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Design And Analysis of Solar Operated Milk Pasteurization System

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Abstract-

Milk pasteurization is a process which involves heating of food or liquid to a temperature that kills disease causing microorganisms and substantially reduces the level of spoilage organisms. In dairy the pasteurization of milk is very important process. All milk produced at a processor and intended for consumption must be pasteurized, legally requiring it to be heated to at least 73°C then cooling it to 4°C to ensure any harmful bacteria are destroyed. For this process, heating of milk is necessary and it done by diesel energy or electric energy. The sources of this energy are very limited and currently India is facing with shortage of about 21% of electric energy. As a solution on this problem to do pasteurization of milk by solar energy. This concept will be really useful for reducing the dependency on either electric energy or diesel energy or coal energy. The aim of the project is to pasteurize 100-liter raw milk per day. The milk is pasteurized by using non-conventional energy like solar energy which will be very helpful to the environment. India is one of the countries which are having long days and more sunshine. The outcome of this project is pasteurized 100 liters of milk in two cycles of 50 liters per day. For one cycle of 50 liters required time is 10 hours 45 minutes. System pasteurizes 100 liters milk in a day. As per the structural analysis of system displacement of solar panel frame due to 66 kg is 12.3 N/mm which permissible value from standard data for selected material is. Also, as per the thermal analysis of chilling plant of system milk of 73°C which is precooled in intermediate receiver up to 35°C needs to be cooled at 4°C is possible. As per thermal analysis, system sustain all the thermal variation happening in it.

Keywords: Solar Energy, Chilling Plant, Milk Pasteurization, Micro-organisms, Temperature sensor, Heater, Parabolic dish collector.

INTRODUCTION-

Solar energy is the radiation from the Sun capable of producing heat, causing chemical reactions, or generating electricity. If suitably harnessed, solar energy has the potential to satisfy all future energy needs. India is a country in which solar energy is available in 2 huge amount and also favorable place for the use of solar energy.

The consumption of non-renewable sources like

oil, gas, wood and coal are increasing at higher rate. The time has finally come to look after some other renewable sources of energy like solar, wind and geothermal energy. Many countries have started utilizing solar energy can cover mostly their demands but they still have to go a long way to exploit this renewable energy to fulfill their daily needs. Some people create a completely wrong picture of the relevance, requirement and importance of solar energy for

India. They usually focus on the cost and affordability in a short-sighted way and ignore the larger issues of energy availability and environmental health. India has a huge advantage in terms of geography. Solar power is free and forever. It is clean and available everywhere.

In the desert zone is having abundant solar energy available and it is suitable for harnessing solar energy for a number of applications. In areas with similar intensity of solar radiation, solar energy could be easily harnessed. Solar energy can also be used to meet our electricity requirements through solar photovoltaic (SPV) cells and that solar radiation gets converted into dc electricity directly. This electricity can either be used as it is or it can be stored in the battery. This stored electrical energy then can be used at night but such systems are costlier one & restrict the application of solar for producing electricity. This energy can be used for cooking, heating, drying, distillation, power[17]. **Mekhilef. S et al. [1]** have concluded that presently, solar energy conversion is widely used to generate heat and produce electricity. It was found that solar thermal is getting remarkable popularity in industrial applications. **Panchal H. et al. [2]** have concluded that solar pasteurization system is used to kill harmful bacteria present in the raw milk. It is carried out in dairy industries with the help of boiler and using wood or coal for heating of the milk. **Thu S. M. et al. [3]** have concluded that refrigeration is the process of removing heat from substance or space to reduce its temperature and transferring that heat to another substance or refrigeration is providing and maintaining the temperature below that of the surrounding temperature **Wankhede U.S. et al. [4]** have concluded that for the chilling plant or ice plant prefer ethylene glycol is the better

option as a secondary refrigerant as per the requirement of the system **Sunaris M. L. et al. [5]** have concluded that pipe is a closed conduit, usually of circular section, which is used for carrying fluids under pressure. The pipe running partially full, in such a case atmospheric pressure exists inside the pipe and also behaves like an open channel. **Panchal H. et al. [6]** have concluded that due to use of fossil fuels for the human activities found a significant effect on the environment as well as people's health.

