Design and development of vacuum compartment for refrigerator

Hemant P. Kadam[1], Swati K. Dhamale[1], Sushant S. Pande[1], Anuj K. Gupta[2]

[1]*Department of Mechanical Engineering, D. Y. Patil College of Engineering, Akurdi, Pune-44*
Savitribai Phule Pune University (SPPU), INDIA

[2]*Whirlpool of India Ltd. Pune*

***Abstract* -- A vacuum storage system in a refrigerator includes a drawer unit which is removabley mounted in housing. The vacuum storage system may be utilized as a storage space or in a vacuum sealing configuration to remove air from food preservation compartment having one way evacuation valves. A switch on a control interface actuates a vacuum source and a front wall of the drawer unit seals against the box of compartment. Air is drawn from the storage space via a hose in communication with the vacuum source and air pressure within the storage space is reduced below the atmospheric pressure. At a predetermined pressure or time, a control deactivates the vacuum source. Later while opening the drawer an non return valve is opened to return the storage space to atmospheric pressure.**

Keywords — Vacuum Compartment; No Load Pull Down; FMEA; vacuum cooling.

I. INTRODUCTION

It is well known that exposure to oxygen over time promotes deterioration of food products. Therefore, packaging food in vacuum sealed containers aids in preserving food products and extending their shelf life. Oxygen in air promotes certain reactions in foods that cause deterioration of quality. For example, oxygen can cause fats in food to go rancid as well as cause certain odour and colour changes. Therefore, removal of oxygen from the package environment will preserve certain quality characteristics and extend the food’s shelf life. Vacuum packing and sealing is thus a means of food preservation that preserves food for a long period of time than conventional plastic wrap or storage bags. Vacuum sealers are commonly used to extend the storage time of refrigerated, dried and frozen foods.

Fresh items such as fruit and vegetables are respiring, transpiring, senescing and dying all at the same time. It is generally accepted that the quality of fruits and vegetables begins to deteriorate upon harvesting and continues to decline quickly thereafter. The effect of temperature on shelf life and decay is dramatic. Vacuum cooling can rapidly and conveniently reduce temperature due to field heat. Vacuum cooling is the standard commercial procedure used for lettuce in many European countries, as well as in the US.

Problem Definition

Designing & developing the compartment to provide a vacuum food storage system that maintains food fresher for long time, in a refrigerator than the current storage systems.

Literature Review

Vacuum cooling is a rapid evaporative cooling technique, which can be applied to specific foods and in particular vegetables. Increased competitiveness together with greater concerns about product safety and quality has encouraged some food manufacturers to use vacuum cooling technology. [3] Traditionally, products such as lettuce and mushrooms have been cooled under vacuum. Recent research has highlighted the possible applications of vacuum cooling for cooling meat and bakery products, fruits and vegetables. [6] Recently, vacuum cooling has been applied to cool viscous food products and bakery products in the food industry, and tuna in the fish industry. [5] More recently, the integration of vacuum-cooling into the processing procedures of prepared consumer foods such as cooked meats and ready meals (e.g., meat, pies and pasta dishes) has widened the application of this technology in line with increasing demands from consumers for safe and high quality products, and from the food industry and regulatory bodies. [1]

A mathematical model is developed to analyse the performance of a vacuum cooler. The model is based on the mass conservation of air and vapour in the vacuum chamber. In the chamber, the vapour evaporated from foods under the vacuum and the vapour removed by the vapour-condenser and vacuum pump contribute to the variation in the vapour partial pressure, and the ingress air and the air released by the pump cause the change of air partial pressure. Experiments were carried out on vacuum cooling of water to validate the model. [4] Mathematical-modelling techniques have been developed which are capable of describing the effect of two environmental variables, plus temperature, on the kinetics of bacterial growth. The models illustrated here demonstrate the effect of water activity and pH on the growth of Staphylococcus aureus and Salmonella typhimurium. Their application to predict the level of possible bacterial growth in hazard analysis techniques is illustrated. [18]

Objectives

The objectives of present work are to develop, the compartment to provide a vacuum food storage system in a refrigerator. The vacuum compartment is intended for food that spoils easily, such as raw meat, fruits, vegetables, etc. and it is sealed with a special door. After closing, a pump is activated automatically with the press of a button to remove air from the sealed drawer and reduce the air pressure to 0.8 bars. The system should keep food fresh longer than non-vacuum cooled food. It also eliminates the need for defrosting.

