Modeling and Static Analysis of Rotary Evaporator Parts using Solidworks

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Abstract

The Rotary Evaporator is used for systematically removal of solvents from samples by using evaporation procedure in chemical laboratories. The working principle of rotary evaporator is that the boiling point of liquids lowers on decreasing their pressure which allows the solvent to vaporize at lower temperatures than when boiled in a normal atmosphere. Molecular cooking for the preparation of distillates and extracts can also be done by this device. After thoroughly studying the device and its functions we have designed the parts of rotary evaporator and assembled using SOLIDWORKS software. In this we have taken vapour duct, rotary mechanism assembly and bench for static analysis using SOLIDWORKS. The maximum static stress and static strain, minimum static stress and static strain of vapour duct, rotary mechanism assembly and bench are analyzed.

Keywords
Rotary evaporator, Solidworks, Vapour duct, Static stress and Static strain.

1. Introduction
A rotating evaporator is a laboratory instrument for evaporating solvents from samples in an efficient and gentle manner. Rotary evaporators are used to extract chemical substances which are further used for other chemical purposes by professors in chemical and biochemical labs.In the industrial field, rotary evaporators are used to extract cannabidiol (cbd), the major component of marijuana, which is then utilized to make medicine in the pharmaceutical field. Rotovap's fundamental premise is to enhance the rate of evaporation of the solvent by lowering the pressure to lower the boiling point of the solvent, rotating the sample to increase the effective surface area, and heating the solution. Mainly the rotovap manufactured in the foreign countries uses cast iron, aluminum and other metals. The rotavaps bodies are made by casting method which increases the material usage and cost. In order to reduce the raw material usage and manufacturing cost the modeling of the body is done with Sheetmetal. This reduces the raw material usage, cost and makes the body can be easily manufacturable and serviceable. This device is currently manufactured in China, by some German OEMs. The cost of the device supplied by these OEMs is huge, with the current world scenario, the manufacturing and import of goods from China has been severely affected, which has resulted in great demand for the device and its spares in the Indian market. This has pushed up the cost of the device exponentially, making both cost and time unaffordable for a lot of Indian laboratories. After thoroughly studying the device and its functions, we are trying to develop a low cost, completely **Make in India** rotary evaporator by modeling and analyzing important components of rotovap.

1.1 Objectives
- To fabricate the device at low cost compared to existing rotary evaporators.
- To increase the serviceability of rotary evaporator.
- To increase the ability to withstand loads.
- To reduce the weight of device compared to present rotary evaporators by fabricating with sheet metals.

2. Literature Review

Rosemary Hoegger et al. (2021) a rotary evaporator is a particularly constructed instrument for the evaporation of solvent under vacuum, according to the manufacturer. The liquid is poured into a revolving flask, which is then placed in a hot bath, where it is dispersed across the wall and evaporated. The rate of evaporation is controlled by the temperature of the heating bath, the size of the flask, the distillation pressure, and the rotation speed. Lisa Nicolus et al. (2022) Because the pressure in the apparatus is reduced, the solvent boils at a lower temperature than usual, and rotating the flask increases the surface area of the liquid and consequently the rate of evaporation. When the solvent vapour comes into contact with a water condenser, it condenses and falls into a receiving flask. She concluded thatthe difference between distillation and rotary evaporation is that the distillate is most often retained in distillation while the residue is retained in rotary evaporation. According to the article of Impact of immersion angle using an immersion angle at 25 degrees guarantees most efficient evaporation rate without jeopardize losing parts of the sample. Nitin Mathur et al. (2016) investigated Corrosion of materials are been calculated using mass loss method when they are in contact with various concentrations of HCL and H2SO4. According to this corrosion inhibition increased to proportionate concentration of the extract. Mild steel has been found to be more vulnerable in acid solutions such as HCl and H2SO4. So we selected less corroded materials in this analysis. According to the Machinery hand book, a very basic equation used to calculate FoS is the ratio of ultimate stress and typical stress. For use with highly reliable materials where loading and environmental conditions are severe and where weight is an important consideration the value of factor of safety should lieinbetween1.3–1.5. Zizeh Jafari et al. (2016) depending upon the rotation speed and rotation time utilized in vacuum rotary evaporator are been studied. Response surface methodology is used to evaluate the mean particle size of poly disparity index and α-tocopherol degradation in the form of nano droplets. Multiple-optimization procedure revealed that the optimum amounts of evaporation speed and time were 30 rpm and 10 min, respectively. Aaditya Srivastava et al. (2015) studied the effect of heat treatment on the mechanical properties of mild steel. They conducted heat treatment processes like annealing, normalizing and hardening on materialsto determine the mechanical properties like ductility, hardness, etc., the specimens were machined according to ASTM standards and conducted finite element analysis on heat treated materials to determine results. They concluded that hardness and tensile strength obtained in hardening process compared to normalizing and annealing. N.J.Rathod et al. (2017) investigated the turning operation machining parameters on SS 304. They used Grey-Based Taguchi approach for multi-objective Turning process optimization for locating best parameter in conjunction for maximum tool and minimum production life. Grey relational analysis was used to acquire optimum parameter levels and also analysis of variance helps in recognition of parameters like speed, feed and cut depth. They concluded that grey relational analysis is a highly efficient method for optimizing multiple-response machining processes. J.Shit et al. (2018) studied the cyclic plastic behavior in transition cycle for material SS316. The material constants are derived from uniaxial strain controlled low cycle fatigue test results from virgin state to saturated stage at Table hysteresis loop. The model developed with kinematic hardening rules are plugged into finite element program and results obtained are compared with experimental results at various strain amplitudes. They concluded that the dilation effect in material SS316 in negligible for low strain amplitudes and saturated LCF loops are simulated satisfactorily for SS316 materials.