Farjana S. H. et al. [7] have concluded that in developing countries, industries and manufacturing sectors consume a major portion of the total consumption of energy, where most of the energy is used for low, medium or high temperature heat generation to be used for process applications known as process heat. **Alarcon J. A. et al. [8]** have concluded that the development of a solar parabolic dish collector prototype for rural areas with high solar resource availability which have no access to electricity service or budget resources to purchase a stove (electric or gas). The solar collector prototype proposes a solution to solve these kinds of issues and use sunlight to work it. **Sah R. P. et al. [9]** have concluded that as there is a time gap between milking and storage, milk spoilage is more in remote areas in India, hence, immediate pasteurization and storing facility is required. For pasteurization heating is compulsory. **Mohammed I. L. et al. [10]** has concluded that for effective performance the design requires that parabolic dish collector track the sun continuously and an automatic electronic control circuit was designed and developed for this purpose. **Rabab Zahira et al. [11]** have Calculated and Discovered Different techniques have been developed to make use of solar radiations such as solar milk pasteurizer and it is possible to pasteurize milk using solar energy

DESIGN OF SOLAR OPERATED MILK PASTEURIZATION SYSTEM -

with careful operation and the actual definition of pasteurization is; the heating of milk to a specific temperatures for a specific time to reduce undesirable enzymes and bacteria to negligible levels. **Zorraquino et al. [12]** have told that the Milk is a natural liquid food, is one of our most nutritionally complete foods. Milk contains bacteria when improperly handles create conditions where bacteria can multiply Antibiotic residues in milk due to use of antibiotics widely in food producing animals, supposed problems for the both dairy industry and consumers.

Marco Lucentini et al. [12-14] have analyzed that technical and economic feasibility of an innovative plant, through the operational simulations of each machinery, related to different radiation conditions during the year. The economic analysis has shown that this solution is worth-while, especially taking advantage from the incentives offered by the national campaign of renewable energy diffusion Moreover, For a correct sizing of a solar plant it is necessary to resort to economic evaluation methods, where the plant is to be considered as an integral part of the conventional plant. **Atia et al. [15]** they have described the application of solar collector in milk processing that involves liquid milk movement and it is an important operation which cannot be overlooked.

Muhammad Usama Yaseen et al. [16] have fabricated a solar milk pasteurizer from standard appliance shipping cardboard with multiple layers of the regular aluminum foil glued onto cardboard which was insulated with a large cardboard box which contained the rectangular area and a removable glass window has been used.

The design of each component of the proposed system is explained in detail here. While designing of each component namely parabolic dish collector, receiver, storage tank, ice plant.

Raw milk storage tank

For designing raw milk storage tank, where raw milk will be stored for the processing. Consider capacity of the tank is 100 liters.

We know that, volume of the tank is given by,

$$\left(\frac{\pi}{4}\right) d^2 * h = 50 * 10^{-3} \quad \dots(1)$$

Height of the tank,
 $h = 1.2 d$

Design of receiver

For designing the receiver system, at the bottom of which all the sun rays will be concentrated, consider 20 liters of milk is kept in the receiver.