Necessity of the device

Increases the life of food by removing oxygen. This reduces growth of spoilage bacteria. Reduces ice crystals on frozen food. Enhances the shelf life of the food products. Reduces the smell & odour of the meat food products.

II. System Description

The present project is directed to a refrigerator vacuum storage system and method of use. The vacuum storage system includes a compartment, such as a drawer unit, which is mounted in the cabinet to define a removable storage space for food products. An optional shelf having air flow apertures therein may be utilized to divide the storage space into separate storage compartments. The drawer unit can be used to store food in a conventional manner, or may be utilized to remove air from compartment to enhance food preservation within the compartment. To this end, a vacuum source in a machine compartment of the refrigerator is placed in communication with the storage space. The desired, compartment to be evacuated is placed into the refrigeration compartment and the vacuum source is actuated via a switch provided on the cabinet. Air pressure within the storage space is reduced, thereby evacuating air within the compartment.

After a predetermined pressure is attained, or after a particular predetermined time, the vacuum source is shut off. During opening of compartment an equalizing valve is opened which returns the storage space to atmospheric pressure, while vacuum conditions are retained in the compartment.

With this system, a consumer is provided with a food storage drawer that may be shifted between an extended or opened position and a retracted or closed position with ease, but which also may be utilized to simultaneously evacuate air from compartment, depending on a consumer's needs. Various concepts are built for the vacuum compartment which is listed below.

A] Sample calculations for Vacuum Compartment Assembly of concept 1:

The drawer of vacuum compartment is assumed to be a simply supported beam on the ribs of the liner of refrigerator cabinet. The sample calculations are made for vacuum compartment assembly of concept 1.

The deflection of the drawer is given by,

$$\delta = \frac{5}{384}\frac{WL^3}{EI}$$

& bending stresses are given by,

$$\frac{M}{I} = \frac{\sigma}{y}$$

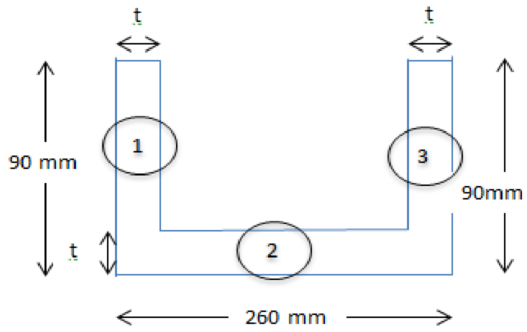


Fig. No 1: Cross Section of the drawer

$$I = I_1 + I_2 + I_3$$

$$= 48.2577\, t^3 - 4786.44\, t^2 + 336886.34\, t \qquad mm^4$$

Also,

$$R_A = R_B = \frac{WL}{2}$$

& Maximum Bending Moment,

$$M = \frac{WL^2}{8} = \frac{W*356^2}{8} = 15842W \qquad Nmm$$

The deflection of the drawer is given by,

$$\delta = \frac{5}{384}\frac{WL^3}{EI}$$

$$\delta = \frac{587474.1667\, W}{[48.2577\, t^3 - 4786.44\, t^2 + 336886.34\, t]E} \dots\dots\dots (1)$$

& bending stresses are given by,

$$\sigma = \frac{My}{I}$$

$$\sigma = \frac{15842\, W*(0.2955\, t + 18.41)}{48.2577\, t^3 - 4786.44\, t^2 + 336886.34\, t}\ N/mm^2 \dots(2)$$

Design for vacuum compartment

Assume that

Factor of safety as F.O.S = 1.5

But Factor of safety [F.O.S] = $\frac{\text{Yield Stress}}{\text{Allowable Stress}}$

Yield stress of HIPS σ_y = 23 MPa

Allowable stress $\sigma_a = \frac{\sigma_y}{F.O.S} = \frac{23}{1.5} = 15.33$ MPa

Therefore,

$$\sigma_a = \frac{15842\, W*(0.2955\, t + 18.41)}{48.2577\, t^3 - 4786.44\, t^2 + 336886.34\, t}$$

If the applied load is W = 75 N

$$15.33 = \frac{15842 * 75 * (0.2955\,t + 18.41)}{48.2577\,t^3 - 4786.44\,t^2 + 336886.34\,t}$$

Therefore on solving above equation for thickness,

we obtain t = 2.73445 mm

Therefore selecting the optimum thickness as

t= 2.80 mm

Substituting the values for weight, the deflection and bending stresses can be evaluated from equations (1) & (2) respectively.