3. Methods

SOLIDWORKS software is used for modeling and assembly of rotary evaporator components. Modeling is the major aspect which is to be considered during designing which helps to picturize and simulates various forces and depicts the effect of those forces that component will experience after fabrication. Subcomponents are designed depending on variables which could affect the stress distribution of the equipment individually. The components of the rotary evaporator are shown in Figure 1.

Figure 1. Rotary Evaporator

3.1 Components

Rotary Evaporator consists of condenser, vapor duct, flask, motor, heating bath, bench, temperature controller etc. as its components. The components are given in Table 1. The actual equipment of Rotary evaporator is shown in Figure 1. Each part is modeled in SOLIDWORKS and assembled. After assembly front and back views are shown in Figure 2 and Figure 3.

Table 1. Components of Rotary Evaporator

S. No.	**Components**	**S.No.**	**Components**
1	Condenser	6	Waterbath
2	Condenser tube	7	Linear Actuator
3	Receiving Flask	8	Motor
4	Vapour Duct	9	Rotary mechanism
5	Evaporating Flask	10	Bench

Table 1 shows the list of the components used in modeling the rotary evaporator.

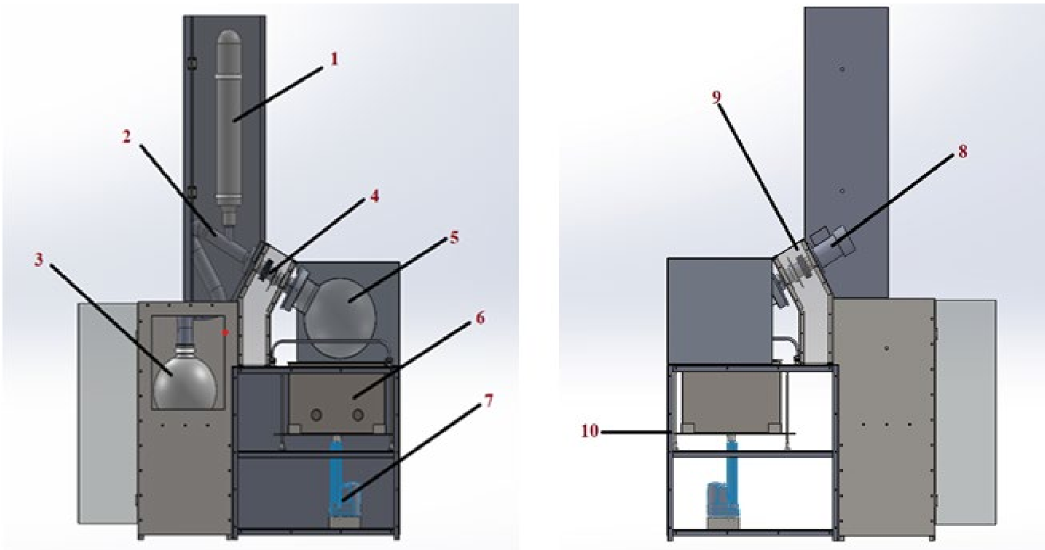


Figure 2. Final Design of Rotary Evaporator

The Rotary evaporator consists three vital components. These components are functioned for different purposes accordingly. Different types of materials are selected according to their functionality. The bench withstands all the parts on it and is easy manufacturable and durable. Rotary mechanism and motor assembly helps in the rotating the flask and creates the rotary effect. The components of the rotary evaporator which are modeled in SOLIDWORKS are shown in Figure 3, Figure 4 and Figure 5.