The thickness of the stainless-steel sheet for the receiver is $t = 0.0015 \text{ mm}$

Let,

D = outside diameter of the receiver.

d = inside diameter of the receiver.

h = height of receiver

Volume of the receiver is given by, (Considering 20 liters tank)

$$\left(\frac{\pi}{4}\right) d^2 * h = 20 * 10^{-3} \quad \dots(2)$$

Assuming height of receiver (h) = 1.2 d

Specification of receiver

Effective surface area, (EFA) $EFA = (p/4) * D^2 + (\pi Dh)$

Design of parabolic dish collector

For designing the parabolic dish collector,

Let,

Concentration Ratio (C) = 10

Dish collector = outside diameter

A collector = Area of parabolic dish collector

C = Area of Collector / Area of Receiver

Area of collector = C * Area of receiver

The acceptable angle can be found out by

$$C = \frac{1}{\sin^2 \phi} \quad \dots(3)$$

Design of heater

Heat required to raising the temperature of milk from 30 °C to 74 °C is calculate by the formula,

$$Q = m * C_p * \Delta T \quad \dots(4)$$

Design of chilling plant

By considering annexure 2 evaporative temperature as 0 °C and condenser temperature as 50 °C, plotting graph on p-h chart.

From Ph graph we got below values,

$$h_1 = 402 \text{ KJ/Kg}$$

$$h_2 = 435 \text{ KJ/Kg}$$

$$h_3 = h_4 = 272 \text{ KJ/Kg}$$

Therefore,

$$(C.O.P)^{th} = \frac{h_1 - h_4}{h_2 - h_1} \quad \dots(5)$$

Refrigeration capacity (RC) required,

Let, 1 lit = 1 kg

$$R.C = Q = m * C_p * \Delta T$$

Mass flow rate of refrigerant,

$$m = \frac{R.C}{\dots} \quad \dots(6)$$

Work input required for compressor,

$$W_{comp} = m * (h_2 - h_1)$$

Selection of compressor

1. 1.5-ton capacity
2. Reciprocating compression
3. Model AW5522
4. Power electric 230v

Therefore, taking standard capacity as 1.5 Hp and selecting the whole system on the basis of compressor load.

Selection of condenser

1. Tube and fin type
2. Copper tube and al fins
3. No of turns and Length - 2 row and 300mm spacing 300mm

Selection of evaporator

1. Surface area approx. 1.3 m²
2. Coiled Tube type evaporator
3. Refrigerant = R22
4. Tube diameter = 3/8 inch

Selection of capillary tube

1. Internal diameter = 2 mm
2. Length = 2 m
3. Copper tube type

Design of solar system

Solar panel design

The first step in designing a solar PV system is

to find out the total power and energy consumptions of all loads that need to be supplied by the solar PV system as follows:

Total load = 1200 watt

Here, considering the total load is the combination of compressor load and condenser fan load.

Working time = 5 hr.

Total load = $1200 * 5 = 6000 \text{ Wh/day}$

Let's Consider 6 hrs. of peak sunshine,

Then Solar panel capacity = $6000 / 6 = 1000 \text{ W}$

For selecting battery, we should know the capacity of that battery so, we considering the voltage, efficiency and depth of discharge as per standard.

Let 24 volts battery

Efficiency of battery = 80%

Depth of discharge = 0.7

Battery capacity = $1000 / 0.7 * 0.8 * 24$

Battery capacity = 74.40 Ah

Therefore, 2 batteries having capacity of 74.40 Ah are selected due to this, 1000 W inverter is selected.

3.SYSTEM MODELLING AND ITS PARTS-

3D experience platform, a cloud-based software program, is used to model the major components. In this 3D model, various parts of the milk pasteurization process are represented, including a parabolic dish collector, receiver, intermediate receiver, raw milk storage tank, compressor, air cooled condenser, expansion valve, evaporator, solar panels, control panel, pump, testing and packaging unit. The 3D experience platform is cloud based software solution which is a product of Dassault systems which contains all the software's of Dassault

systemes such as Catia, solid works, simulia, delmia etc. The 3D experience platform allows you to save all the data on cloud and perform all the operations and modelling on cloud basis.

3.1 Raw Milk Storage Tank

The following Figure 1 shows that the 3D model of plastic made raw milk storage tank of having 50 liters capacity which is modelled in 3D experience platform.