B] Selection of vacuum pump:

The vacuum pump was mounted on the compressor mount plate (CMP) near the compressor in the mounting fixture. The details of vacuum pump are as follows.

Rated Voltage: 12V

Rated Current: 1800mA

Flow Rate: 13.0 lpm

Output pipe diameter: 7mm

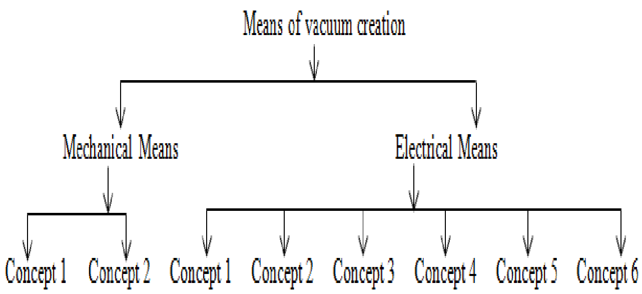
Size: ϕ 60mm × 120mm

Negative Pressure: -375mmHg (-50KPa)

Maximum Pressure: 525mmHg (70KPa)

C] CAD Model Representation

Different concepts were proposed for the vacuum compartment and modelling of which was done in PTC Creo 2.0. Two concepts of mechanical means and three concepts of electrical means were developed in the lab. The material used was High Impact Polystyrene (HIPS) and General Purpose Polystyrene (GPPS). Prototypes developed were 1:1 scaled model of actual product. The CAD models of different concepts are as follows.



1) *Mechanical means of vacuum creation:*

To evacuate the air from the compartment manual force was required to be applied. Hence the mechanism was developed to evacuate the compartment manually. CAD model representation of mechanical means is as shown

Concept 1:

Fig. No 2: Concept 1 of vacuum creation of mechanical means

Concept 2:

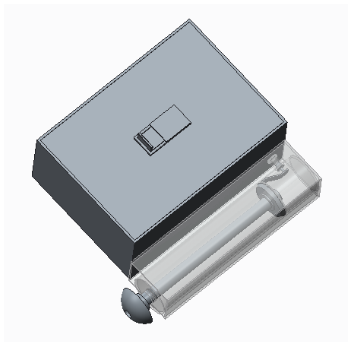


Fig. No 3: Concept 2 of vacuum creation of mechanical means

2) *Electrical means of vacuum creation:*

In this type of vacuum creation the micro diaphragm vacuum pump is used, which is mounted on CMP near compressor, and connected to compartment with vacuum hoses.

Concept 1:

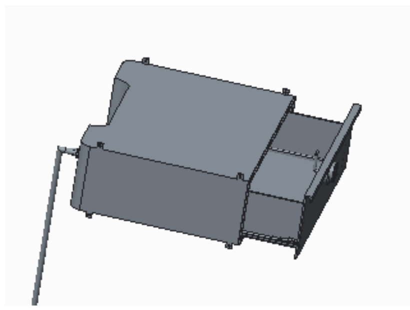


Fig. No 4: Concept 1 of vacuum creation of electrical means

Concept 2:

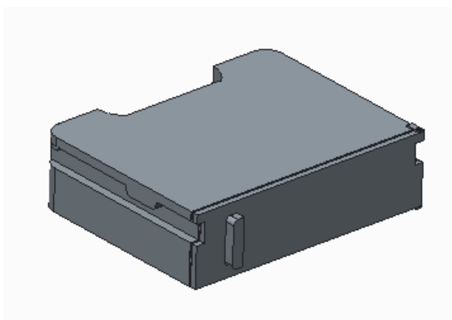


Fig. No 5: Concept 2 of vacuum creation of electrical means

Concept 3:

