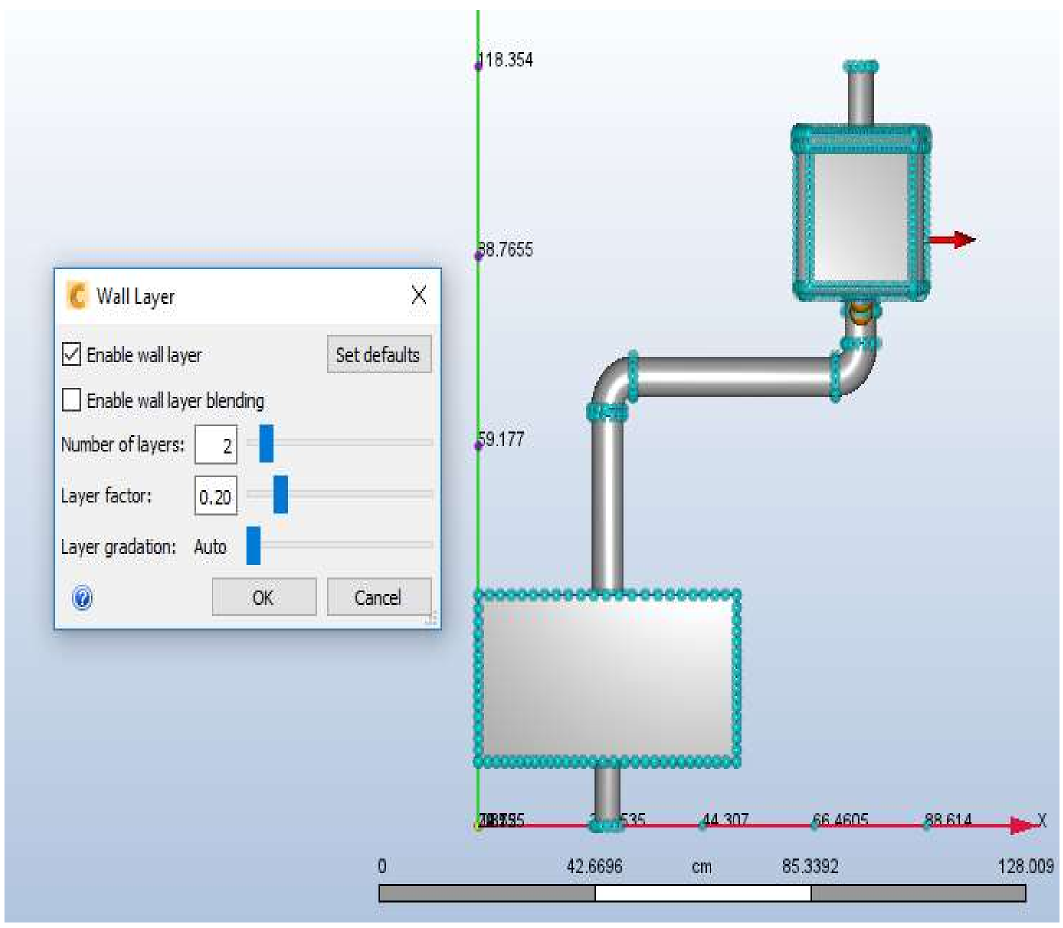
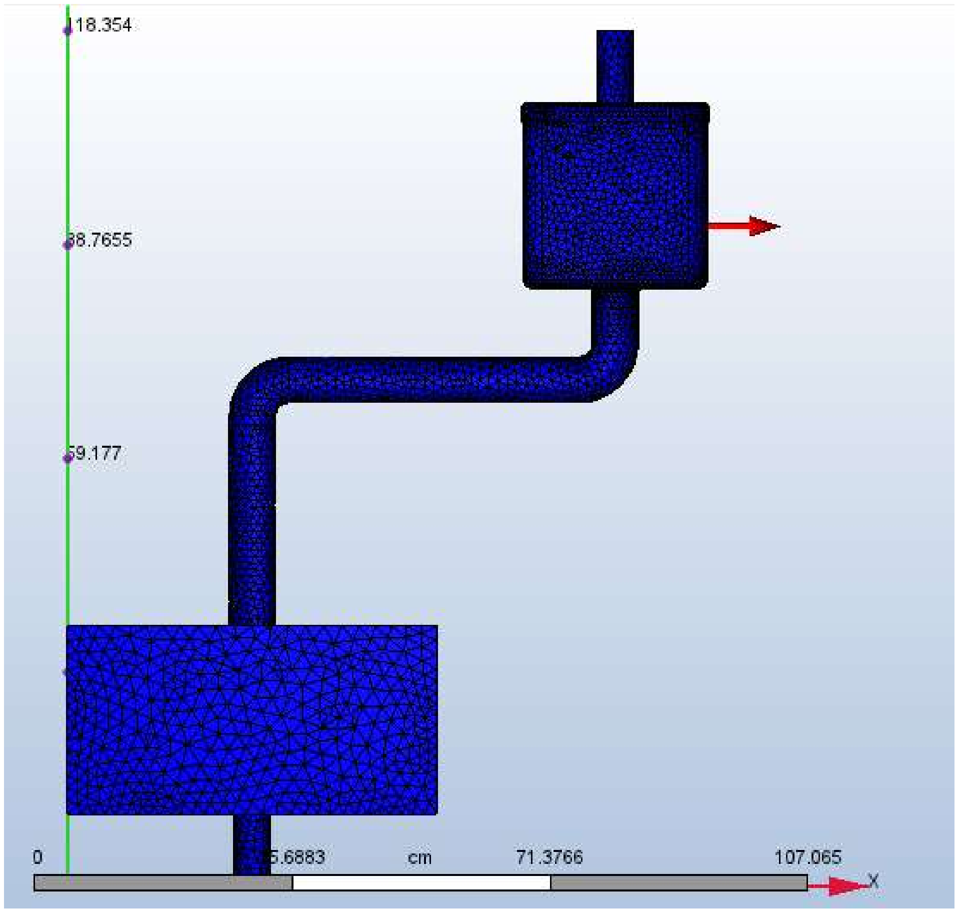


Figure 17: Meshing



Surface refinement	1
Gap refinement	0
Resolution factor	1.0
Edge growth rate	1.1
Minimum points on edge	2
Points on longest edge	10
Surface limiting aspect ratio	20
Surface growth rate	1.2
Enhancement growth rate	1.1

Table 8: Automatic Meshing parameters

Mesh enhancement	1
Enhancement blending	0
Number of layers	2
Layer factor	0.2
Layer gradation	1.05

Table 9: Mesh Enhancement

Number of Nodes	75254
Number of Elements	306668

Solving

After setting all necessary conditions, the model has been solved with 100 iterations, the solver time was 218 seconds.

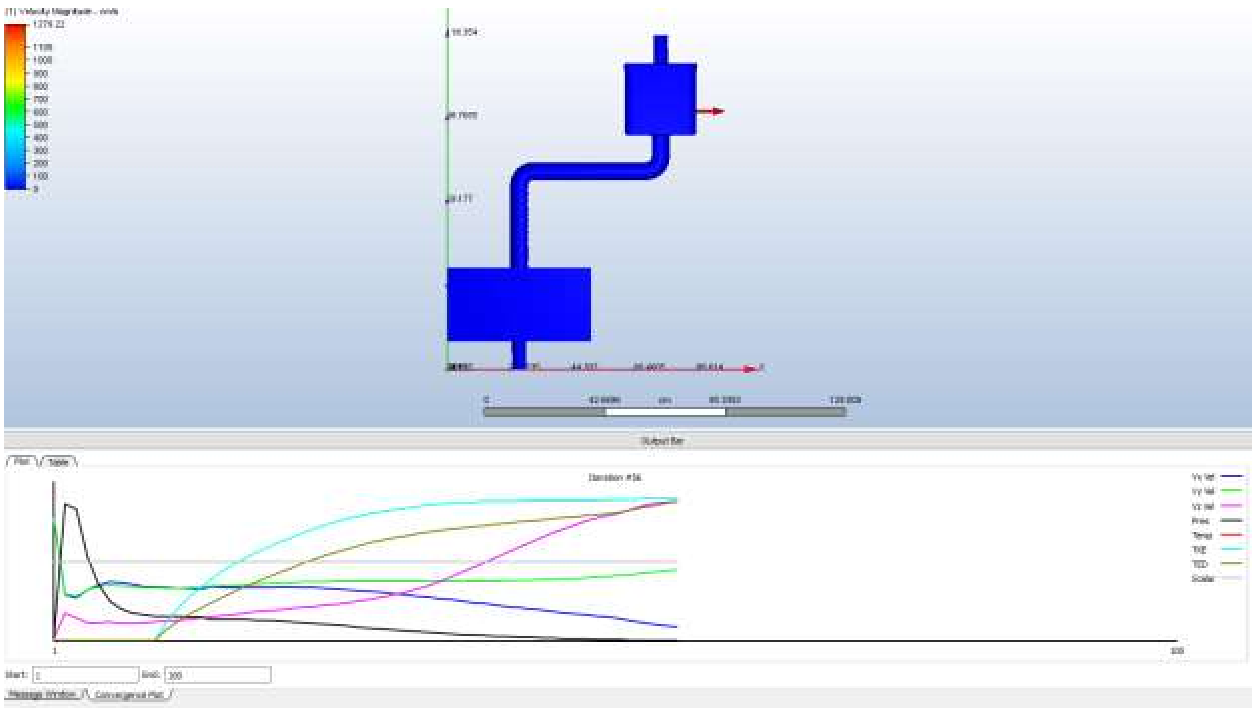


Figure 18: Model solution

The most important thing in the simulation was to analyze the velocity, pressure and mass flow rate in and out of the system. In the figure above, one can see the changing in the parameters according to the geometry of the model.

Mass flow	22.5129 g/s	-22.4167 g/s
Volume flow	18687.1 cm^3/s	-18607.2 cm^3/s

Table 10: Mass Balance

After solution steps

After solving the system model, there are some more steps required to complete the study and analyze the flow.

These steps are:

- Adding flow plane;
- Adding the required traces
- Adding mass to the particles.

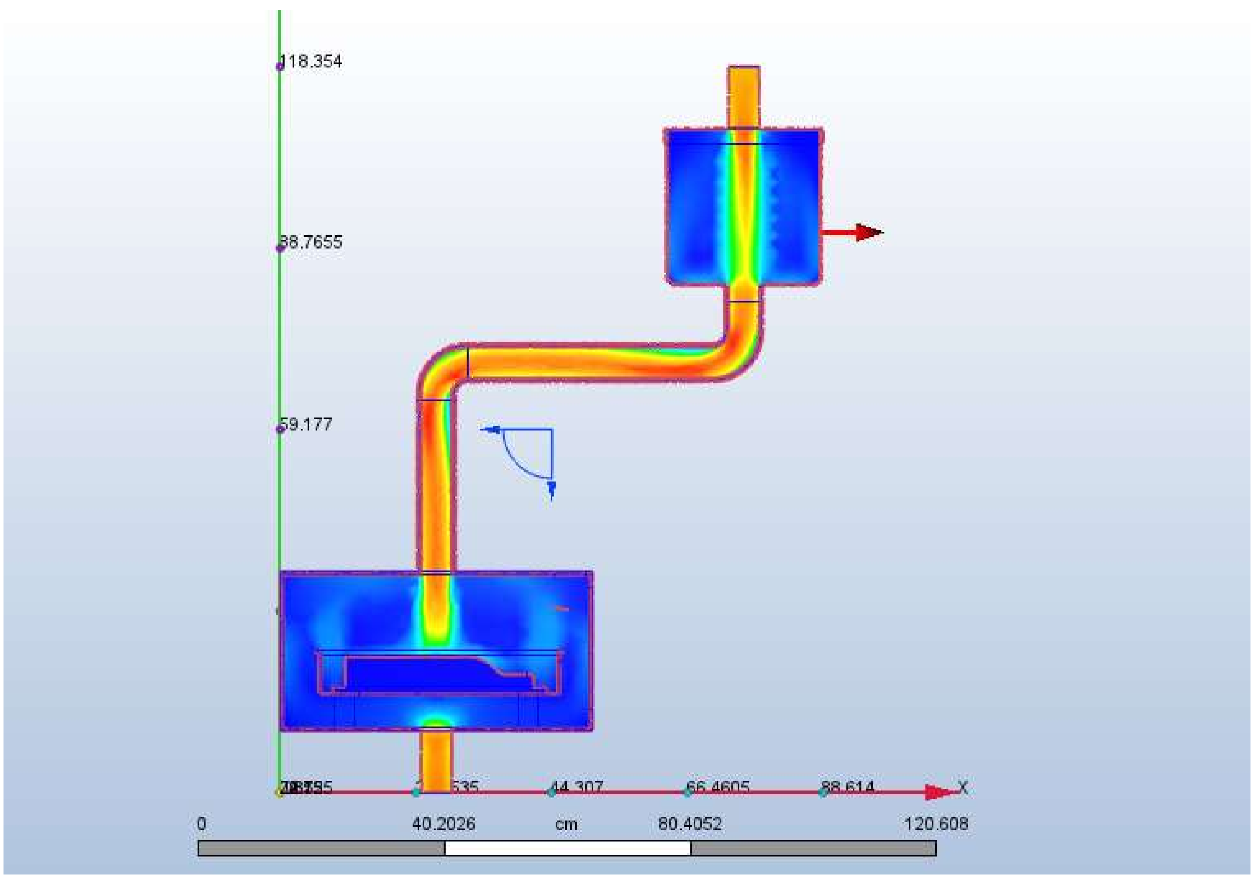


Figure 19: Flow Plane

After adding the flow plane, the surface is visible where flow will occur. The different colors shown in the figure are indicating different parameters such as, velocity, temperature and pressure.

After adding the plane, one can add the particle traces on the inlet. After adding the traces, the flow of the can be easily shown by such traces though the flow plane.

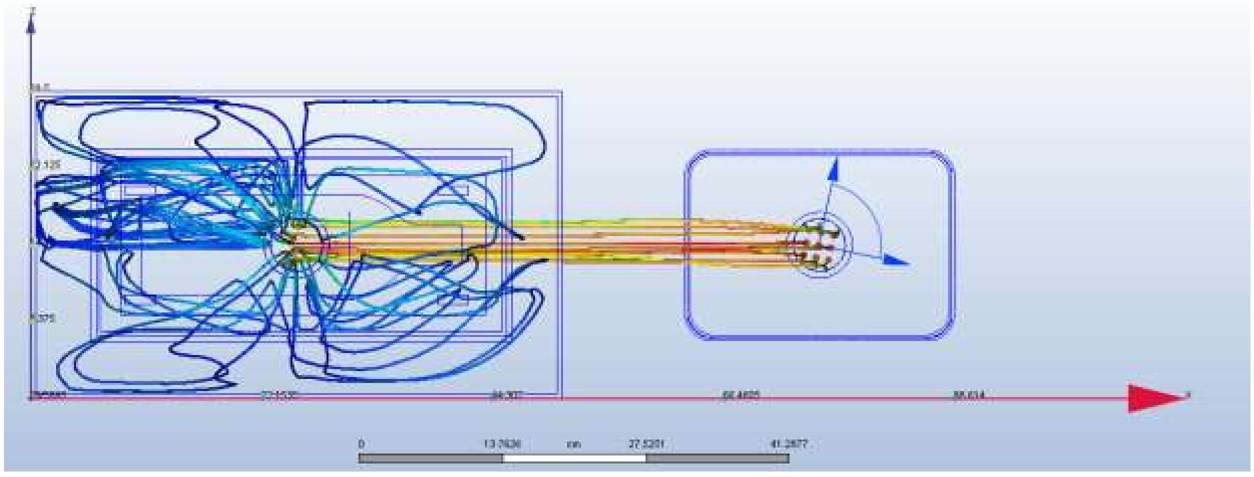


Figure 20: Traces

In the figure 20, the particle traces are easily shown from the top view. To have more clear concept, these traces must be converted into the massed particles. That massed particles are close to the original material so the results can be useful. Particle density of the original material is 282 Kg/m^3.

The same density has been assigned to the particles. The coefficient of restitution was assumed as 0.2[2]. In the figure below, the particle flow can be easily seen.