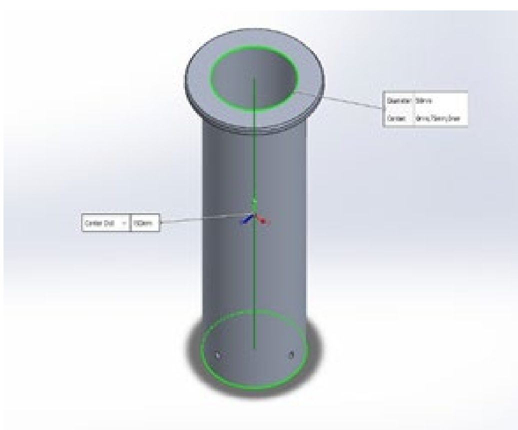


Figure 3. Vapour Duct

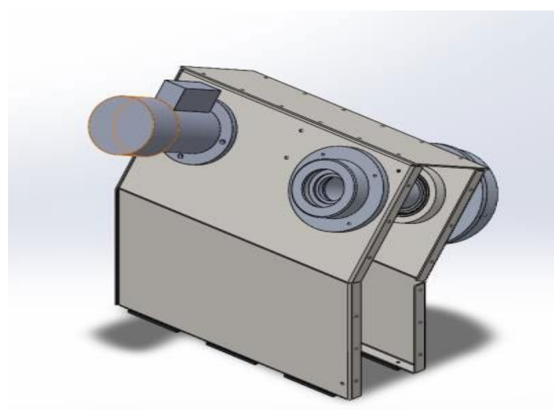


Figure 4. Rotary Mechanism and motor assembly

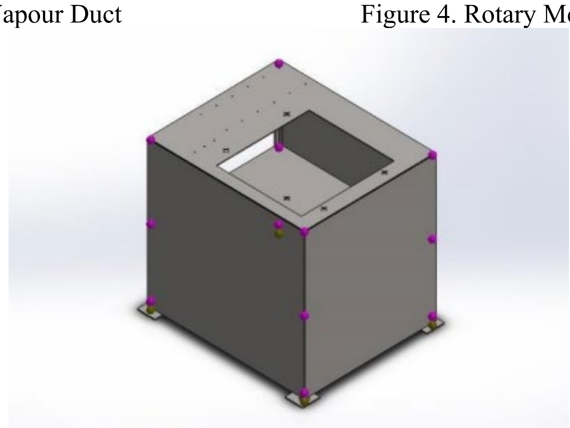


Figure 5. Bench

4. Data Collection

4.1. Selection of material

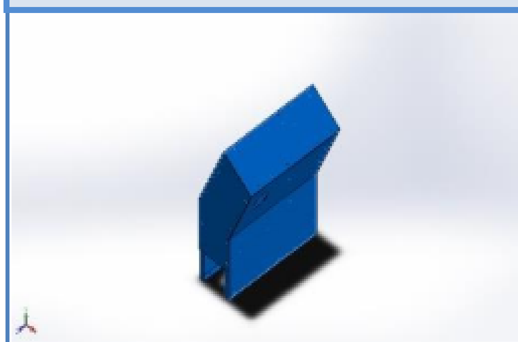
According to content mentioned in the text book 'Material Selection in Mechanical Design' by Ashby, M.F. Proper material selection, for engineering purposes, is a difficult problem for the designer. The selected material should complete the objective of the problem at low cost. The mechanical properties of the material are associated with those where the material can handle the applied loads and forces. [10]. The material selected here is EN24T carbon steel which is a high strength steel alloy. This alloy has good machining properties which can also be used at high temperature applications.