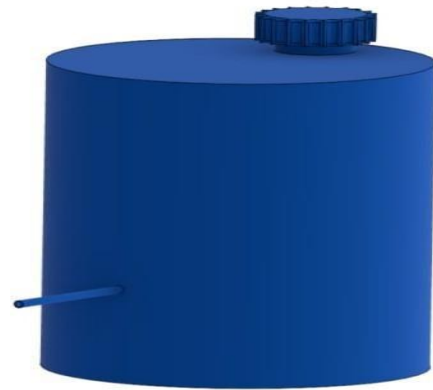


Figure 1. Model of Raw Milk Storage Tank

3.2 Parabolic Dish Collector

The following Figure 2. shows that the 3D model of parabolic dish collector having dish diameter 2 meter. Material of dish is galvanized steel. It is used to collect the sun radiations and concentrate on receiver to heat the milk



Figure 2. Model of Parabolic Dish Collector

3.3 Receiver

The following Figure 3 shows that the 3D model of receiver having 50 liters capacity. It is made up of stainless steel 316 food grade material. This part is used to store 50 liters of milk to heat by using parabolic dish collector.



Figure 3. Model of Receiver

3.4 Intermediate Receiver

The following Figure 4 shows that the 3D model of intermediate receiver having 50 liters capacity. It is made up of stainless steel 316 food grade material. The purpose of installing intermediate receiver is to reduce the temperature of heated milk in order to reduce load on chilling plant.

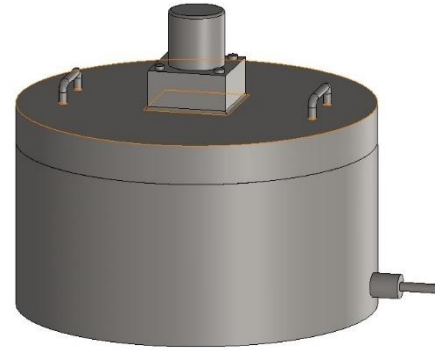


Figure 4. Model of Intermediate Receiver

3.5 Compressor

The following figure 5 shows that the 3D model of compressor having 1.5 TN capacity. It is the part of chilling plant. Purpose is commonly to compress the refrigerant as part of refrigeration process.



Figure 5. Model of Compressor

3.6 Chilling Plant

The following Figure 6 shows that the 3D model of chilling plant having 50 liters capacity wound with solenoid coil contains R22 refrigerant which circulating around the annular tank. This is the Actual section where

exchange of heat between refrigerant and milk happens. It is main section of system where all the heated milk is cooled at about 4°C . Plant

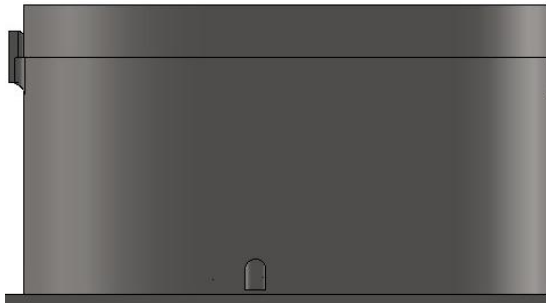


Figure 6. Chilling plant

3.7. Solar Panel

4. MODELING OF SYSTEM

The following Figure 8 shows that solar operated milk pasteurization system. This system modelling is done on 3D experience platform.