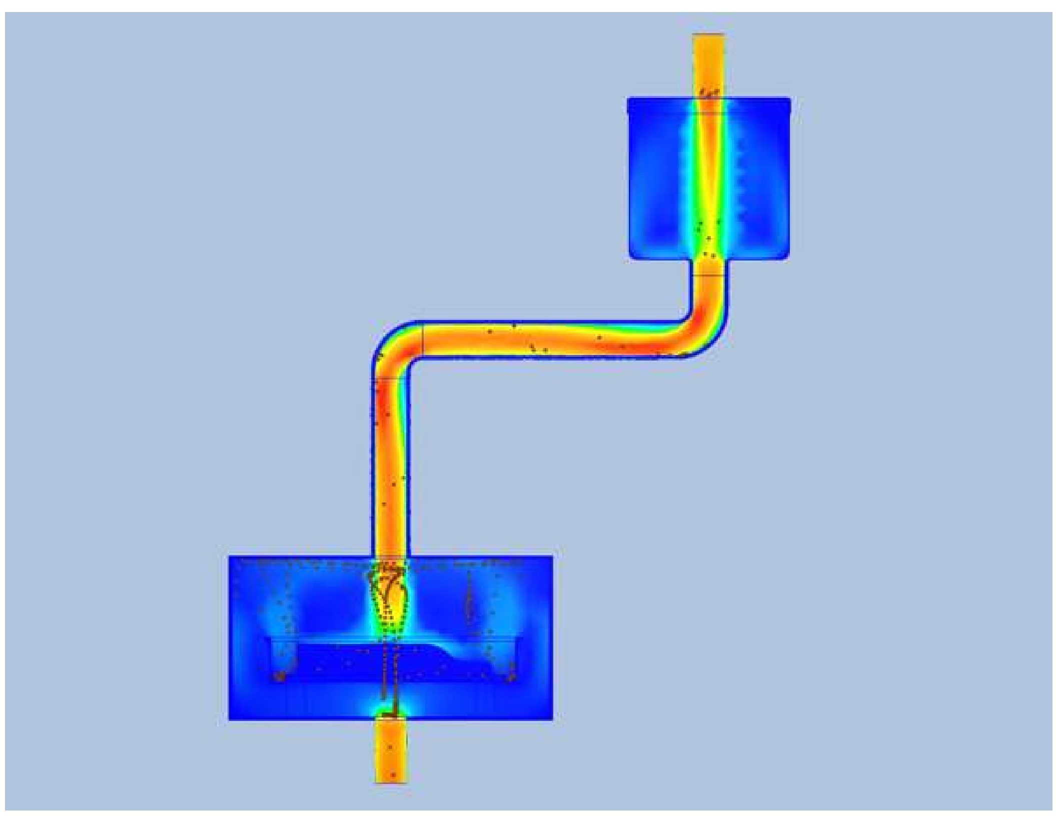


Figure 21: Massed particle flow

[2] The coefficient of restitution is the ratio of the final to initial relative velocity between two objects after the collide.

Results

This was the first simulation to analyze and meet the best conditions for the original design of the project. The velocity increased from 10 to 13 m/s until the end of the simulation. In the figure 21, there is shown that the particles are not completely filling the mold.

The main purpose of the simulation in our project is to analyze the flow of the material. The coefficient of restitution tells that how much a particle will bounce after colliding with the other particle or surfaces. It has value from 0.01 to 0.5 (Briggs, 1945)[26].

Table 11: Inlet results

Inlet 1	inlet bulk	3330.21
	inlet bulk	24.85 C
	inlet Mach	0.0254291
	mass flow in	22.5129 g/s
	minimum x,y,z	0.0
	node near	3826.0
	Reynolds	28163.3
	surface id	159.0
	total mass flow	22.5129 g/s
	total vol. flow	18687.1
	volume flow in	18687.1

Table 12: Outlet results

Outlet 1	mass flow out	-22.4167 g/s
	minimum x,y,z	0.0
	node near	21889.0
	outlet bulk	-0.0
	outlet bulk	24.85 C
	outlet Mach	0.0237928
	Reynolds	28042.9
	surface id	162.0
	total mass flow	-22.4167 g/s
	total vol. flow	-18607.2
	volume flow	-18607.2

5.6. Scenario 2

In the first scenario, it was analyzed that material was not spreading in all the mold because there was just one inlet and the mold length is more than its width. The inlet hole just points in the middle of the mold which doesn’t allow the material to spread around the mold.

Therefore, in the second scenario, it has been decided to place two inlets on the top of top of the box. They will be placed along the length of the mold. The purpose is to analyze if the material spread around the mold equally in this case.

In this scenario and the scenario which will be discussed in future, only the results and important facts will be discussed.

CAD model

The design of the pipeline was changed, just for the simulation purpose to see the best results. So, on the basis of these results, a prototype has to be built for testing and experimenting the process.

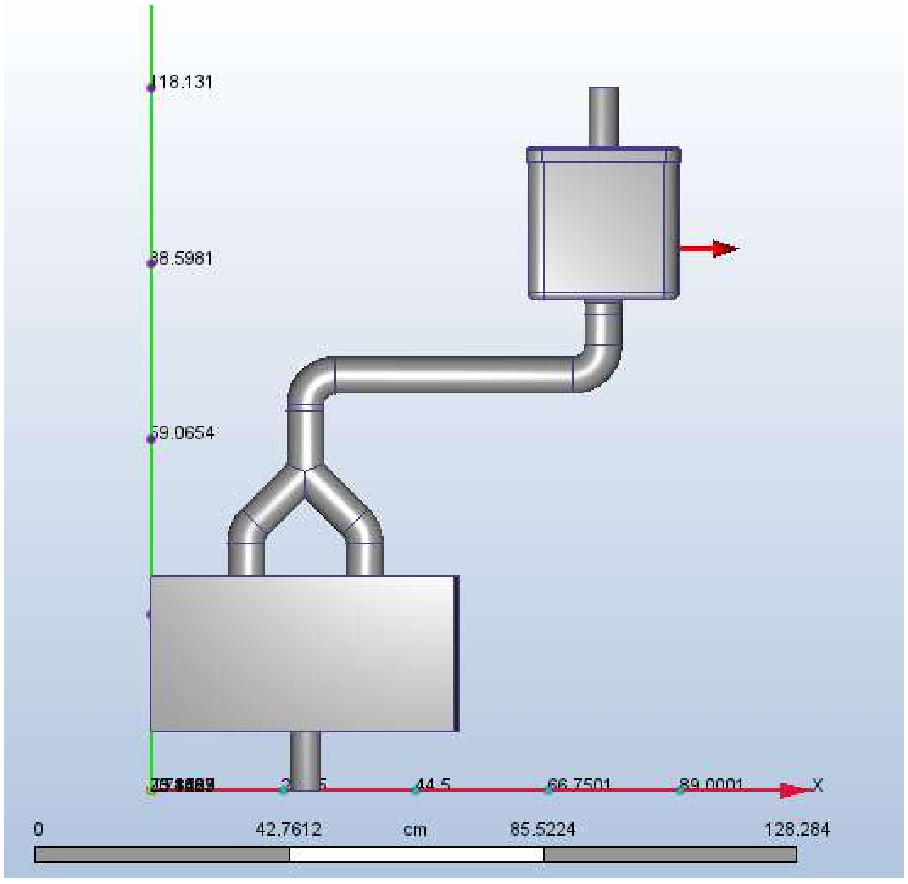


Figure 22: Two inlets (Y component)

Same material and boundary conditions as scenario 1 has been assigned to this model in order to compare the results.

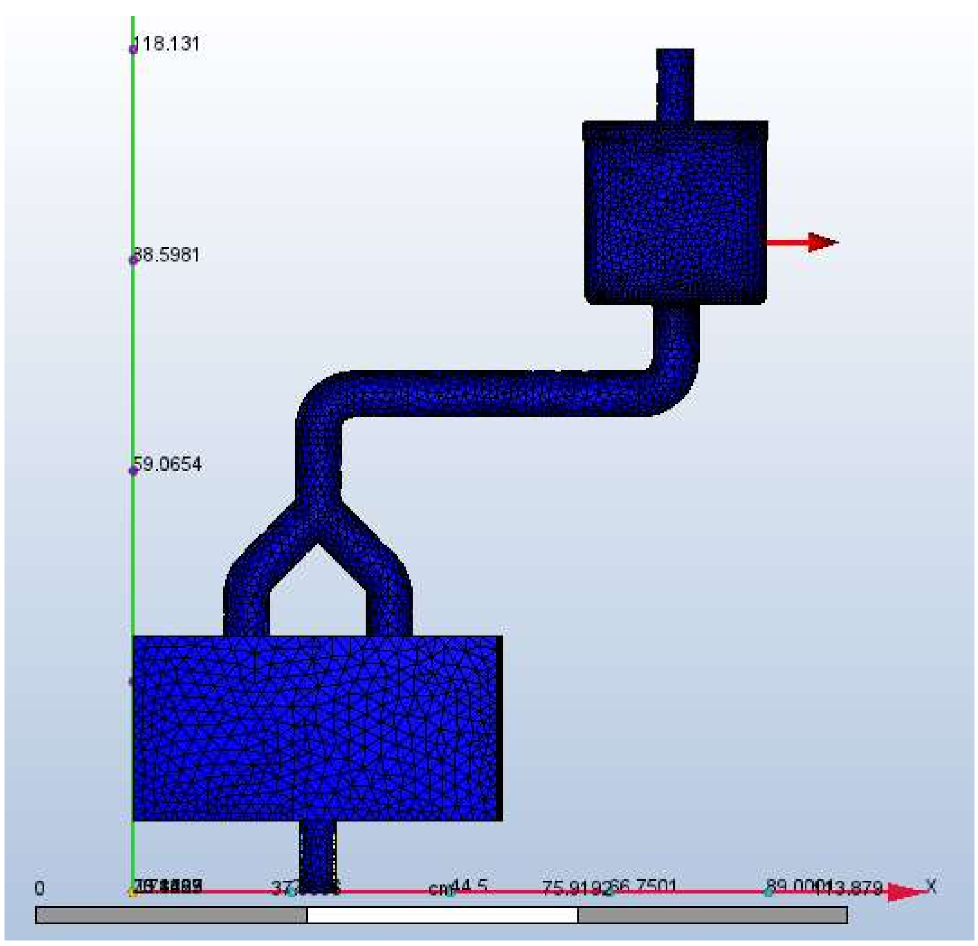


Figure 23: Meshing

Almost same parameters were applied to this model for meshing, as scenario 1.

Table 13: Mesh parameters

Surface refinement	1
Gap refinement	1
Resolution factor	1.0
Edge growth rate	1.1
Minimum points on edge	2
Points on longest edge	10
Surface limiting aspect ratio	20
Surface growth rate	1.2
Enhancement growth rate	1.1
Refinement length	0.755447752311
Fluid gap elements	1.0
Thin solid elements	0.2

Table 14: Mesh enhancement factors

Mesh enhancement	1
Enhancement blending	0
Number of layers	2
Layer factor	0.2
Layer gradation	1.05

Table 15: Nodes and Elements

Number of Nodes	77295
Number of Elements	314246

Solving and Results

The same iterations have been applied to this model, which were 100. And the solving time was 294 seconds.

The velocity component changed slightly comparing to first scenario. It increased from 10 m/s to 12.82 m/s, as it is shown in the figure 24.

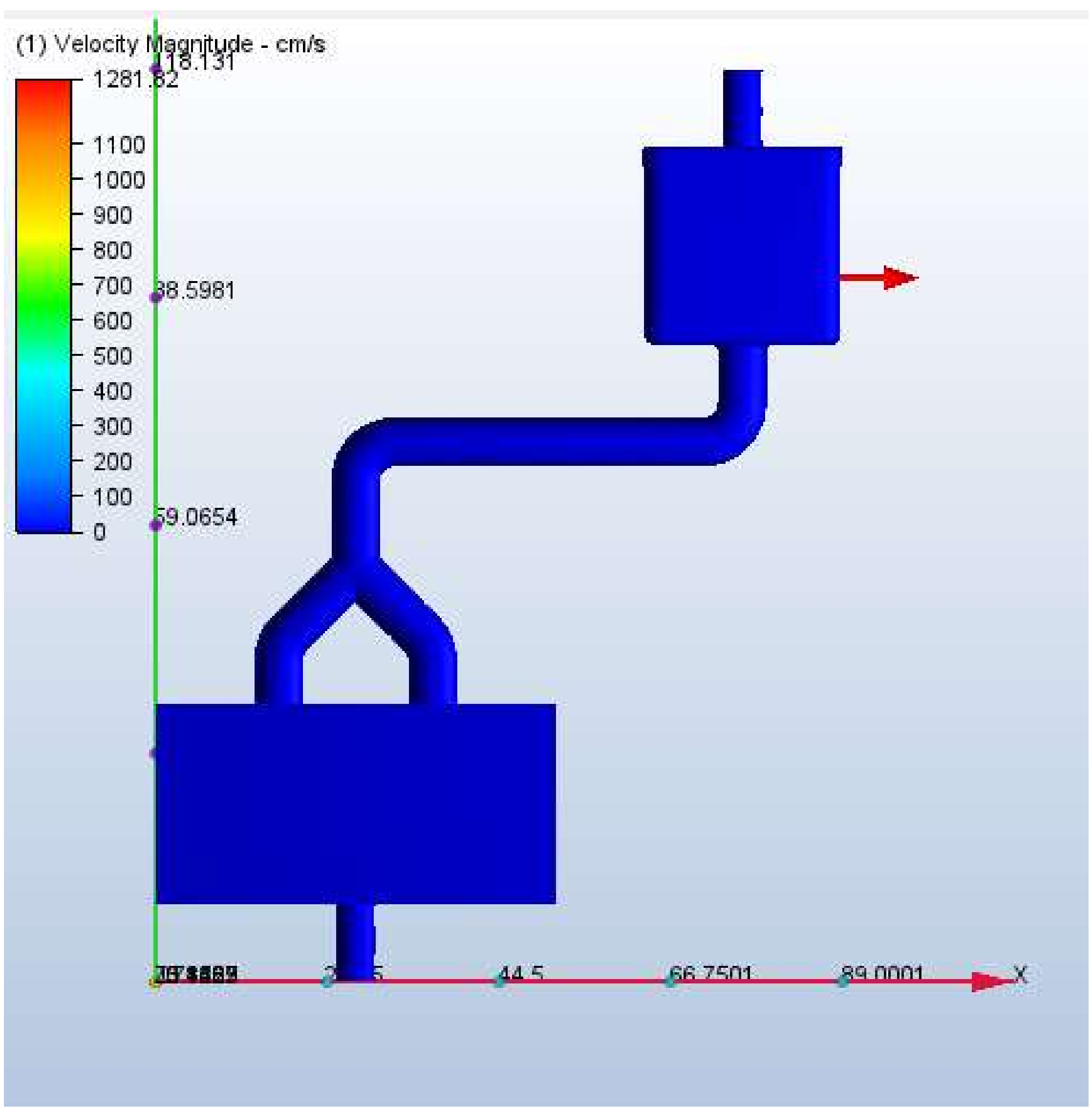


Figure 24: Velocity magnitude

Traces

A better result was found when applied the flow traces, comparing to first scenario which was just with one inlet. The material was spreading in a balance to whole surface area of the mold.

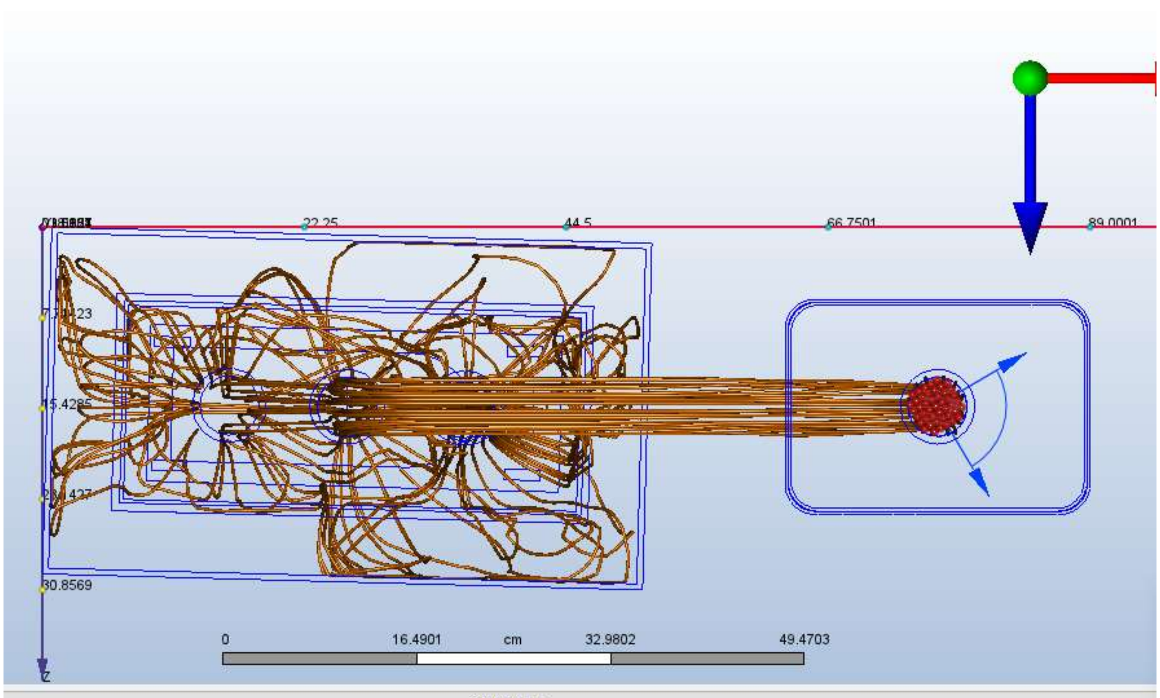


Figure 25:Top view particle traces

A little bounce has been found in the material, it was because of the coefficient of restitution value (0.3). But the fact is slightly different in such way, that the material used in original project comparing to simulations has little different properties. Because the original material which is fungus material, has been developed recently and never been used to simulate in such way.

But the most important thing is the density of the material, which has been measured as 282 Kg/m^3. The only thing that slightly differs is the bounce of the material, which can be controlled by the program.