Table 2. Material properties of Vapour Duct

Model Reference	Properties
	Name: **6061- T6 (SS)** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.75e+08 N/m^2** Tensile strength: **3.1e+08 N/m^2** Elastic modulus: **6.9e+10 N/m^2** Poisson's ratio: **0.33** Mass density: **2,700 kg/m^3** Shear modulus: **2.6e+10 N/m^2** Thermal expansion coefficient: **2.4e-05 /Kelvin**

The Table 2 shows the analysis of the vapour duct done in the SOLIDWORKS. The material used in the analyzing the duct is 6061-T6 and has good strength to weight ratio. The material is used for engineering and structural applications. The mechanical properties of the material are mentioned in the Table.

Table 3. Material properties of Rotary Mechanism

Model Reference	Properties
	Name: **Plain Carbon Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.2059e+08 N/m^2** Tensile strength: **3.9982e+08 N/m^2** Elastic modulus: **2.1e+11 N/m^2** Poisson's ratio: **0.28** Mass density: **7,800 kg/m^3** Shear modulus: **7.9e+10 N/m^2** Thermal expansion coefficient: **1.3e-05 /Kelvin**

Rotary mechanism is modeled and analyzed in the SOLIDWORKS. The material used in the analyzing the component is plain carbon steels which are highly durable, sustainable and affordable. The material is used for extremely hard components like machine parts and industrial castings. The mechanical properties of the material are mentioned in the Table 3.

Table 4. Material properties of Bench

Model Reference	Properties
	Name: **Plain Carbon Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.2059e+08 N/m^2** Tensile strength: **3.9982e+08 N/m^2** Elastic modulus: **2.1e+11 N/m^2** Poisson's ratio: **0.28** Mass density: **7,800 kg/m^3** Shear modulus: **7.9e+10 N/m^2** Thermal expansion coefficient: **1.3e-05 /Kelvin**

Bench is modeled and also analysis is donein the SOLIDWORKS. The material used in the analyzing the component is plain carbon steels which are highly durable, sustainable and affordable. The material is used for extremely hard components like machine parts and industrial castings. The mechanical properties of the material are mentioned in the Table 4.

4.2 Selection of motor

To make the distillation process more effective, the flask containing solution has to be rotated at a certain speed. Because of the flask rotation, there is an agitation in the liquid of water bath which improves the heat transfer in the flask and solvent. The increased surface area in the flask results in an increased evaporation rate. At higher speed of the motor, there are possible chances of mechanical problems with the rotary evaporator, Vibrations damaging the equipment and at high turbulence; water in the bath could spill over. Hence, considering these problems, right motor should be selected with precise calculations.

Load to rotate (F) = 25 kgs = 25*9.81 = 245 N
Radius ofPulley (r) = 50mm = 0.05 m
Speed (N) = 140 RPM
Torque (T) = F*r = 245*0.05 = 12.5 N-m
Power (P) =2*∏*N*T/60= (2∗3.14∗140∗12.5)/60 =180Watts.

Hence,we considered DC INDUCTION GEAR MOTOR as the possible motor for the functioning of rotary evaporator. The properties of the motor are in the following Table.

Table 5. Selection of motor for functioning

Possible motor	
Motor Model	TM 71 A2 (TW 40 71 B5)
Gear Ratio (i)	20
Torque (N-m)	20
Speed (RPM)	140
Rated Power (Watts)	370

5. Results and Discussion

The body deforms whenever loads are applied to it, and the effect of the loads is transferred throughout the body. Under applied loads, Linear Static analysis will calculate strains and stresses of the body. Static analysis is applied in SOLIDWORKS for the individual components of the rotovap where they experience loads and forces. Simulation results of the individual components are as follows.

5.1 Vapour Duct Static Stress and Strain Analysis

After modeling the components and assembly, an analysis is performed in order to justify the usage of the rotary evaporator, by considering the working conditions of the rotary evaporator. Torque acts on the vapor duct due to the pulleys placed on it which is in contact with the motor. The results are as follows.