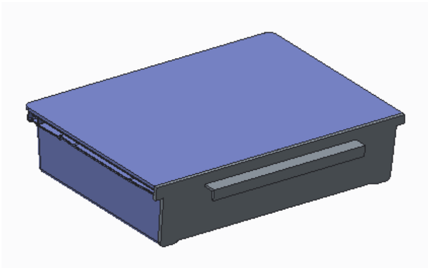


Fig. No 6: Concept 3 of vacuum creation of electrical means

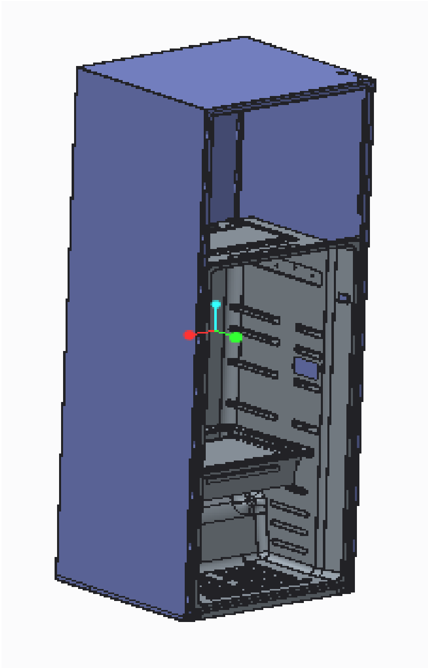


Fig. No 7: Placement of vacuum compartment within the refrigerator.

III. EXPERIMENTAL VALIDATION

The prototypes of concepts of electrical means of vacuum creation were developed as appeared in CAD model. In Concept Selection Event (CSE) two concepts of mechanical means and three concepts of electrical means were selected for development based on FMEA. The concept scoring more ranking in PUGH Matrix was finalised.

Material Properties are as follows

Table No1: Material Properties

Material	Modulus of Elasticity (MPa)	Poisson's Ratio	Yield Strength (MPa)	Tangent Modulus (MPa)
HIPS Class 7	1780	0.36	23	178
GPPS	2640	0.35	38	0.35

A] SHELF DEFLECTION TEST:

The shelf deflection test was carried out as per the standards of Whirlpool W10510631, in structural laboratory of PDC PRO Pune. The electrical means of vacuum creation concepts were selected for deflection testing.

The results obtained were as follows.

Table No2: Deflection Testing

Load in kg	Deflection in mm		
	Concept 1	Concept 2	Concept 3
3	0.9	3.6	1.06
6	1.83	6.44	2.07
9	2.79	8.95	2.97

Fig. No 8: Shelf Deflection Testing of concept 1

Fig. No 9: Shelf Deflection Testing of concept 2

Fig. No 10: Shelf Deflection Testing of concept 3

B] NO LOAD PULL DOWN (NLPD) TEST:

NLPD test was carried out in Performance Lab of PDC PRO Pune. The test was carried as per the Whirlpool specifications I-WTM-P-160.11

The product is kept 16 hours for soaking at 43 ^{o}C ambient with humidity 45-50%, with all of its doors opened. Once the product is placed on stall, 150 mm of distance is kept from rear side wall to ensure proper heat transfer. The compressor is bypassed from STM-8 board to keep the product in continuous run mode for 6 hours. The freezing compartment & refrigeration compartment temperatures should be -18 ^{o}C & -5 ^{o}C respectively. The condenser out temperature should be less than 55 ^{o}C and suction is less than 43 ^{o}C.

Fig. No 11: Test set up for NLPD testing

From above test results the following observations are made.

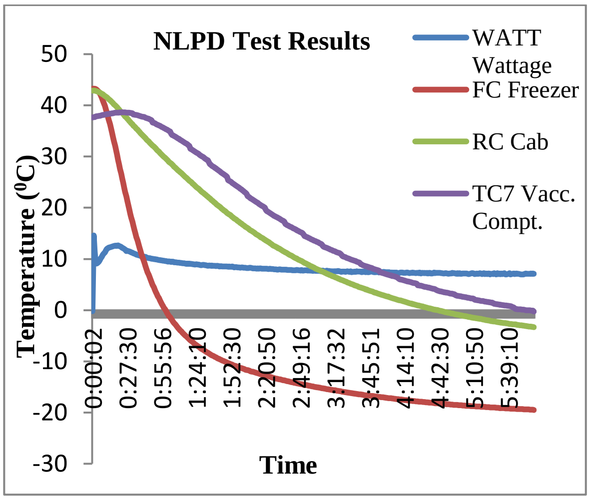


Fig. No 12: Graph of NLPD test out comings

After 6 hours, Freezer Temp: -19.4 ^{o}C, Ref. Cab Temp: -3.3 ^{o}C, Condenser Out: 52.1 ^{o}C, Suction: 44 ^{o}C, Vacuum Compartment Temp: -0.1 ^{o}C

The product was found eligible for further testing's.