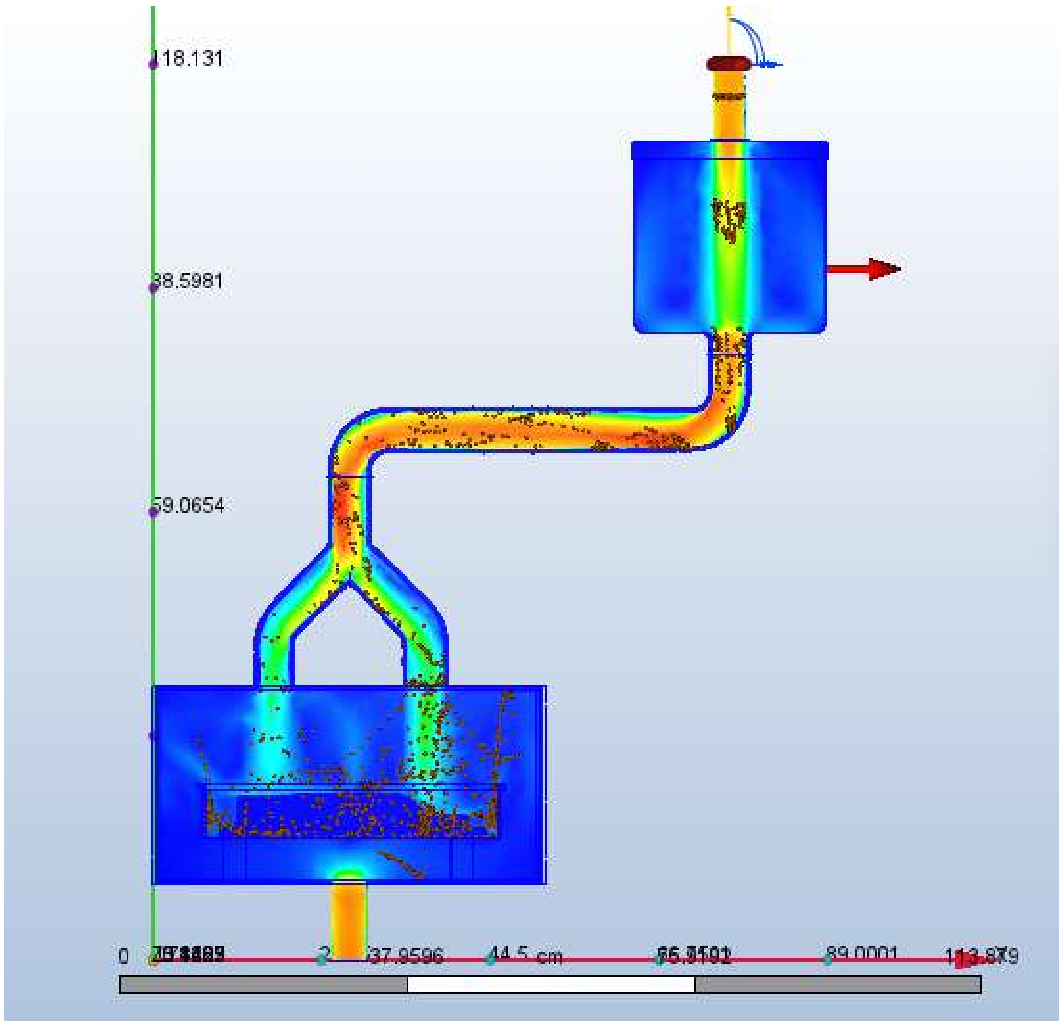


Figure 26: Material flow

As shown in the figure 26, the material is spreading in the mold gradually. A little bounce was found.

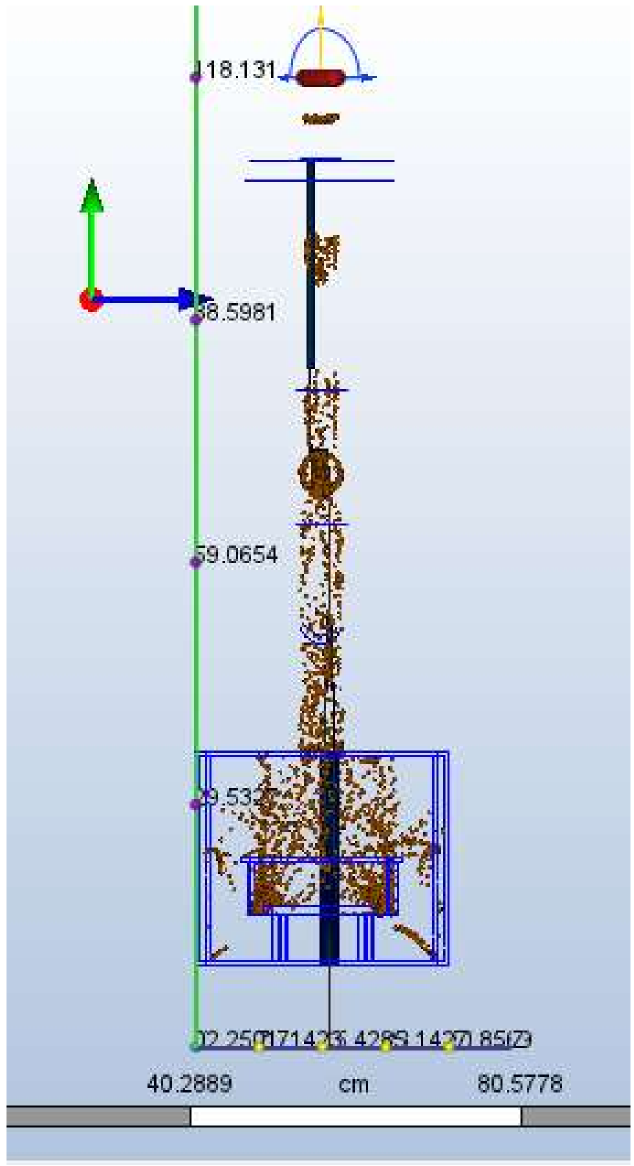


Figure 27: Top view

In the figure above, it is shown that material is spreading in the mold in a better way.

Table 16: Inlet Data

Inlet	inlet bulk	3279.59
	inlet bulk	24.85 C
	inlet Mach	0.0254291
	mass flow in	22.5129 g/s
	minimum	0.0
	node near	4024.0
	Reynolds	28163.3
	surface id	177.0
	total mass	22.5129 g/s
	total vol. flow	18687.1
	volume flow	18687.1

Table 17: Outlet Data

Outlet	mass flow out -22.2911 g/s minimum 0.0 node near 4012.0 outlet bulk -0.0 outlet bulk 24.85 C outlet Mach 0.0238951 Reynolds 27885.7 surface id 175.0 total mass -22.2911 g/s total vol. flow -18502.9 volume flow -18502.9

Mass flow	22.5129 g/s	-22.2911 g/s
Volume flow	18687.1 cm^3/s	-18502.9 cm^3/s

5.7 Scenario 3 (2 inlets increasing diameter)

To spread the material and control the velocity on the same time, the diameter has been decided to continuously increasing, which was 2 inch. In this scenario the diameter will increase from 2 to 3 inch gradually.

The velocity assigned to the material was 12 m/s. the purpose was to compare the results of increasing the velocity with increasing the diameter.

CAD Design

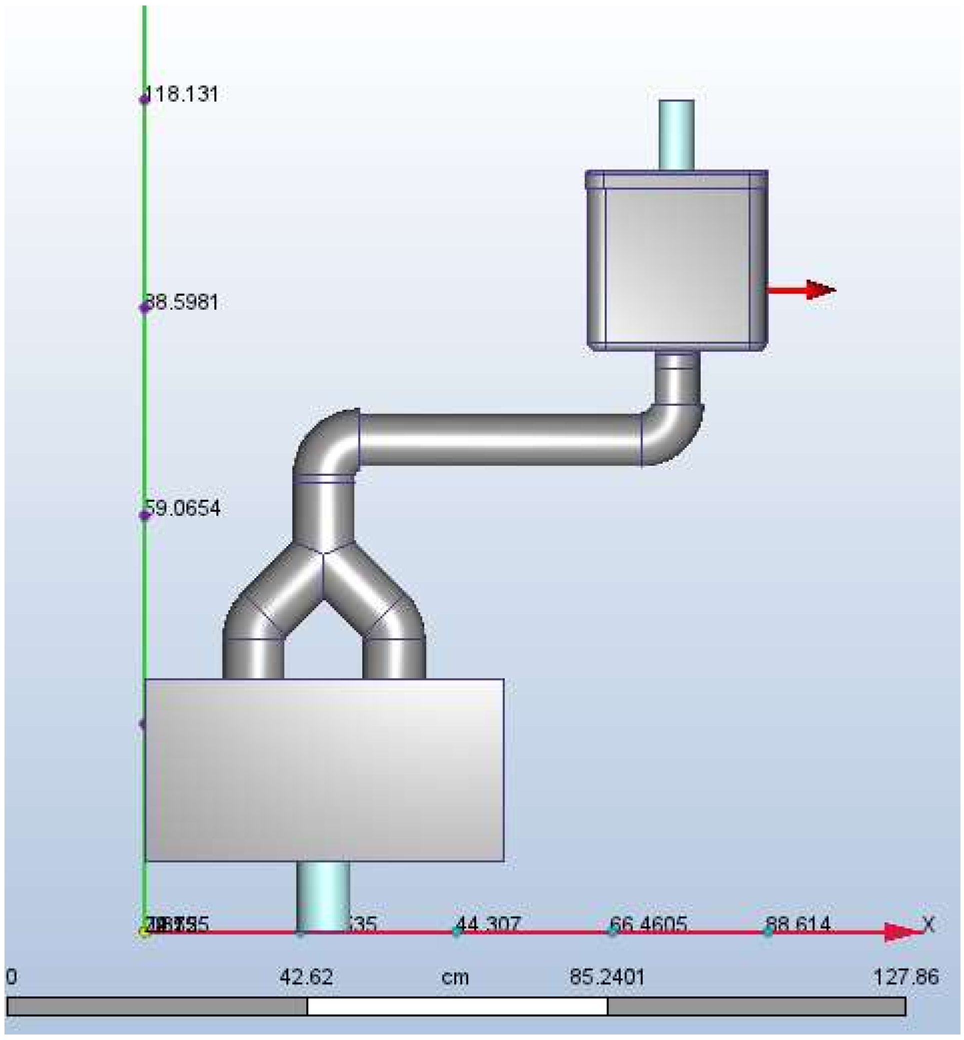


Figure 28: CAD Design

The diameter is gradually increasing from inlet to outlet, as shown in the figure above.

Meshing

After assigning the boundary conditions, the meshing was done.

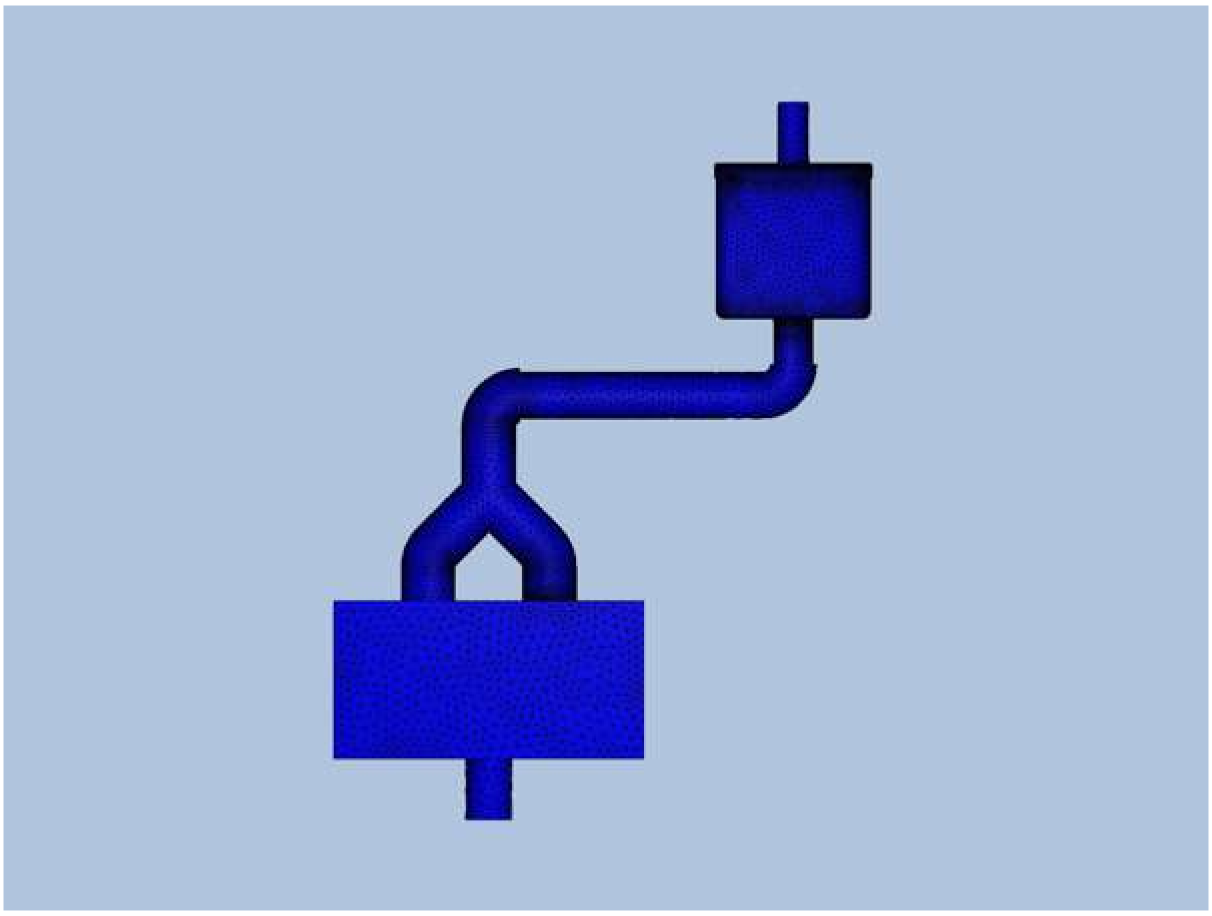


Figure 29: Meshing Model

Table 18: Nodes and Elements

Number of Nodes	161783
Number of Elements	678422

Solving and Results

After solving this model, the results were totally different and unrespectable. Because most of the material was going just towards one side of the mold. It happened because of the increased diameter in the Y inlet section.

Traces

The material is going to left side of the box mostly, and on right side there is less material.

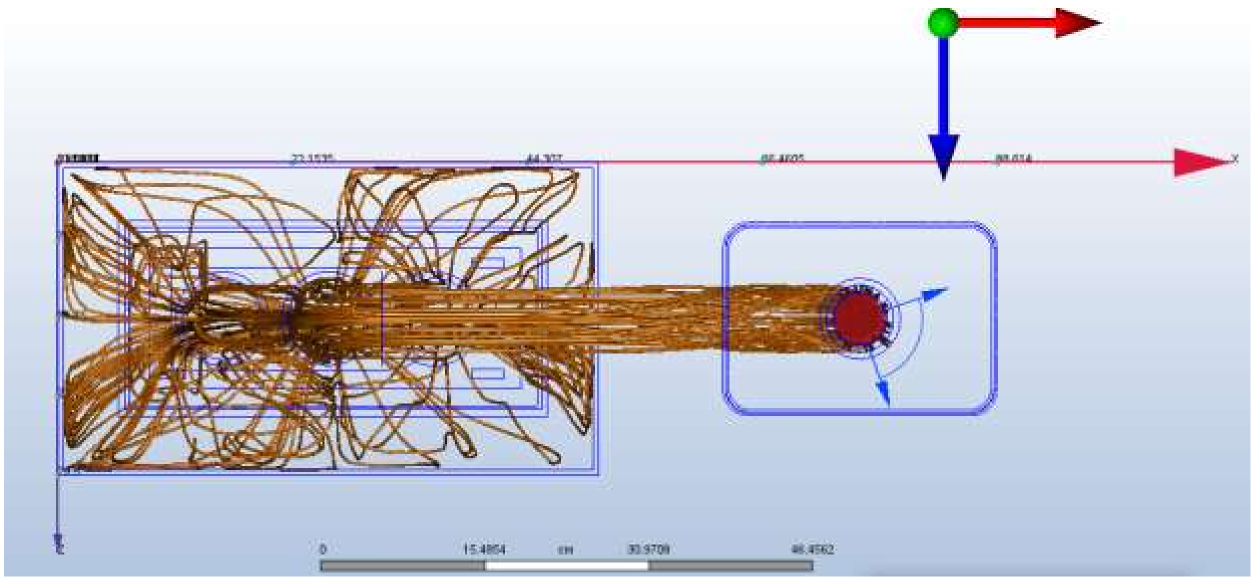


FIgure 30: Traces

The air velocity pushed the material towards left wall of the Y section, which results to fall the material just in left part of the mold. One other problem was found in this scenario was, the material was not flowing out completely. It would result in such way that the box can be filled out after certain time. The problem was the flat bottom surface of the injection box. The air velocity was pushing the material down and hitting the bottom, that was also the one reason of the bounce.