Name	Type	Min	Max
Stress1	P1: 1st Principal Stress	-2.110e+03N/m^2 Node: 3963	4.168e+05N/m^2 Node: 5654

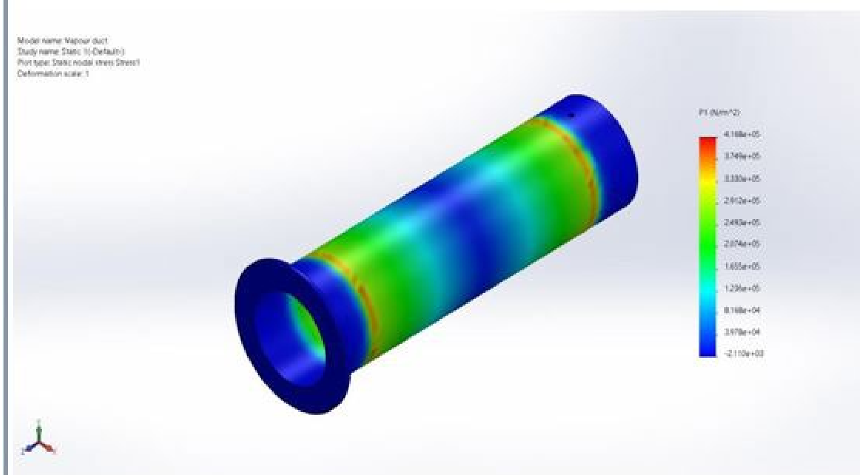


Figure 6. Vapour Duct – Static Stress Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	8.507e-13 Element: 5576	7.724e-06 Element: 3452

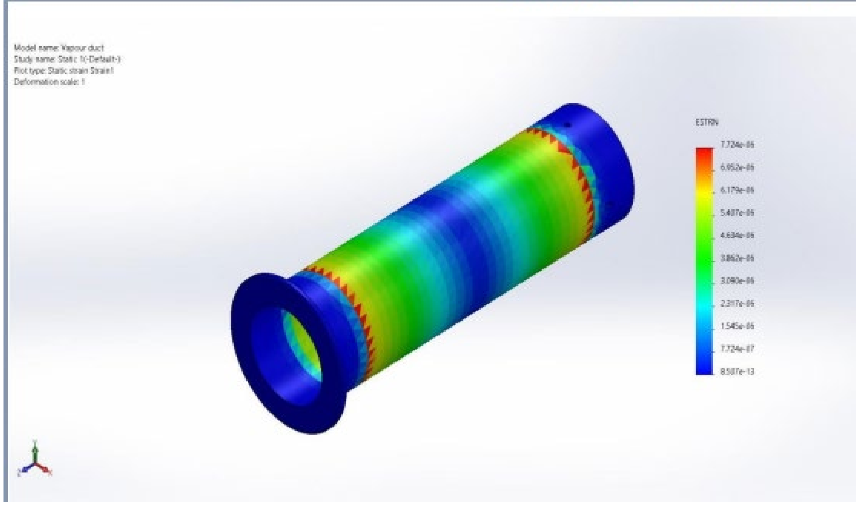


Figure 7. Vapour Duct – Static Strain Analysis

The analysis results of the static stress developed on the vapour duct when 12.265 N-m torque is applied by considering factor of safety as 2.25 gives minimum principal stress as –2.110e+03N/m^2 and maximum principal stress as 4.168e+05N/m^2. The static strain analysis results on the vapour duct gives minimum strain as 8.507e-13 and maximum strain as 7.724e-06. These results are tabulated and shown in Table 6.

5.2. Rotary mechanism assembly Static Stress and Strain Analysis

Loads acts on the rotary mechanism and motor assembly due to the weight of the motor and bearings placed on it. The simulation results are as follows.

Name	Type	Min	Max
Stress1	P1: 1st Principal Stress	-2.995e+03N/m^2 Node: 19261	4.810e+08N/m^2 Node: 3167