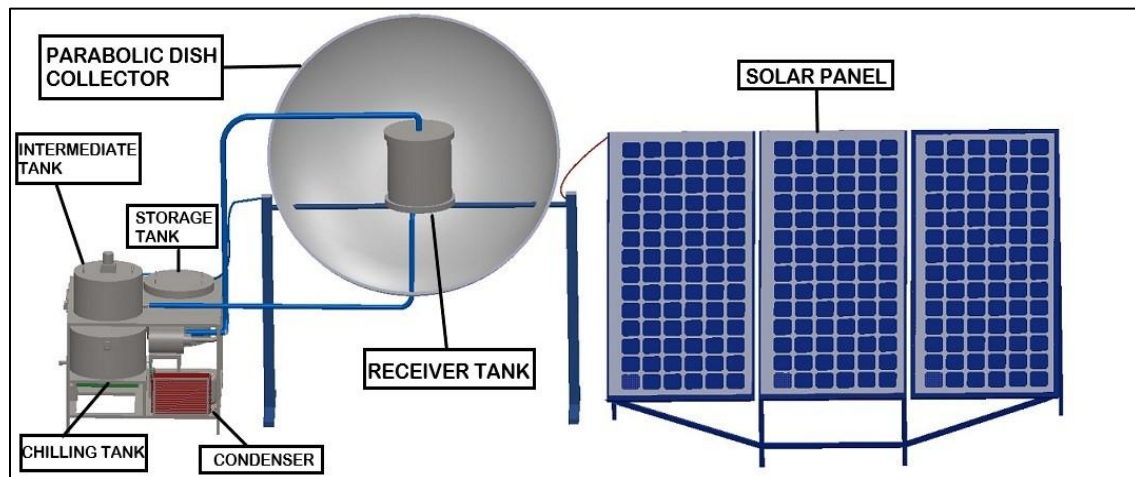


Figure 8. 3D Model of Milk Pasteurization System

Above model shows 3D model of solar operated milk pasteurization system drawn and assembled in 3D Experience software. Whole system contains parabolic dish collector, receiver,

The following figure 7 shows that the 3D model of solar panel having 1000 W capacity. The purpose of installing solar system is to fulfill the electricity need required for the chilling plant. The whole chilling system runs on solar system.

Figure 7. Model of Solar Panel



intermediate receiver, raw milk storage tank, compressor, air cooled condenser, expansion valve, evaporator, solar panels, control panel, pump, testing and packing unit with some purpose. As pasteurization process involves

heating of milk up to a specific temperature in order to kill harmful bacteria's which are harmful to human being and cooled at specific temperature to increase its life which indirectly means to stop bacteria growth.

Lactometer testing measures the amount of water in milk and is done in raw milk storage. All the collected milk is stored here and tested for lactometer. It works on the principle of specific gravity of milk. It consists of a test-tube and a meter bulb. The reading on the meter indicates how pure or impure your milk is. The deeper the bulb sinks, the more dilute/impure the milk.

Milk from raw milk storage is pumped to the receiver to heat. Where a solenoid valve is employed to check the quantity of milk coming from raw milk storage to receiver when it reaches up to 50 liters it automatically cuts off the supply. Here, the process of heating of milk is done by means of parabolic dish collector.

Parabolic dish collects all the sun radiations and focuses on receiver containing milk to heat milk up to 73°C. To check a desired the heating temperature, temperature scanners are installed. A temperature scanner is used to check temperature. When the infrared radiation falls on the thermopile surface, it gets absorbed and converts into heat. Voltage output is produced in

proportion to the incident infrared energy. The detector uses this output to determine the temperature, which gets displayed on the screen. This heated milk is then passed to intermediate receiver in order to precool the milk up to 35°C.

The purpose of precooling the milk is to reduce the load of chilling plant. This precooled milk is then passed to chilling plant where the temperature of milk is reduced to 4°C to increase its storage life. Chilling plant is the unit contains compressor, condenser, capillary tube and evaporator. A solar system of 1 KW is installed to provide the electricity needed for the chilling plant.

Here the process of actual pasteurization completes. In order to get feedback to the operator that the required temperature is achieved or not temperature sensors are installed near chilling plant. A temperature sensor measures the amount of heat energy or even coldness that is generated by an object or system, allowing us to "sense" or detect any physical change to that temperature producing either an analogue or digital output. After cooling of milk, it ready to get packed and dispatched to the customer. To pack this milk a manual hand operated milk packaging machine of 12 inches is provided. The complete process is requiring five hours to pasteurize 100 liters of milk per day

4.2 Material Selection of System

Table 1 shows the comprehensive material breakdown for each component of the solar milk processing rig, mapping the physical materials directly to their engineering purposes."