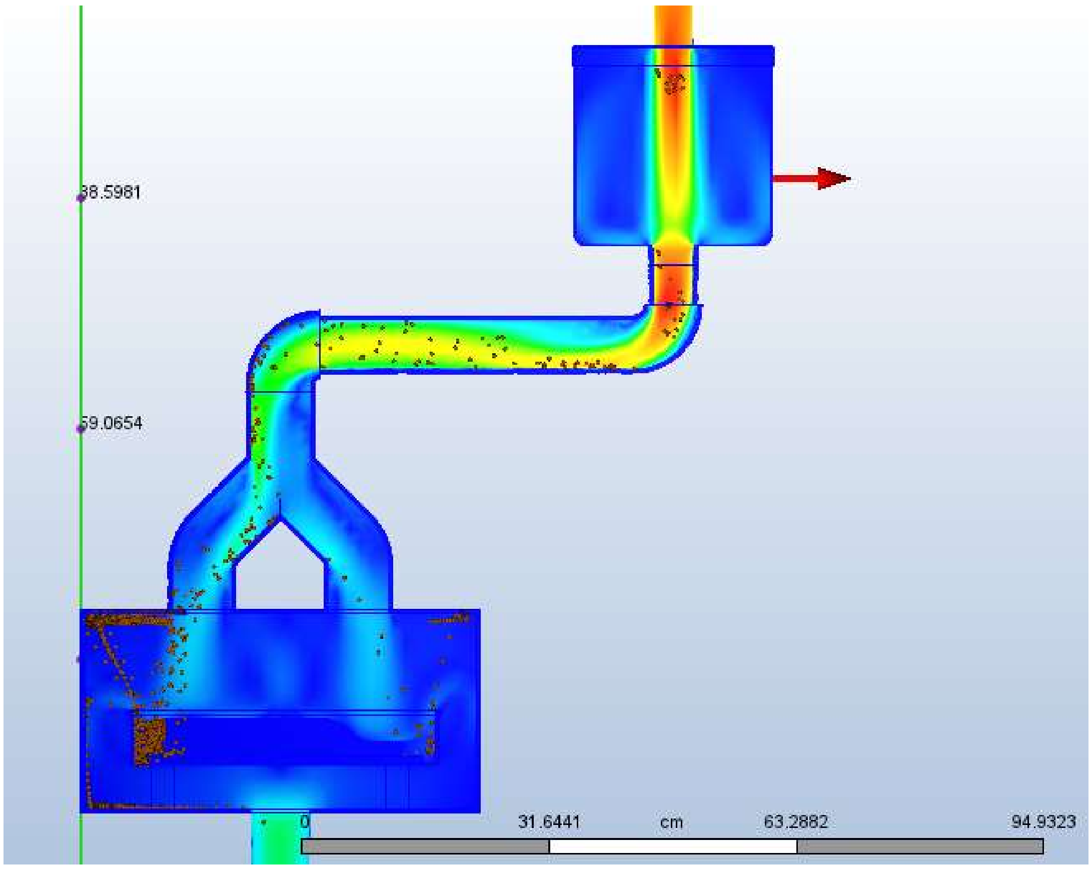


Figure 31: Material flow

As shown in figure 32, one can clearly see the material spreading through the mold in an inefficient way.

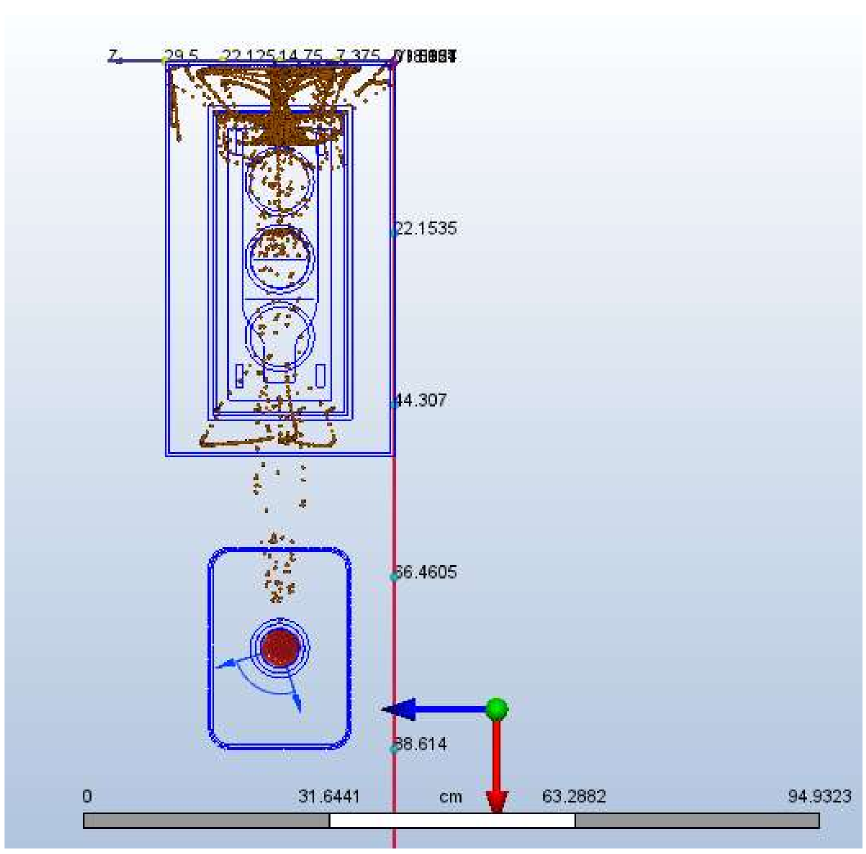


Figure 32: Top View

5.8. Scenario 4 (Open from down)

In this scenario CAD model has been modified to solve the problem. There were two problems were found in previous scenario:

- Material flow in one side of the mold;
- Material not flowing outside of the box.

CAD Model

To solve this problem, the bottom of the box was modified and the pipe design was changed as well to see the better results. In this model, for pouring the material into mold just one inlet has been made but with 3-inch diameter. And two air outlets were made in parallel to that pipe and was supposed to connect with the vacuum. There was also an outlet in the bottom of the box for material flowing out.

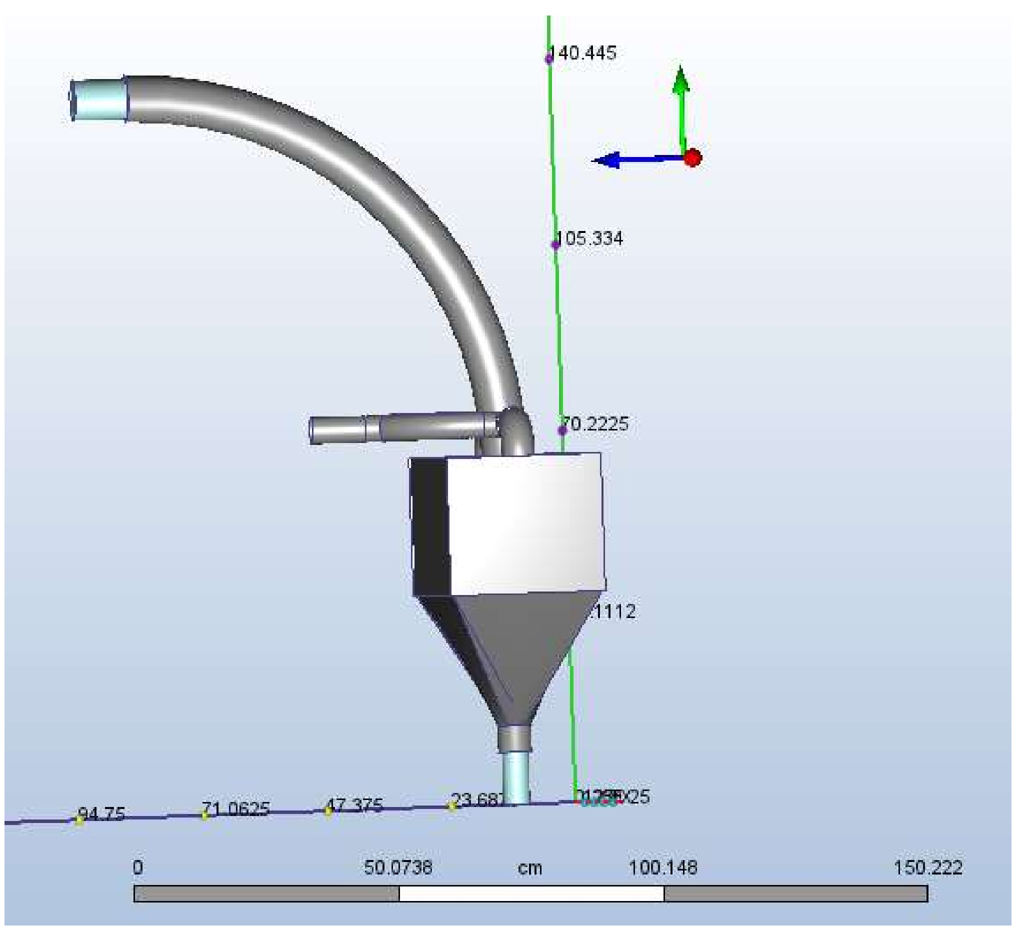


Figure 33: CAD model

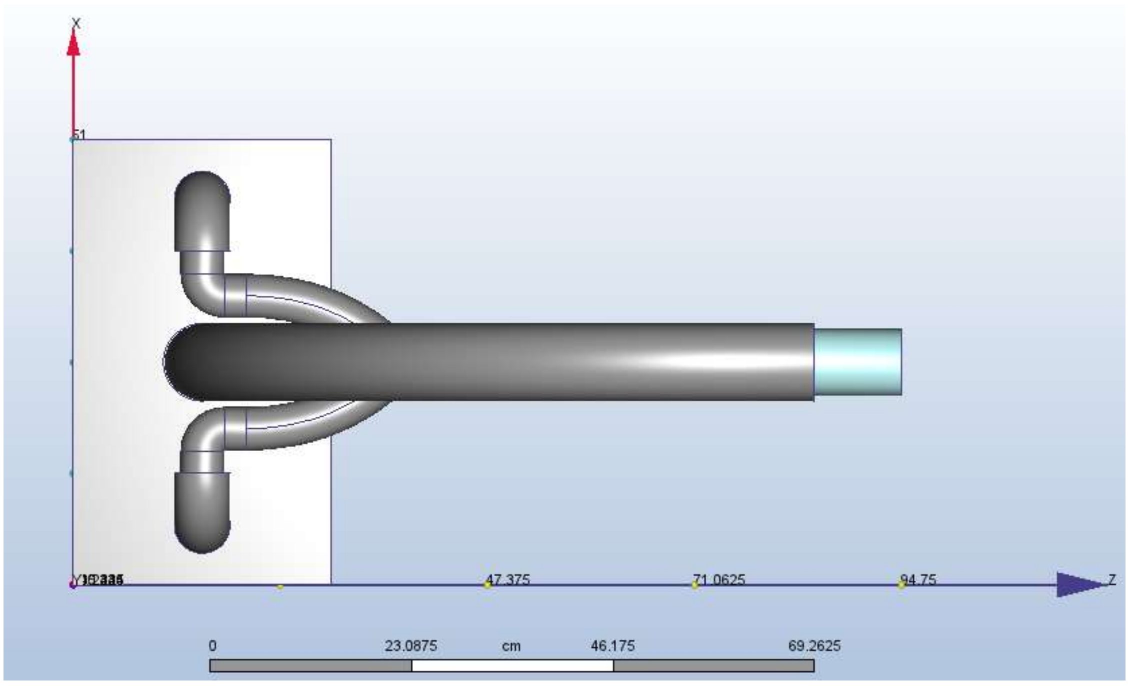


Figure 34: Top view

This design model was simulated with 2 different scenarios:

- Open from bottom outlet and closed top outlet;
- Open from top outlet and closed from bottom.

The second case will be discussed in the next scenario.

Mesh analysis

Since the design of the CAD model is changed, meshing has to happen again to have better results.

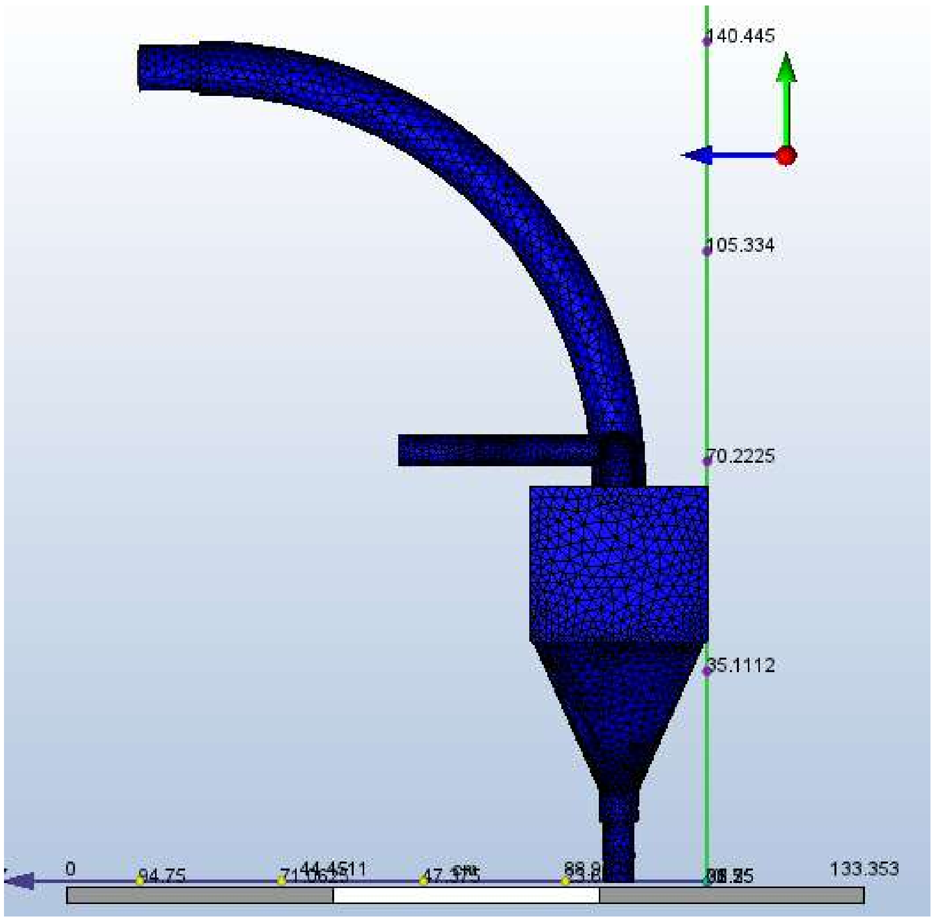


Figure 35: Meshing

The same parameters were applied for the mesh analysis and the end results are shown in the table 19 below.

Table 19: Nodes and elements

Number of Nodes	67074
Number of Elements	277313

<u>Solving and Results</u>

This scenario was created to solve the 2 problems discussed before and analyzing the flow of the material.

Traces

As closing from the top, the material spread in the mold and excessive material goes out from the bottom. To make the bottom as cone shape was a good decision because it allows the air flow to keep going with the walls and not just hit the flat surface and bounce backward.

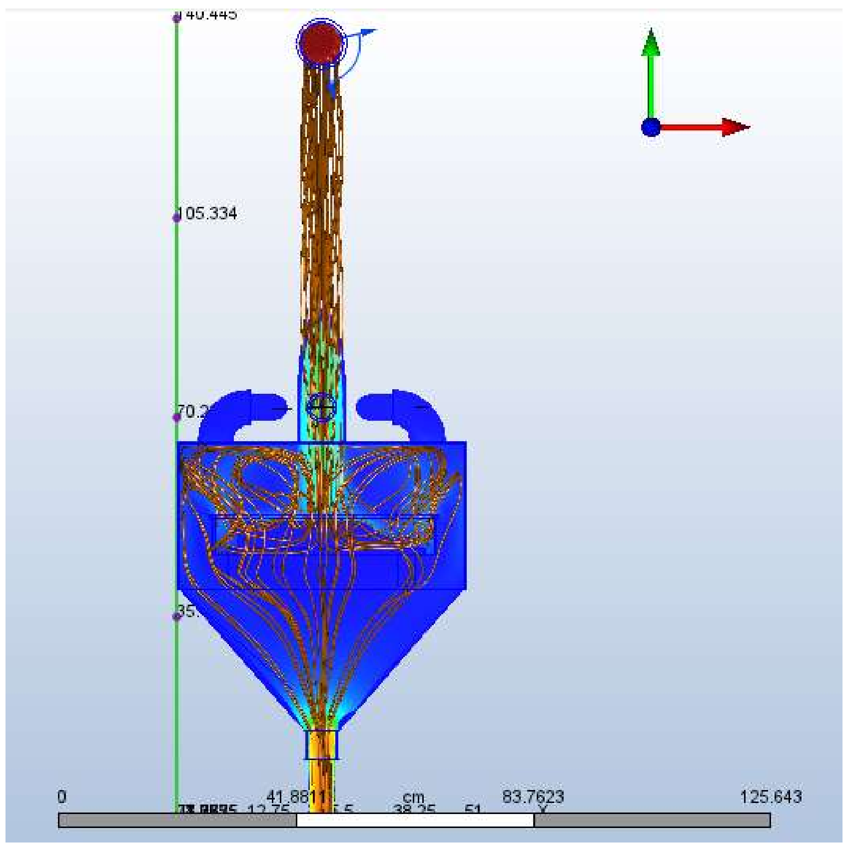


Figure 36: Particle Traces

Massed particle flow

Converting traces to massed particles it need to give them a mass with density.