C] FOOD FRESHNESS TEST:

Food freshness test was to be taken on spinach. The vacuum compartment was kept at the position of fruit crisper in GenX 292L (Product id: 153104623). Another GenX 292L (Product id: 153903825) with no change in position of fruit crisper was used for the comparison.

Both the products were allowed to stabilize and obtain same temperature at the position of fruit crisper. These products were then loaded by vegetables. The moisture loss was then estimated by measuring the weight every 24 hours.

1. MOISTURE LOSS MEASUREMENT:

The test was carried out for 7 days with standard door opening procedure. The results of this test are as shown below.

Table No3: Moisture loss in spinach

Days	**Moisture loss in Spinach in gram**	
	With vacuum	**Without vacuum**
Day-0	130	130
Day-1	126.2	124.5
Day-2	125.3	118.3
Day-3	125	111.2
Day-4	122.8	105.4
Day-5	121.5	99.5
Day-6	118.7	93
Day-7	116	88.9

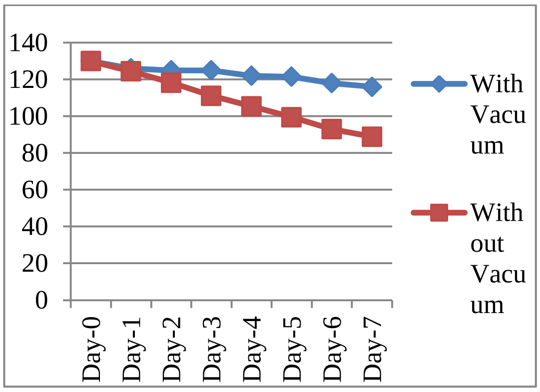


Fig. No 13: Graph indicating the moisture loss in spinach within vacuum and non-vacuum storage conditions.

2. VITAMIN C LOSS MEASUREMENT:

The loss in weight in the sample provided from the GenX 292L product with vacuum compartment is less as compared to that of the sample provided from GenX 292L product without vacuum compartment.

Test Procedure:

1. 10g of sample of Spinach + 90 ml 3% Metaphosphoric acid

2. Mix the sample and Metaphosphoric acid in a beaker with a mixer.

3. Filter the mixture with the help of filter paper

4 Fill the burette with Dye Solution.

5. Add the dye solution to sample in the beaker until the solution turns from colourless to the pink colour.

$$\text{Dye Factor} = \frac{0.5}{Titre} = \frac{0.5}{4.5}$$

$$= 0.1111$$

mg of ascorbic acid per 100 g or ml =

$$\frac{(Titre) * (dye\ factor) * (volume\ made\ up) * (100)}{(a\ liquot\ of\ extraction\ taken\ for\ estimation) * (Weight\ or\ volume\ of\ sample\ taken\ for\ estimation)}$$

$$= \frac{2.7 * 0.1111 * 100 * 100}{10 * 10} = 29.9997 \approx 30 \text{ mg}$$

The following observations were seen from the test

Table No2: Vitamin C determination in spinach

Day	Vitamin C in mg	
	With Vacuum	Without Vacuum
Day 0	30	30
Day 3	24.38	20.65
Day 5	18	15.23
Day 7	12.825	9.15

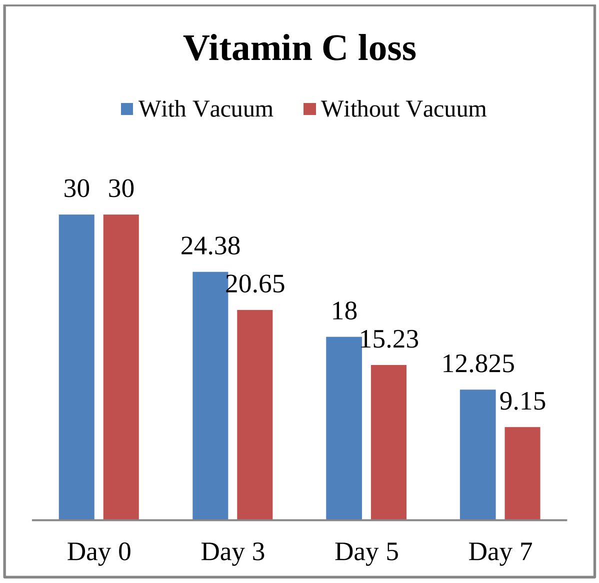


Figure No 13: Graph indicating the loss of Vitamin C in spinach

IV. Future Scope

In this paper the testing carried out were on the prototype of scale 1:1. Experimentation is planned for the different vegetables, fruits, meat, dough, etc. within the vacuum compartment in application.