Table 1. Selection of Materials of System

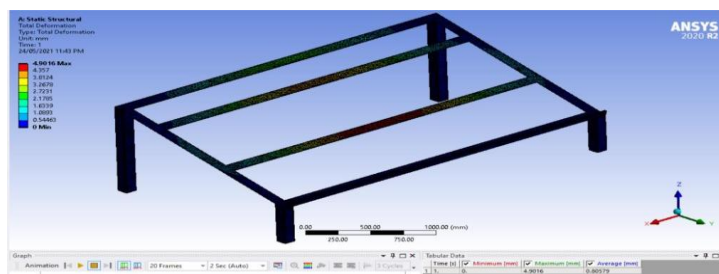
Components	Material used	Reason
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1.Parabolic frame	Mild steel	High strength, good elastic property,good weld ability, high rigidity & ductility, easily available & economical, easy to fabricate.
2. Supporting system for parabolic dish, receiver & heat exchanger	Mild steel	High strength, good elastic property,good weld ability, high rigidity & ductility, easily available & economical, easy to fabricate.
3. Storage tank & receiver	Stainless Steel	Good conductivity of heat, less corrosive, good surface finish, non-reactive with the milk.
4. Heat exchanger Shell & Coil	Stainless steel & Copper	Good conductivity of heat, less corrosive, good surface finish, non- reactive with the milk Less corrosive, easy to bend, economical
5. Ionized sheet	Anodized Aluminum (Wax Coated)	High reflectivity, good surface finish, less absorptivity, light in weight & reflectivity.
6. Sheet	Stainless Steel	Good reflectivity, high surface finish.
7. Flexible pipe	Stainless Steel	High temp carrying capacity
8. Valve ½”	Stainless Steel	High temp carrying capacity, light in Weight

5. ANALYSIS OF SYSTEM

5.1 Structural Analysis of Solar Panel Frame

It includes the structural analysis of solar panel



frame. It shows deformation of frame while in loading condition with different color. Each color shows the specific quantity of result of

Fig. Displacement of Solar Panel Frame

Figure 9. Displacement of Solar Panel Frame

In the above Figure 9 shows vertical rods of solar panel frame are fixed in three directions. Load of the solar panels is applied on frame in downward direction perpendicular to ground surface. Weight of solar panels is of 66 kg. Above result shows that with such inputs frame gets deformed and values of deformation in N/mm are shown with different colors. With such inputs the frame gets displaced to 4.90mm results in generating stress of 12.43 N/mm² shown in figure 7.2. The standard value of mild steel is having ultimate tensile strength 470 N/mm² and the yield strength is 370 N/mm². As per the analysis, the

5.2.1 Thermal Analysis of Heated Milk

analyzed part. Also, the specific areas are marked with the colors specifying more or less deformation in part.

stress developed in frame is 12.43 N/mm². As compare to the standard values, stresses developed and deformation happened is negligible. As per analysis design is safe

5.2 Thermal Analysis of Chilling Plant

It includes the thermal analysis of chilling plant tank at various temperatures. As part of pasteurization process, temperature of milk reduces from 35°C to 4°C. The variation of temperature in tank is displayed by various colors indicating different temperature in Kelvin.