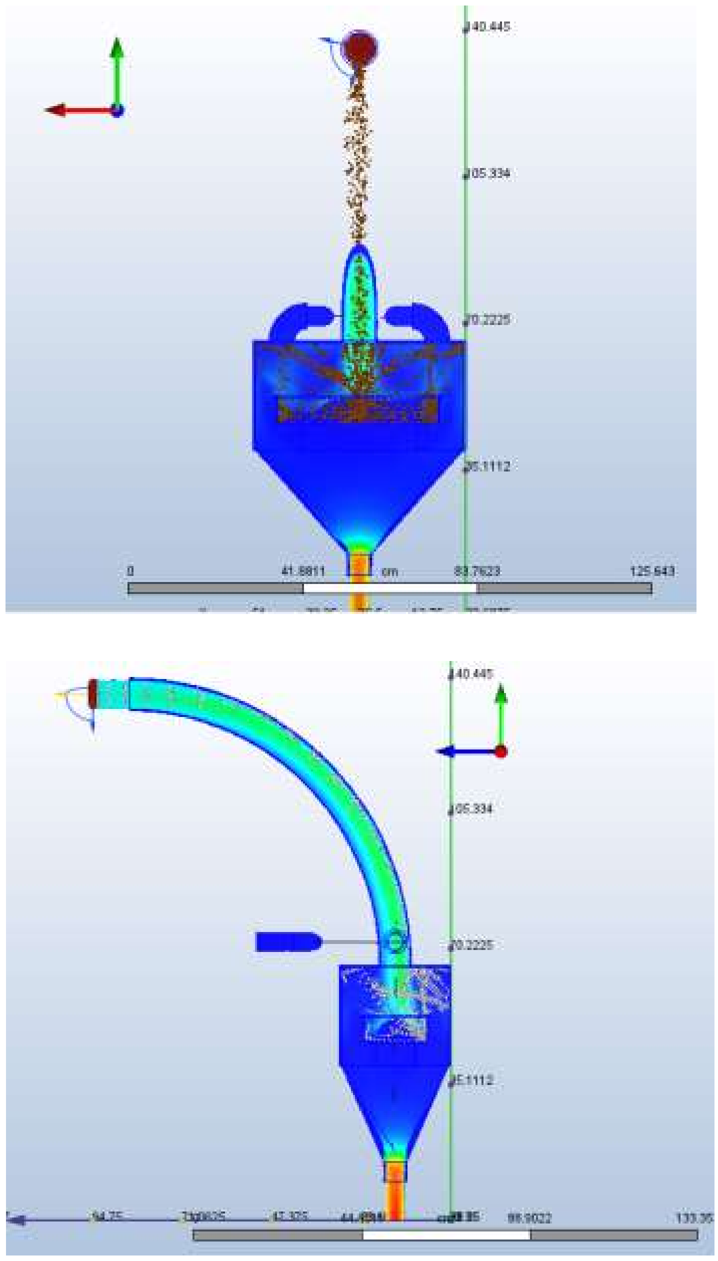


Figure 37: Traces front view and side view

It is clearly shown in the figures above the material is spreading in the mold in a better way.

Table 20: Mass flow rates

Mass flow	40.5233 g/s	-40.2208 g/s
Volume flow	33636.7 cm^3/s	-33385.6 cm^3/s

The mass flow and volume flow rate are increased in inlet and outlet respectively comparing to previous models.

Table 21: Inlet Data

Inlet	inlet bulk	3249.38
	inlet bulk	24.85 C
	inlet Mach	0.0201021
	mass flow in	40.5233 g/s
	minimum	0.0
	node near	1396.0
	Reynolds	33795.9
	surface id	72.0
	total mass	40.5233 g/s
	total vol. flow	33636.7
	volume flow	33636.7

Table 22: Outlet data

Outlet	mass flow out	-40.2208 g/s
	minimum	0.0
	node near	419.0
	outlet bulk	-0.0
	outlet bulk	-0.0 C
	outlet Mach	0.0443465
	Reynolds	50315.4
	surface id	14.0
	total mass	-40.2208 g/s
	total vol. flow	-33385.6
	volume flow	-33385.6

5.9. Scenario 5 (open from top outlet)

In this scenario, the same Cad model was used but open from the top outlet. The mesh analysis is the same for both models so it will not be discussed in this scenario.

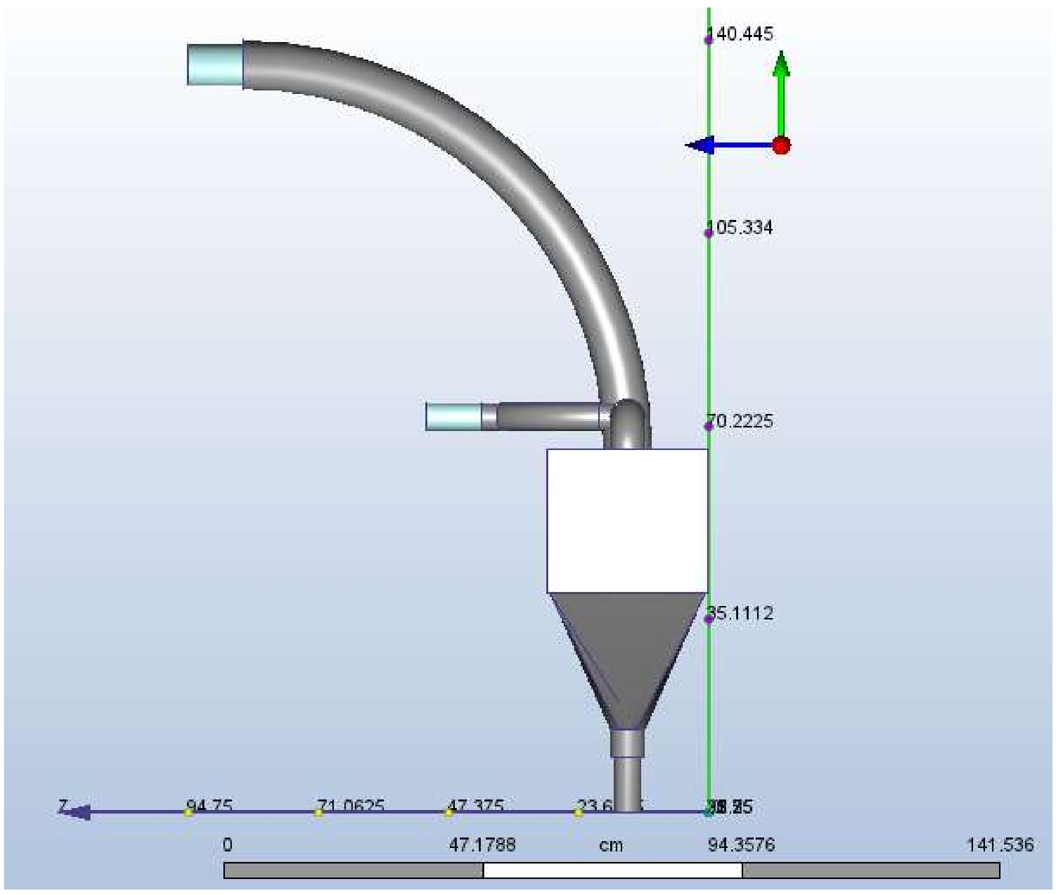


Figure 38: Cad design with boundary conditions highlighted

The colored parts shown in the figure 38 are indicating the boundary conditions applied on those parts since the bottom outlet is kept closed to see the variation of material flow. The velocity given at inlet was 8 m/s.

Traces

In the figure 39, the traces are shown for material flow. As one can see that material is flowing towards left part more. It happens because air goes to until the bottom of the box and since the outlet is closed from down air bounce back upwards and it effects the material that is falling down.

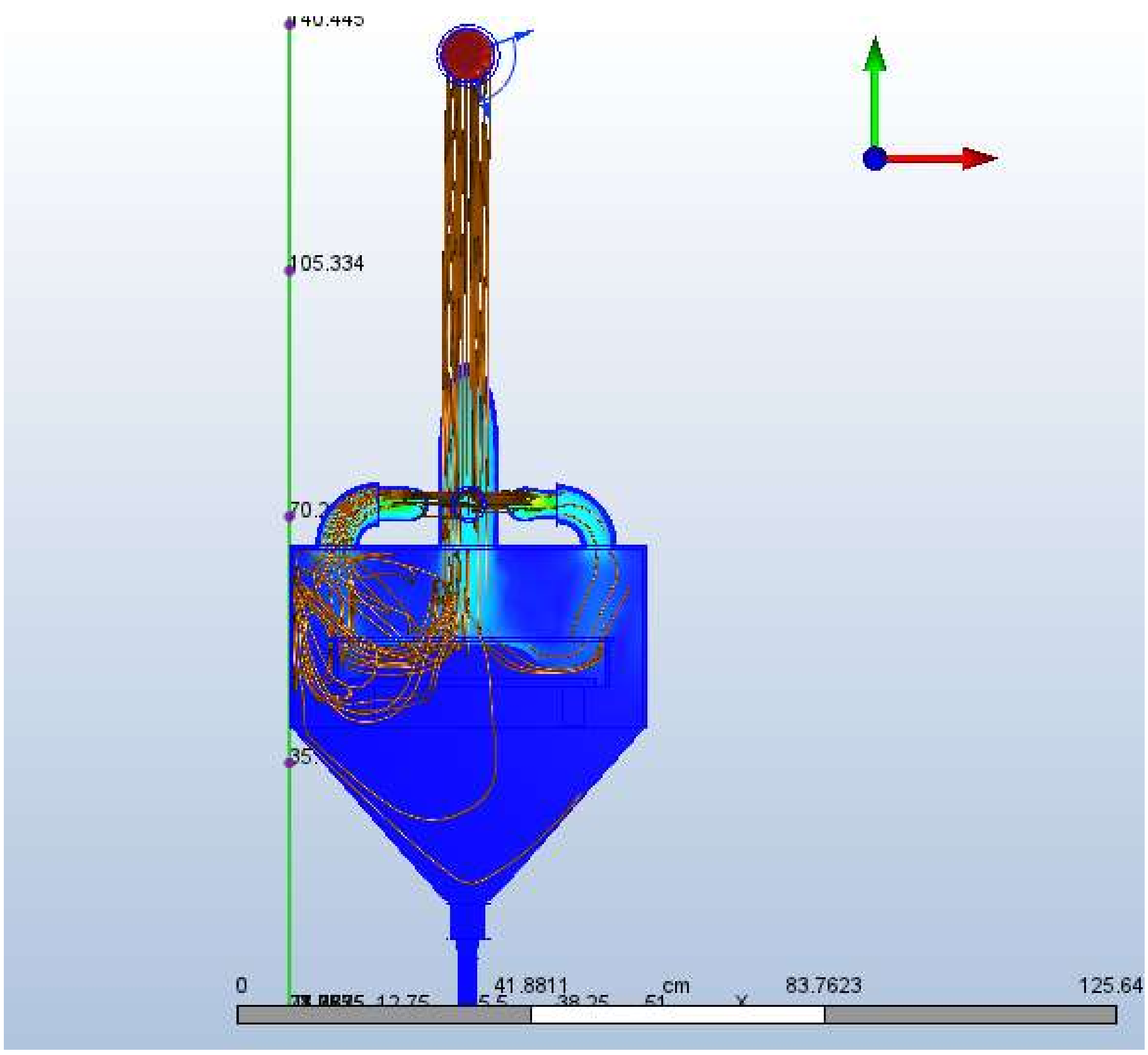


Figure 39: Traces

Results

In the section below, there are some outputs for this scenario.

Table 23: Mass flow rate

Mass flow	40.5233 g/s	-40.279 g/s
Volume flow	33636.7 cm^3/s	-33433.9 cm^3/s

Inlet 1	Inlet bulk	7299.25
	inlet bulk	24.85 C
	inlet Mach	0.0201021
	mass flow in	40.5233 g/s
	minimum	0.0
	node near	4305.0
	Reynolds	33795.9
	surface id	74.0
	total mass	40.5233 g/s
	total vol. flow	33636.7
	volume flow	33636.7

Outlet 1	mass flow out	-40.279 g/s
	minimum	0.0
	node near	4050.0
	outlet bulk	-0.0
	outlet bulk	24.85 C
	outlet Mach	0.0410021
	Reynolds	50388.3
	surface id	65.0
	total mass	-40.279 g/s
	total vol. flow	-33433.9
	volume flow	-33433.9

5.10. Scenario 6

In this scenario, the design was slightly changed to see the progress in flow and improve the design as much as possible before building the original prototype for experiments.

CAD Model

The bottom part is the same as previous model but the pipeline was changed from inclined to horizontal and vertical sections.

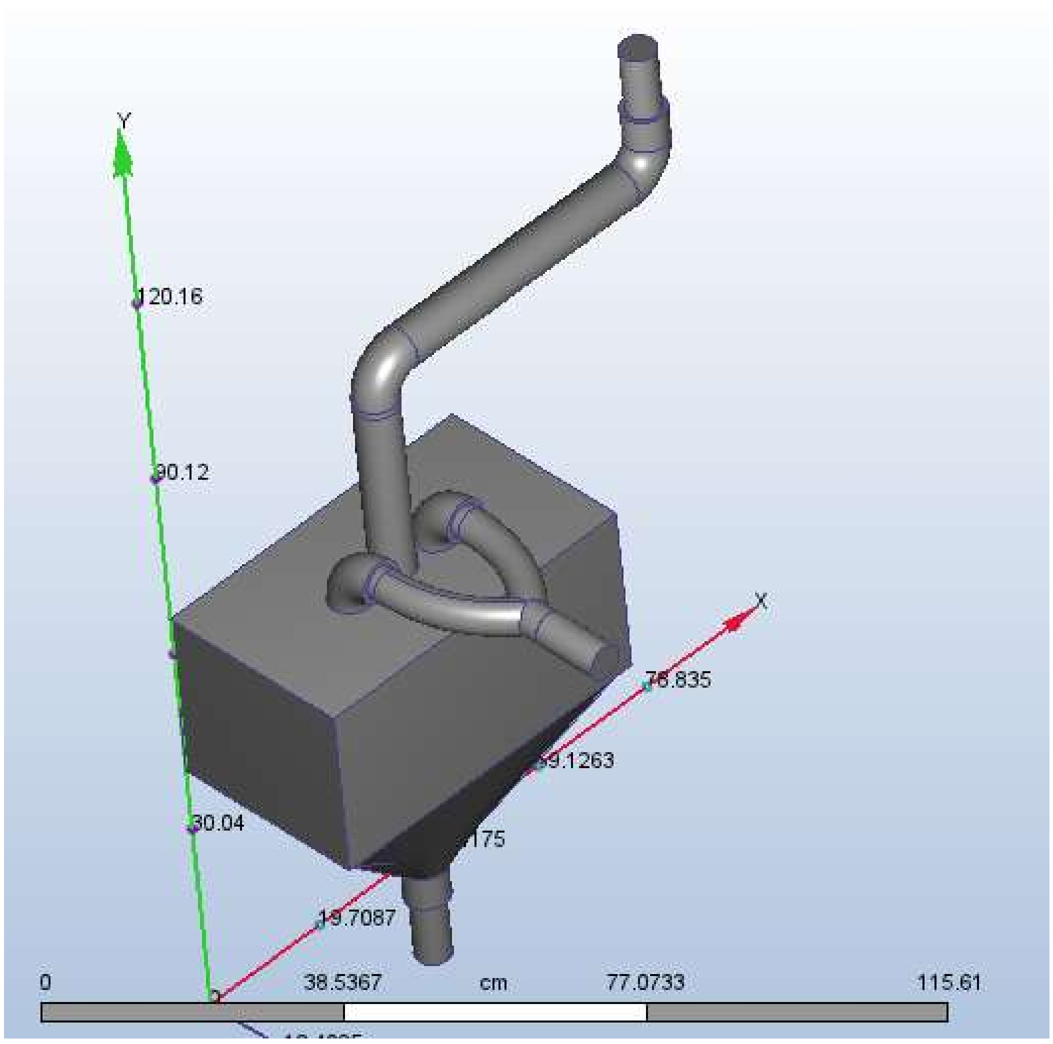


Figure 40: CAD Design

Meshing

Mesh has been made for the model because the parts were redesigned so it was necessary to make the mesh.