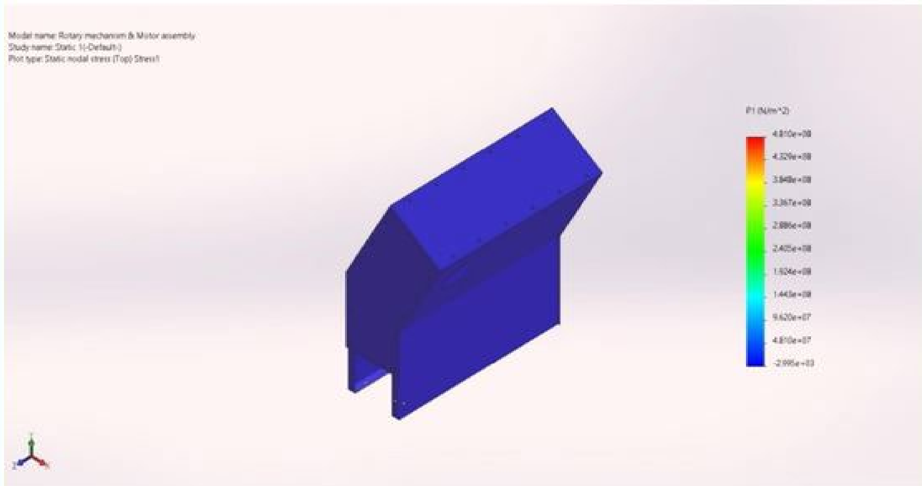


Figure 8. Rotary mechanism – Static Stress Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0.000e+00 Element: 1040	1.492e-06 Element: 3590

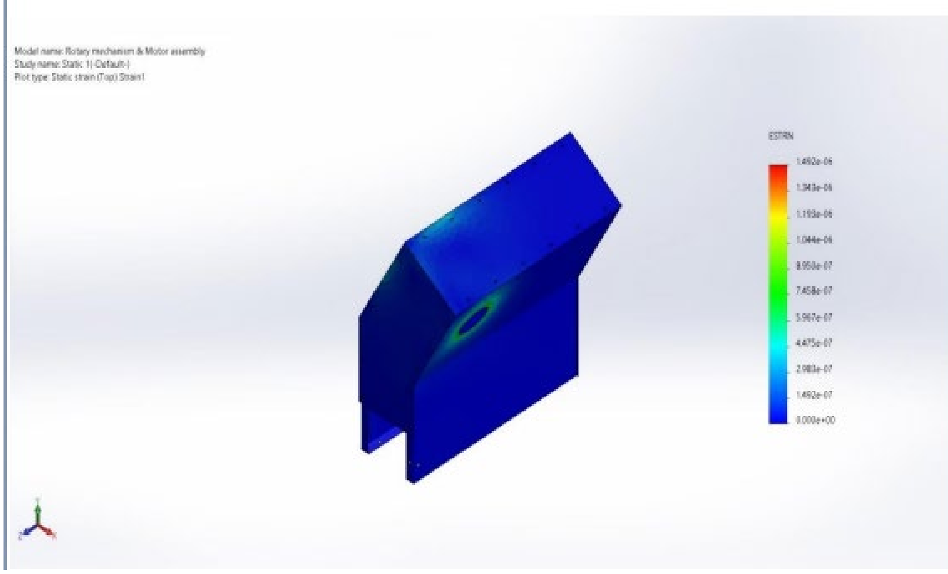


Figure 9. Rotary mechanism – Static Strain Analysis

The analysis results of the static stress developed on the rotary mechanism when load is applied by considering factor of safety as 1.4 gives minimum principal stress as –2.995e+03N/m^{2}and maximum principal stress as 4.810e+08N/m^2. The static strain analysis results on the rotary mechanism give minimum strain as 0 and maximum strain as 1.492e-06. These results are tabulated and shown in Table 6.

5.3. Bench Static Stress and Strain Analysis

Loads acts on the bench due to the weight of the rotary mechanism and water bath placed on it. The simulation results are as follows.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.000e+00N/mm^2 Node: 110954	1.356e+02N/mm^2 Node: 45309