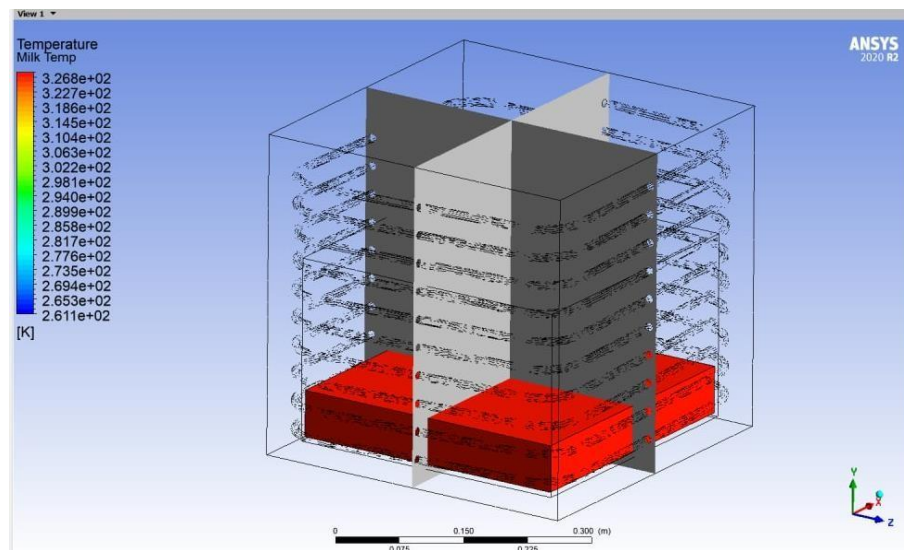


Figure 9. Thermal Analysis of Heated Milk

In the above Figure 9 shows that input temperature of chilling plant is 35°C which is to be cooled up to 44°C as per requirement. For

thermal analysis of milk, temperature input for tube is 0°C and that of glycol is -12°C is provided. While performing its function as per

the input, temperature of milk varies. This variation of temperature at base of tank is happening in milk due to temperature variation is shown in above result.

5.2.2. Temperature Distribution of Tube Wall in Cut Plane.

In the below Figure 10 shows that the temperature distribution of tube wall in cut plane. Temperature distributed due to temperature variation in tube and glycol. Here heating milk object is hidden. Red color around the edges shows higher temperature about 54°C as moves upwards color changes showing reduction in temperature of milk.