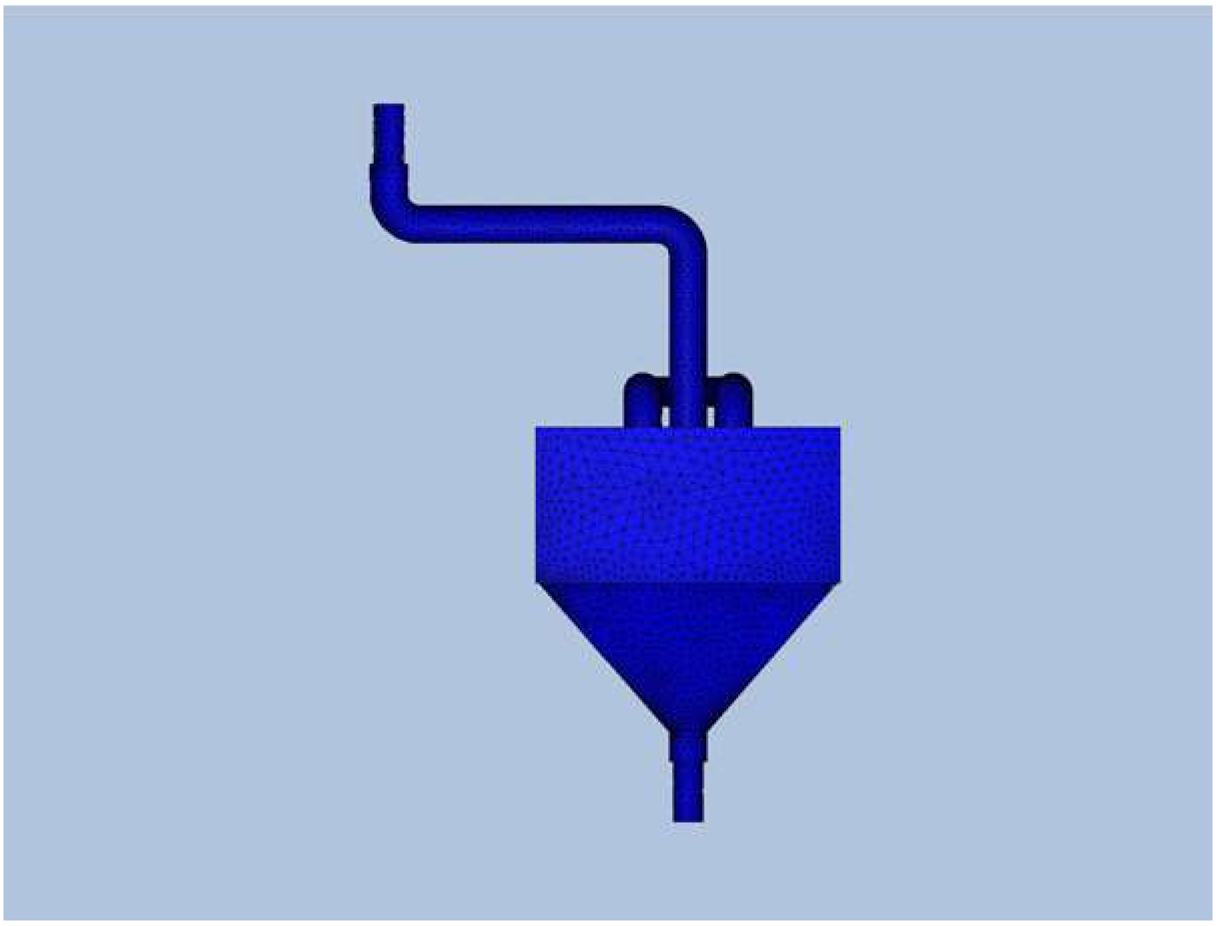


Figure 41: meshing

Table 24: mesh

Number of Nodes	65659
Number of Elements	270485

Traces

After solving the model, the traces have been created for the flow. Air is flowing through the pipes and going out from top outlets. Material flow can be seen in the traces down in the figure

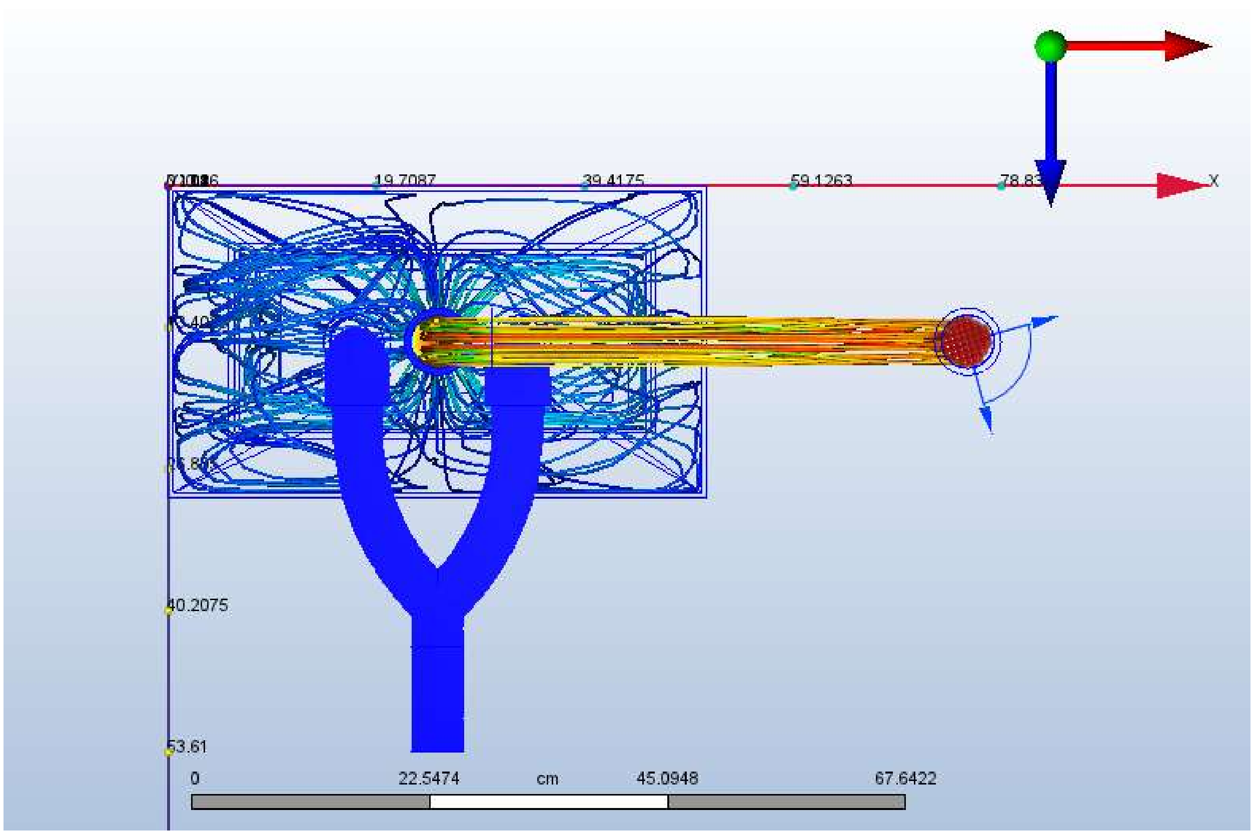


Figure 42: Traces

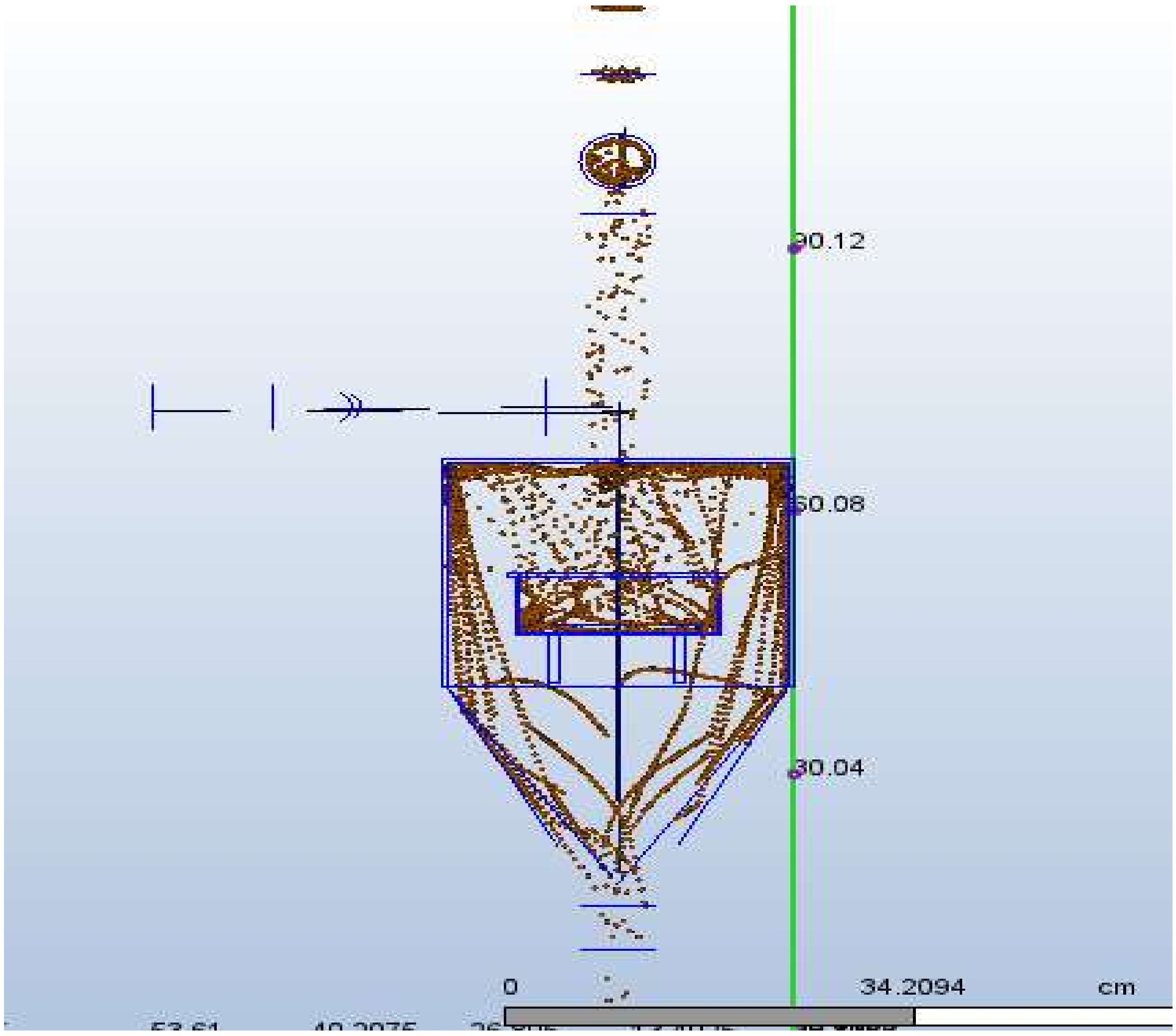


Figure 43: Material Flow

As seen in the figure 43, the material is pouring inside the mold in a better way and also flowing out from the box in the outlet downside.

Results

Mass flow	22.5129 g/s	-22.3138 g/s
Volume flow	18687.1 cm^3/s	-18521.7 cm^3/s

Inlet	inlet bulk	2785.37
	inlet bulk	24.85 C
	inlet mach	0.0252847
	mass flow in	22.5129 g/s
	minimum	0.0
	node near	18084.0
	reynolds	28163.3
	surface id	127.0
	total mass	22.5129 g/s
	total vol. flow	18687.1
	volume flow	18687.1

Outlet	mass flow out	-22.3138 g/s
	minimum	0.0
	node near	2736.0
	outlet bulk	-0.0
	outlet bulk	24.85 C
	outlet mach	0.0238738
	reynolds	27914.1
	surface id	125.0
	total mass	-22.3138 g/s
	total vol. flow	-18521.7
	volume flow	-18521.7

5.11. Scenario 7 (Final Prototype)

In this scenario, design for final prototype has been created. A part for excessive material has been added in the design.

CAD Model

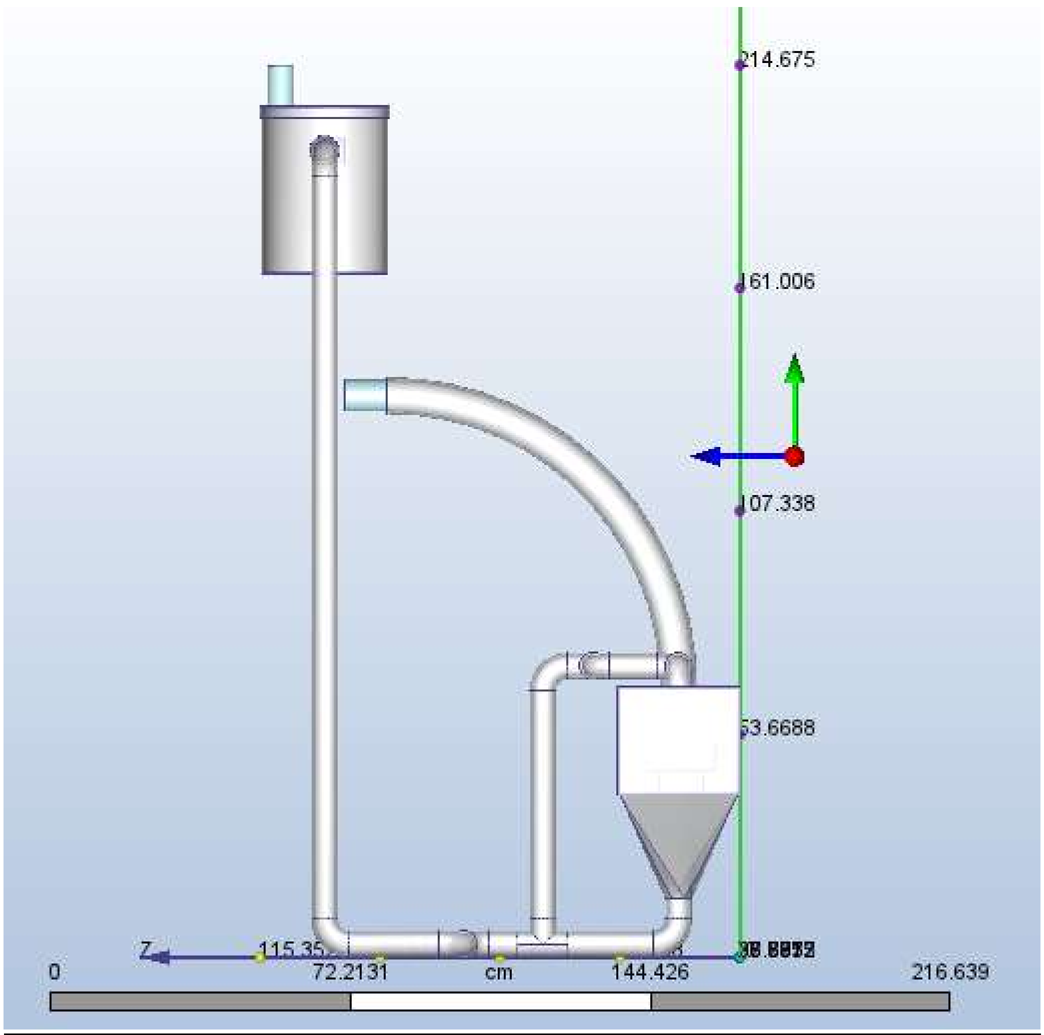


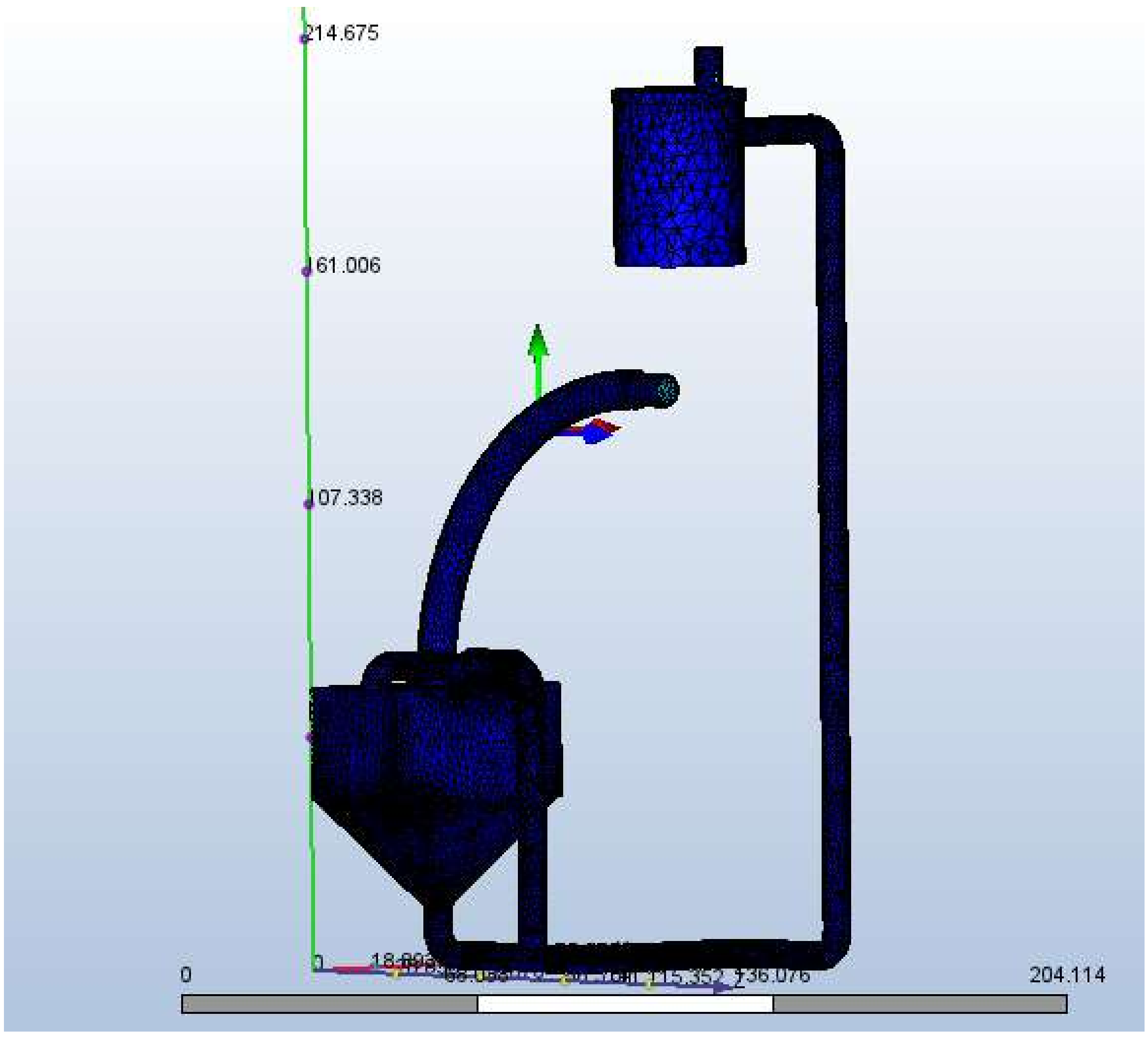
Figure 44: CAD Design

The last scenario was used for the injection system and another design was added into model, which includes:

- Pipeline horizontal and vertical;
- A handmade cyclone separator.