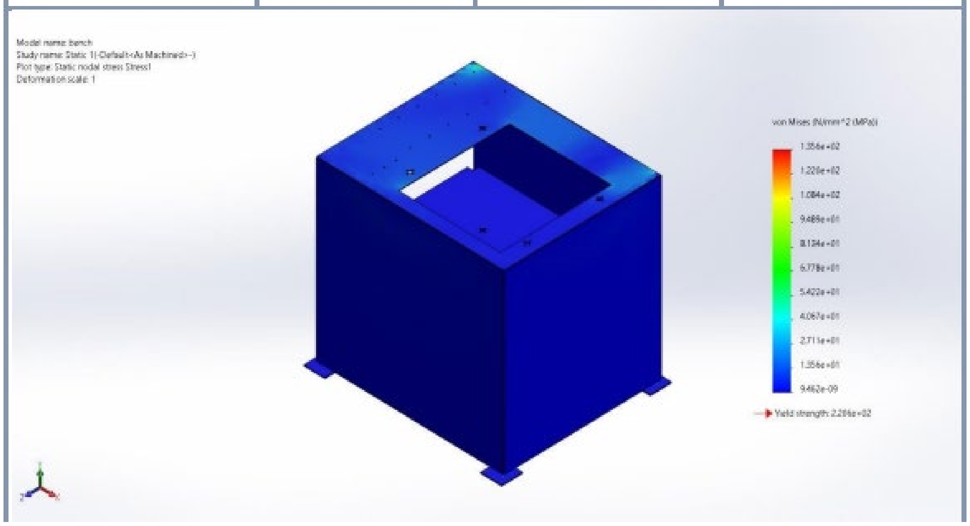


Figure 10. Bench – Static Stress Analysis

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0.000e+00 Element: 54612	2.941e-04 Element: 29323

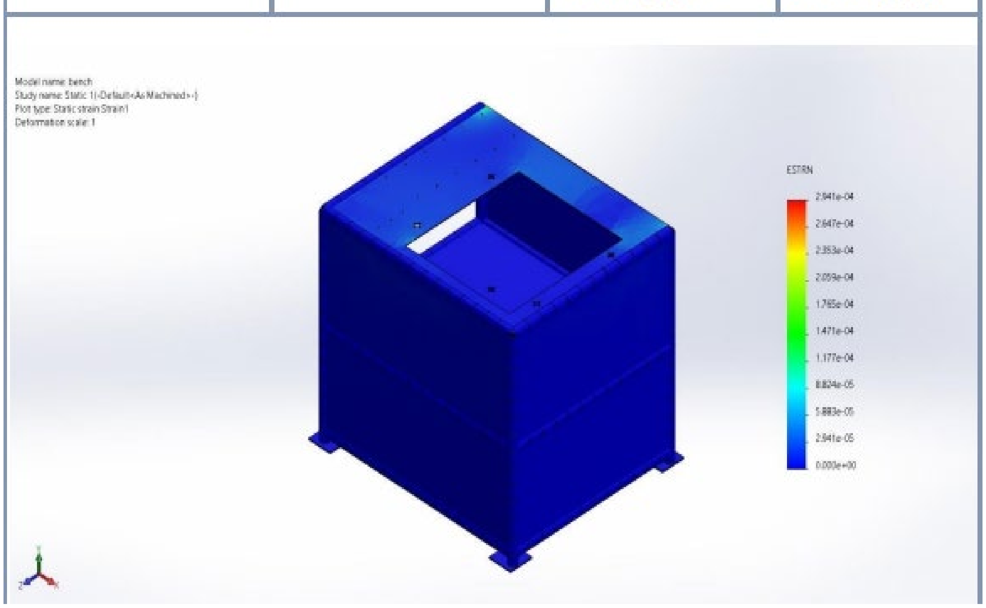


Figure 11. Bench – Static Strain Analysis

The analysis results of the static stress developed on the bench when load is applied by considering factor of safety as 1.25 gives minimum principal stress as 0 and maximum principal stress as1.356e+02N/mm^2. The static strain analysis results on the bench give minimum strain as 0 and maximum strain as 2.941e-04. These results are tabulated and shown in Table 6. Table 6 shows the results of the static analysis done on the components of the rotary evaporator.

Table 6. Static analysis results

PARTS	STRESS		STRAIN	
	Minimum (N/m^2)	Maximum (N/m^2)	Minimum	Maximum
Vapour Duct	-2.110×10^{3}	4.168×10^{5}	8.507×10^{-13}	7.724×10^{-06}
Rotary Mechanism	-2.945×10^{3}	4.810×10^{8}	--	1.492×10^{-06}
Bench	--	1.356×10^{2}	--	2.941×10^{-04}

6. Conclusion

The design and analysis on the structure of the rotary evaporator is developed successfully and it indicates that the design of the rotary evaporator created has good enclosures provided for the equipment for preventing the unexpected spillage of the chemicals and breakage of the glassware. Material for the parts of the rotary evaporator is selected on the basis so that it can with stand their actions from strong acid and alkaline substances. Static Analysis is done in SOLIDWORKS simulation on the parts of the rotary evaporator where they experience loads and forces. Torque is applied on the vapor duct and Loads are applied on rotary mechanism and bench by considering factor of safety. The simulation results unambiguously shows that the parts designed are effective and give better performance under working conditions. Hence, this design comes with easy manufacturability and increased serviceability compared to the imported equipment accompanying good aesthetics with full safety conditions.

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