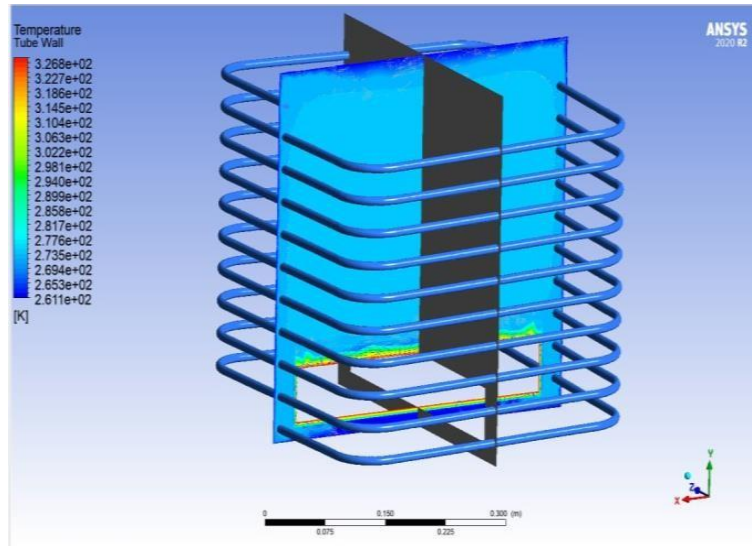


Figure 10. Thermal Analysis of System

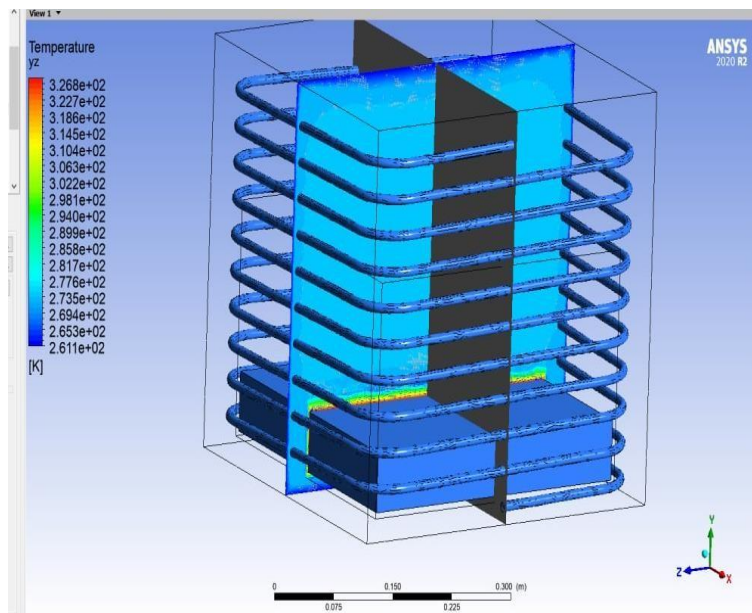


Figure 11. Temperature Distribution of Tube Wall in Cut Plane.

5.2.3 Temperature Distribution of Milk Tank

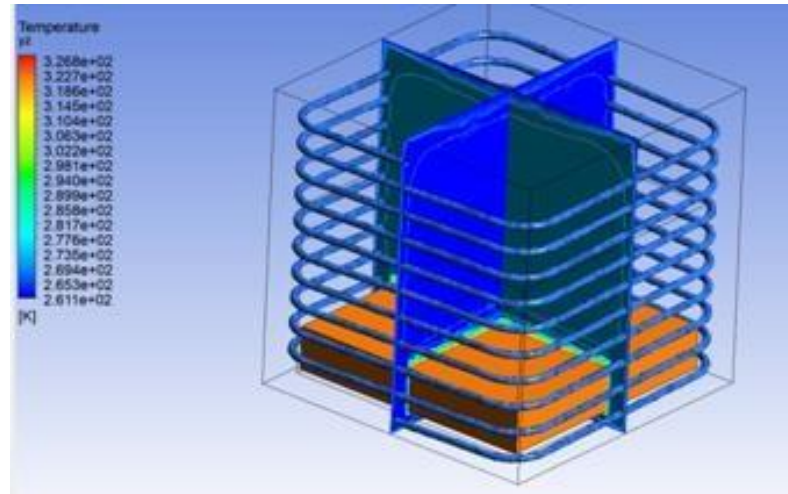


Figure 12. Temperature Distribution of Milk Tank

In the above Figure 12 shows that temperature distribution of milk tank. Figure shows milk temperature in the refrigeration tank up to 35 °C and it distributed through tubes. Milk temperature is 35 °C and glycol temp -12 °C.

6. CONCLUSION

Two cycles per day of pasteurizing 100 liters of milk produces 100 liters of milk ready for packing and sale in about 22:30. Two cycles per day result in 100 liters of milk pasteurized in one day. Based on structural analysis, the load applied to the panels develops stress of 12.43 N/mm², therefore, the panel frame material will not fail. Through chilling, temperature variations across a milk container are successfully achieved from 73°C to 4°C as indicated in the thermal analysis.

When it comes to the calculation of electric energy, we can generate 1000W of power from five hours of pick sunshine. Solar panels with a 1 KW capacity provide all of the electricity required for the chilling plant. With a 1500-watt

heater, one hundred liters of milk can be heated through AC power in a cloudy environment. Selection of stainless steel 316 food grade materials 1.2mm of sheet for parts coming in contact of milk of can sustain all variations of temperature. System sustains all the thermal changes happening in it. We can cut off the cost of electricity required for process. Selection of parts helps to reduce the overall cost. Payback period is near about 5 years. As per the analysis this project is practically possible.

With the development of this small size solar operated milk pasteurization unit people from rural background where sufficient amount of electricity, milk collection dairies, transportation facilities such things are not available can

pasteurize their own cows, buffalo's milk with less cost required. In such a system, people can eliminate the need for electricity for the pasteurization process by using renewable energy sources like solar energy. These units help milk-producing individuals from rural areas start their own businesses, which leads to economic support for their families. According to the material selection for the project, its physical properties, durability, structural analysis, and thermal analysis of selected parts, the following conclusions are made.

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