The material that goes out from the down side will not be wasted and sucked until cyclone separator and will go again to mixer.

Mesh



Mesh Results

Surface refinement	1
Gap refinement	0
Resolution factor	1.0
Edge growth rate	1.1
Minimum points on edge	2
Points on longest edge	10
Surface limiting aspect ratio	20
Surface growth rate	1.2
Enhancement growth rate	1.1

Mesh enhancement	1
Enhancement blending	0

Number of layers	3
Layer factor	0.45
Layer gradation	1.05

Number of Nodes	909357
Number of Elements	3846770

Traces

Material is flowing throw the pipeline and also going out from bottom until cyclone. Traces are showing the material

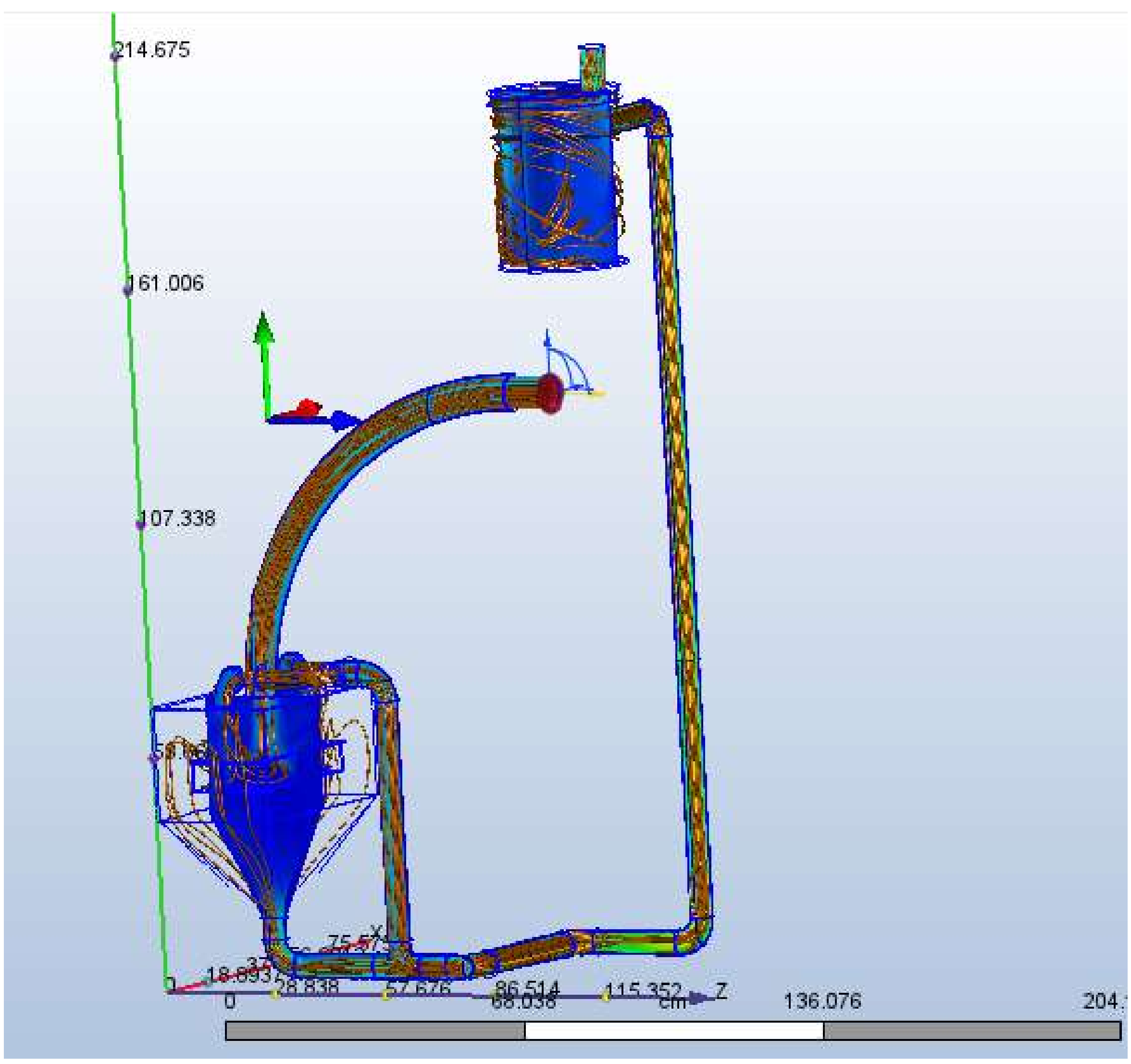


Figure 45: Traces

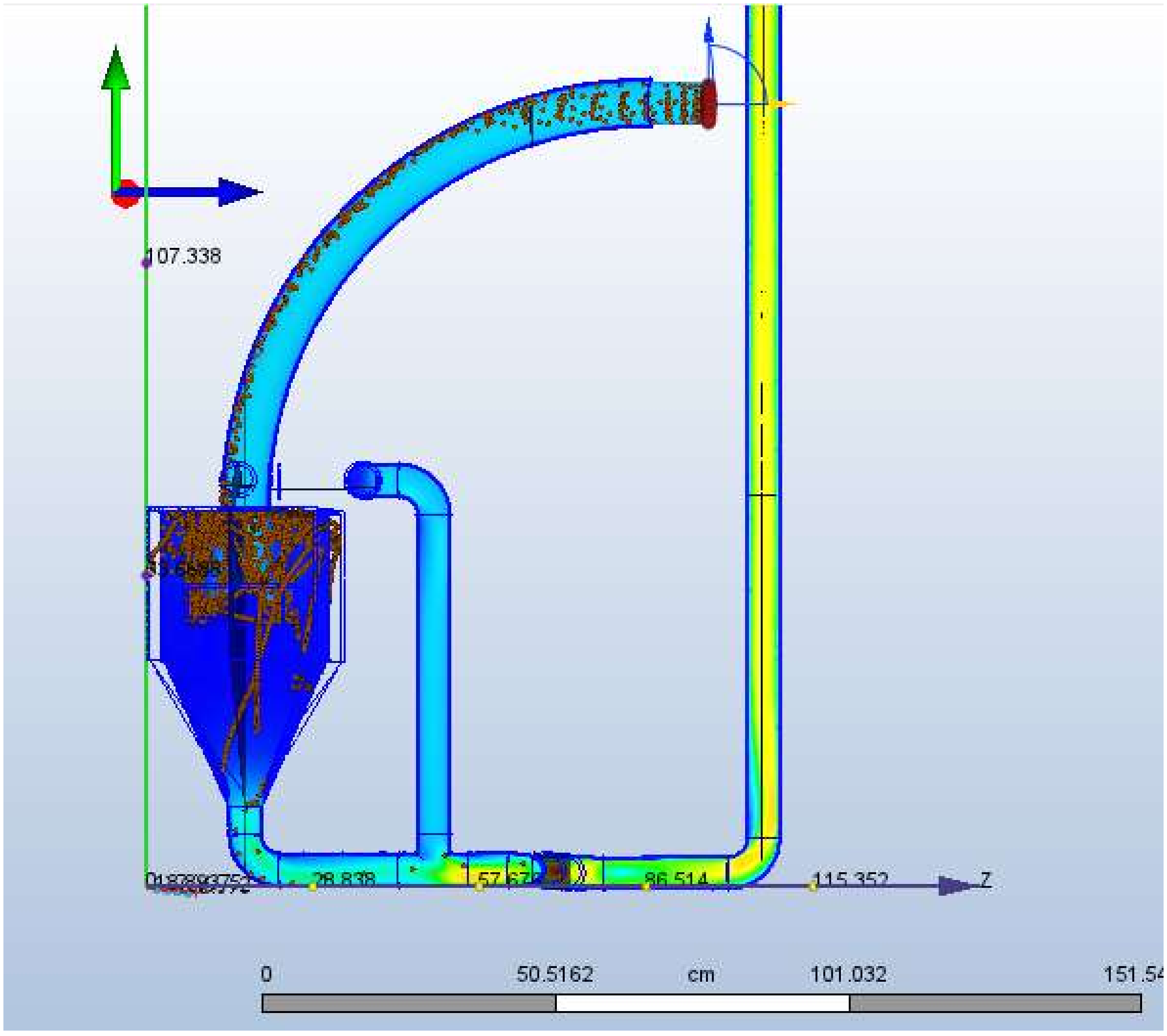


Figure 46: Material flowing out from box

Massed particles flow

A really good result has been found in the simulation, the model was successful because as the purpose was to fill the mold and take it back to the cyclone. As shown in the figure it is clearly working. In next stage this prototype will be made to make experiments if it meets the requirements what was seen in the simulations.

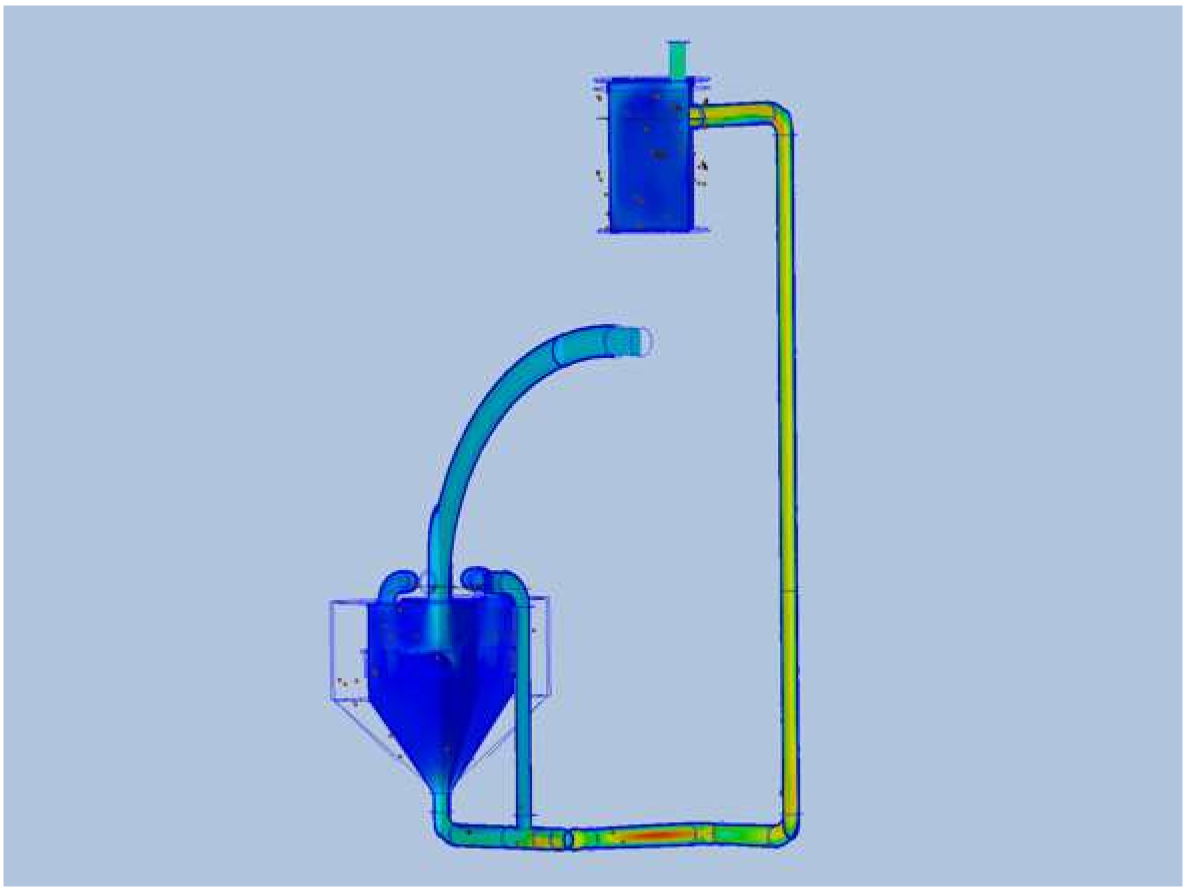


Figure 47: Particle flow

Results

Table 25: inlet outlet data

Mass flow	34.6041 g/s	-34.341 g/s
Volume flow	28723.4 cm^3/s	-28505.0 cm^3/s

Table 26: inlet

Inlet	inlet bulk	14549.3
	inlet bulk	24.85 C
	inlet Mach	0.0179802
	mass flow in	34.6041 g/s
	minimum x,y,z	0.0
	node near	6202.0
	Reynolds	28859.4
	surface id	198.0
	total mass flow	34.6041 g/s
	total vol. flow	28723.4
	volume flow in	28723.4

Table 27: outlet

Outlet	mass flow out	-34.341 g/s
	minimum x,y,z	0.0
	node near	6007.0
	outlet bulk	-0.0
	outlet bulk	24.85 C
	outlet Mach	0.0249049
	Reynolds	34368.0
	surface id	187.0
	total mass flow	-34.341 g/s
	total vol. flow	-28505.0
	volume flow	-28505.0

5.12. Scenario 8 (Final assembly)

This scenario will be discussing about the final design and simulation of the material through the model.

<u>Cad Model</u>

Based on the prototype final model and simulation results, a final assembly design has been made in Solidworks. In this design, instead of a handmade made cyclone, a good cyclone has been designed just to test if it meets the project requirements.