V. Conclusion

The objectives are validated in a prototype which is 1:1 scaled model of actual product. It has been proved that vegetables can be preserved for longer time in vacuum compartment of refrigerator than the conventional refrigerator. It has been observed that, the nutritional value of the spinach is more in vacuum compartment storage. Also along with it the existing means of food storage has been studied. Different concepts for the built up of vacuum compartment has been developed. A systematic approach of failure mode effect analysis of different concepts & design verification plan has been done.

Acknowledgment

It gives me an immense pleasure to express my gratitude to all those who have helped in bringing this paper into reality. Although it is impossible to gratify everyone individually I shall anticipate that acknowledgement would surpass through all my well-wishers.

I wish to express my sincere thanks Dr. Tapobrata Dey & Mr. Ajay Pathak for their valuable guidance and encouragement in carrying out the project work. The rounds of discussion with them gave fruitful direction to this work.

I am also thankful to Mr. Santosh Wakchaure of Whirlpool of India Ltd. for his kind co-operation and valuable guidance throughout the project.

I conclude my gist of acknowledgements by thanking all the individuals who have expressed their concern and have played an individual role in the accomplishment.

REFERENCES

[1] Drummond L., Zheng L., Sun D. W., Vacuum Cooling Of Foods, *Emerging Technologies for Food Processing*, 2005, pp. 477-495.

[2] Sun D. W., Wang L., Development of mathematical model for vacuum cooling of cooked meat, *Journal of Food Engineering* 77, 2006, pp. 379-385.

[3] McDonald K., Sun D. W., Vacuum cooling technology for food processing industry: a review, *Journal of Food Engineering* 45, 2000, pp. 55-65.

[4] Wang L., Sun D. W., Modelling vacuum cooling process of cooked meat- part 1: analysis of vacuum cooling system, *International Journal of Refrigeration* 25, 2002, pp. 854-861.

[5] Sun D. W., Zheng L., Vacuum cooling technology for the agri-food industry: Past, present & future, *Journal of Food Engineering* 77, 2006, pp. 203-214.

[6] Dostal M., Petera K., Vacuum cooling of liquids: mathematical model, *Journal of Food Engineering* 61, 2004, pp. 533-539.

[7] Jin T. X., Experimental investigation of the temperature variation in the vacuum chamber during vacuum cooling, *Journal of Food Engineering* 78, 2007, pp. 333-339.

[8] Sun D. W., Wang L., Modelling cooling process of cooked meat- part 2: mass and heat transfer of cooked meat under vacuum pressure, *International Journal of Refrigeration* 25, 2002, pp. 862-871.

[9] Gatzen, H. H., Saile, V., and Leuthold, J., Micro and Nano Fabrication Tools and Processes, Springer-Verlag Berlin Heidelberg, Germany, 2015, pp.7-63.

[10] Patent No. 6,148,875 (United States), June 18 1997, Vacuum Food Storage System, 2000.

[11] Patent Publication No. US2012/0326588 A1 (United States), Sep. 6, 2012, Refrigerator Vacuum Storage System, 2012.

[12] Patent No. US 8,281,606 B2, (United States), Feb. 6, 2008, Refrigerator Vacuum Storage System, 2012.

[13] Patent No. 3,216,214 (United States), May 18, 1964, Vacuum generation apparatus with closed fluid circuit ejector system, especially for vacuum generation of home refrigerator cells and the like, 1965.

[14] Patent Publication No. US 2006/0090427 A1, (United States), Oct. 31, 2005, Refrigerator with integral vacuum sealer, 2006.

[15] Patent No. US 8,915,093 B2 (United States), Feb. 20, 2013, Vacuum storage apparatus with sliding drawers, 2014.

[16] Khurmi R. S. and Gupta J. K., Machine Design, Eurasia Publishing House, New Delhi, 2005, pp. 261-265.

[17] Bansal R. K. Strength of Materials., Laxmi Publications, 2009, pp.380-408

[18] Broughall J.M., Brown C., Hazard analysis applied to microbial growth in foods: development and application of three-dimensional models to predict bacterial growth. International Journal of Food Microbiology, 1984, pp. 13-22