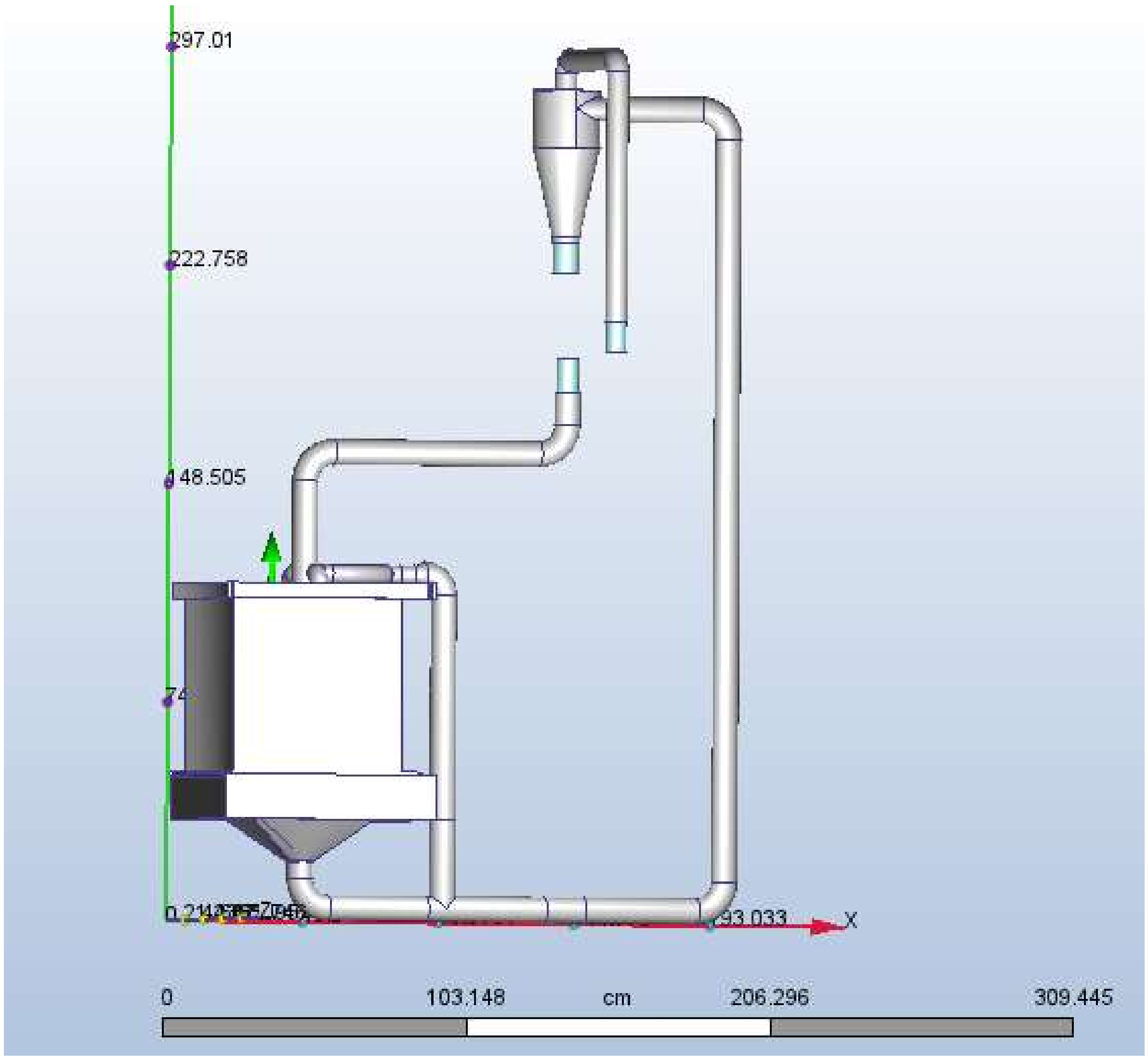
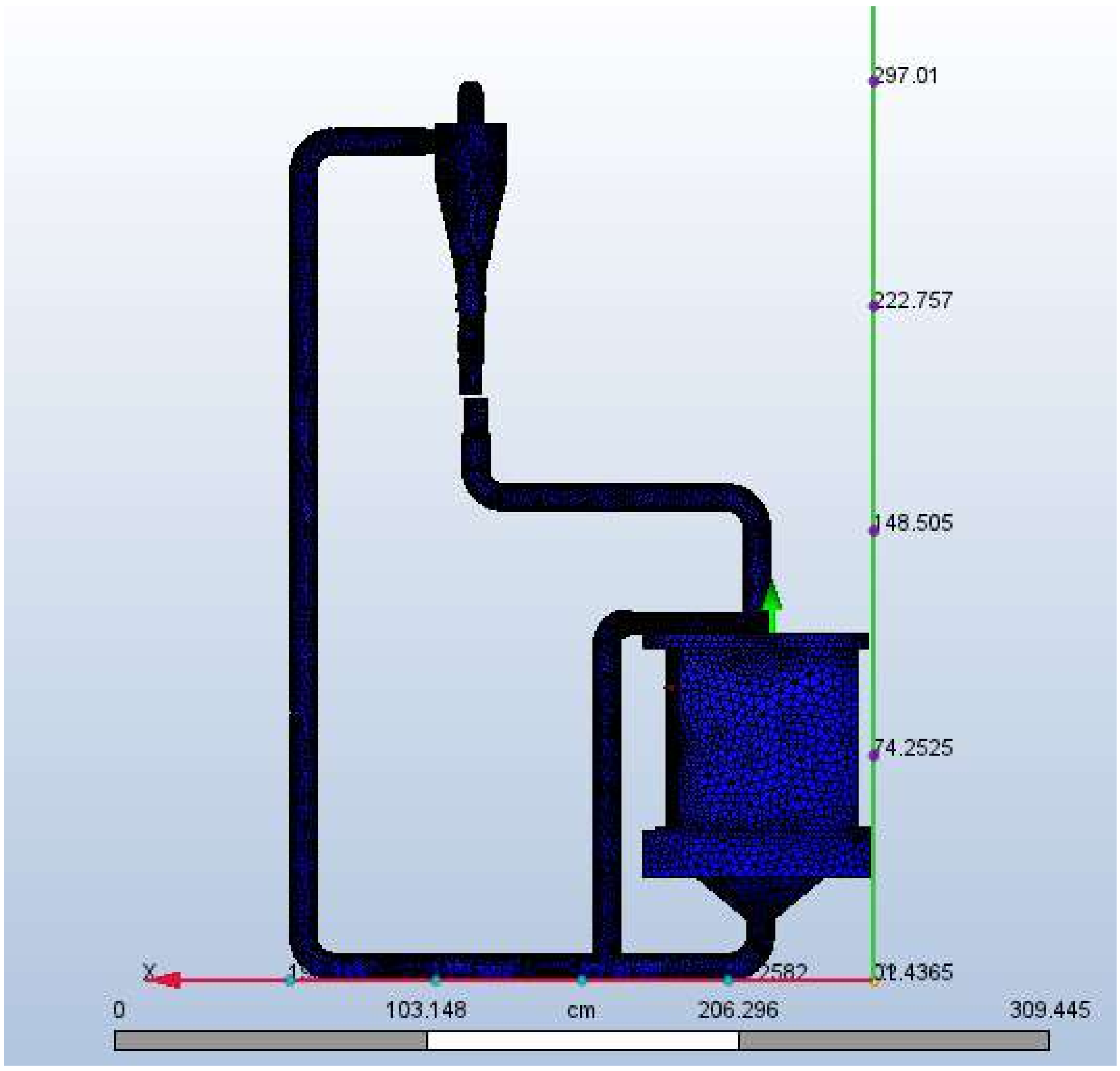


Figure 48:design

Meshing



Results

Surface refinement	1
Gap refinement	0
Resolution factor	1.0
Edge growth rate	1.1
Minimum points on edge	2
Points on longest edge	10
Surface limiting aspect ratio	20
Surface growth rate	1.2
Enhancement growth rate	1.1

Mesh enhancement	1
Enhancement blending	0
Number of layers	3
Layer factor	0.45
Layer gradation	1.05

Number of Nodes	909357
Number of Elements	3846770

Traces

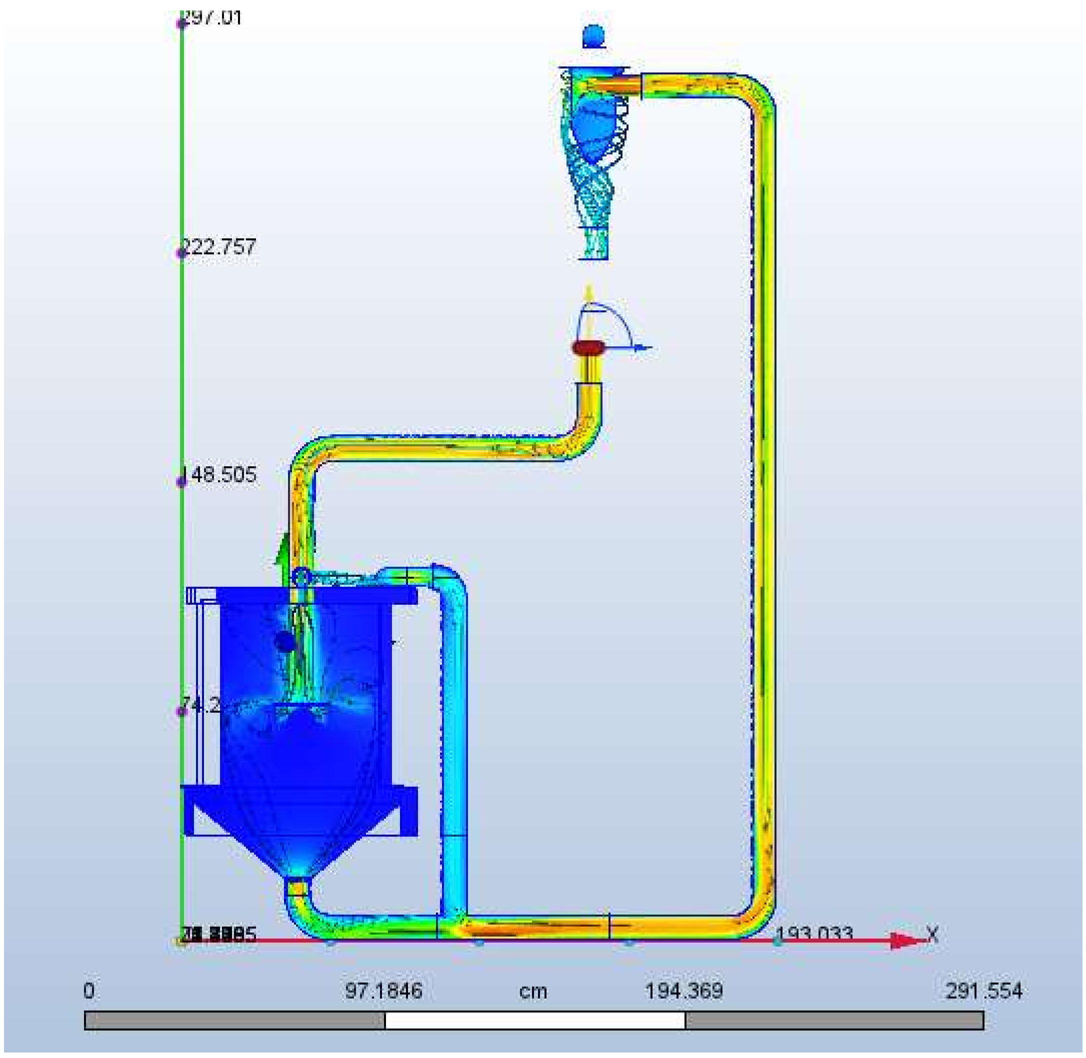


FIgure 49: Traces

A good result has been found and traces are showing the model is working properly.

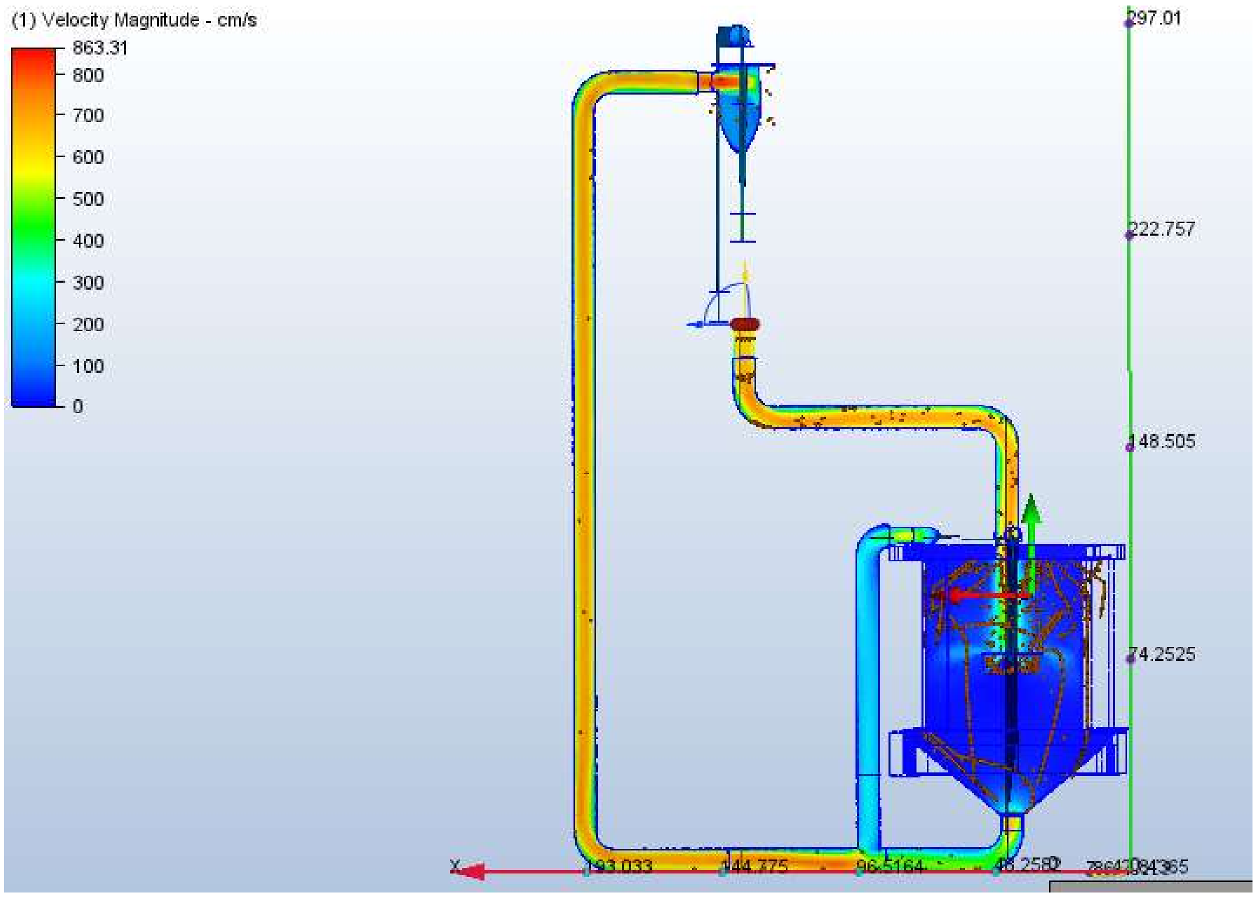


Figure 50: Massed particles

As shown in the figure above, the massed particles are working on the principle of traces flow as well. A new fact has been found here, because top outlet pipe is not taking any material so as experimented in previous scenario to close one outlet at once, there is no need to close or put some gating system in the machine.

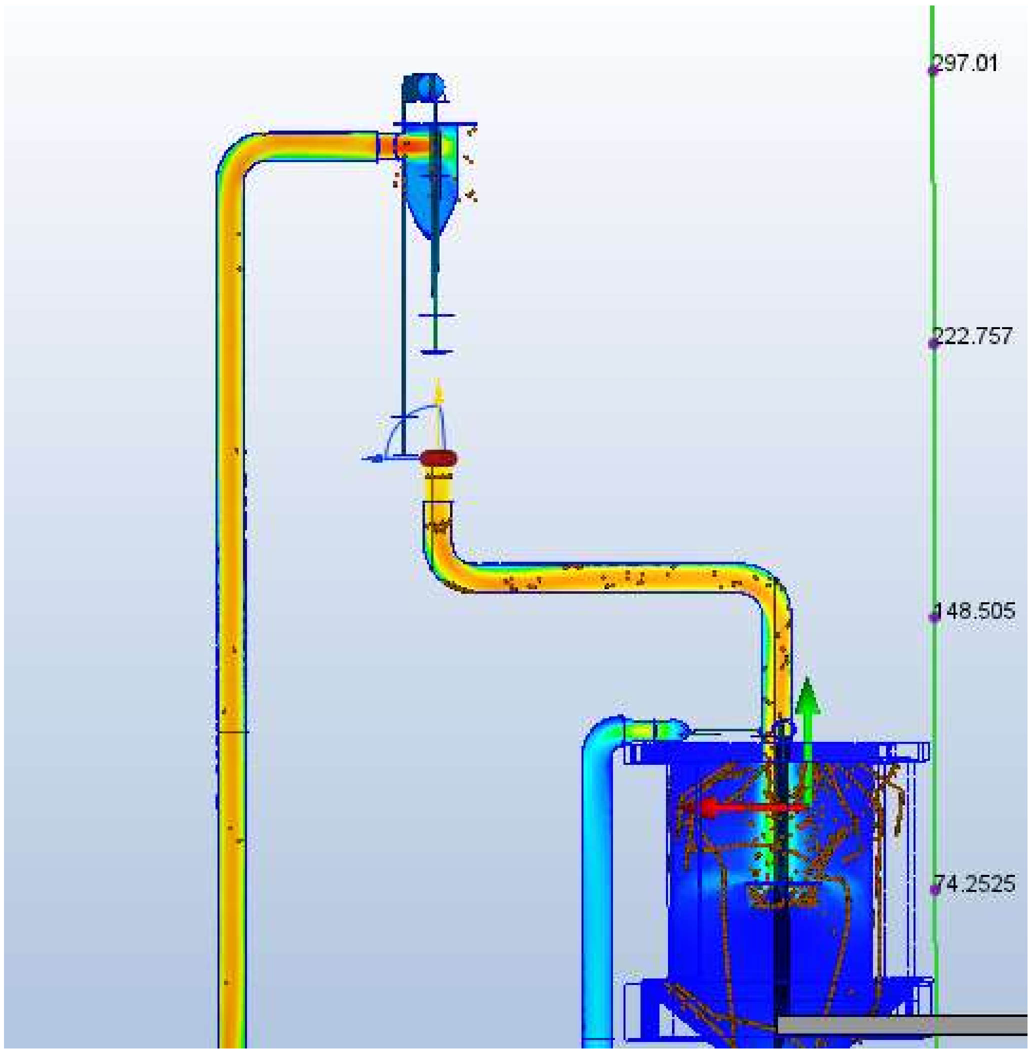


Figure 51: Cyclone

Results

Inlet 1	inlet bulk	2416.55
	inlet bulk	24.85 C
	inlet mach	0.0151708
	mass flow in	30.3925 g/s
	minimum x,y,z	0.0
	node near	52425.0
	reynolds	25346.9
	surface id	217.0
	total mass flow	30.3925 g/s
	total vol. flow	25227.5
	volume flow in	25227.5

Outlet 1	mass flow out -25.0669 g/s minimum x,y,z 0.0 node near 4231.0 outlet bulk -0.0 outlet bulk 24.85 C outlet mach 0.00822703 reynolds 17647.0 surface id 215.0 volume flow -20806.9

Outlet 2	mass flow out -5.28712 g/s minimum x,y,z 0.0 node near 4217.0 outlet bulk -0.0 outlet bulk 24.85 C outlet mach 0.00285532 reynolds 4774.02 surface id 211.0 total mass flow -30.354 g/s total vol. flow -25195.6 volume flow -4388.62

Mass flow	30.3925 g/s	-30.35402 g/s
Volume flow	25227.5 cm^3/s	-25195.52 cm^3/s

6. Conclusions and further research

Simulations gave a good result about making the final design of the prototype and the final design of real machine. The last two results finally meet the design and project requirements for material flowing. The material real properties have to be discovered as soon as possible to have better results in the future. The height of the machine can be a problem for building original machine; it must be reduced to reduce the power requirements. In the next stage, the system can be automated it requires some programing skills which will allow the machine to run. A small real based prototype also can be made to analyze the power, losses and velocity requirements.

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