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Design and development of solar based incubation room for fermented dairy products

IA Chauhan and AG Bhadania

Abstract
Incubation at proper temperature is a mandatory step in the manufacture of fermented dairy products. The basic aim of the project was to design and develop a solar based incubation room to maintain 40-42 ºC temperature using solar thermal system in order to replace electrical air heaters which are traditionally used in dairy plants. The use of solar thermal energy not only helps in reducing the cost of energy but also contributes in combating adverse effect on environment. An experimental solar based incubation room having storage capacity of 100 crates was designed for the incubation conditions required for the manufacture of dahi. The system was equipped with hot water generation, storage, circulating pumps, instruments and controls. The performance of the system was evaluated in terms of solar fraction throughout the year.

Keywords: Solar energy, incubation room, design, room heating

1. Introduction

The demand for fermented dairy products especially dahi, chhass, probiotics and many functional fermented dairy products is increasing on account of realizing the health benefit of these products. In the manufacture of fermented dairy products, the milk after inoculation of suitable starter culture, it is kept in incubation room at constant temperature ranging from 37 to 45 °C depending on the type of the culture used for growth of the microorganisms. In most of the dairy plants, the electrical air heating system is being used to maintain the temperature of incubation room. The power consumption of the electrical heater is quite high depending on the ambient conditions, capacity of the incubation room and cost of electrical power. The continuous increase in energy demand, the degradation of environment through emission of greenhouse gases and the rise in fuel prices are the main driving forces behind the efforts for more effectively utilizing various sources of renewable energy. Rapid increase in energy usage characteristic of the past 50–100 years cannot continue indefinitely as finite energy resources of earth are exhaustible [1]. Therefore, there is a need to explore the use of renewable energy sources to meet the energy demand for various applications [2]. Solar energy is the one most abundant renewable energy source and emits energy at a rate of 3.8 × 1023 kW, of which, approximately 1.8 × 1014 kW is intercepted by the earth [3]. The primary forms of solar energy are heat and light. Sunlight and heat are transformed and absorbed by the environment in a multitude of ways [4]. The technology available to convert intensity of solar radiation into heat energy can be easily adopted for various applications. The utilization of solar energy for incubation rooms is an economical and environmental friendly alternative of using electrical air heaters. Therefore, there is a need to design and develop an experimental incubation room using solar energy.

2. Materials and Methodology

The major components of the experimental solar based incubation room are evacuated tube solar collectors having heat pipe, insulated hot water tank, incubation room with water to air heat exchanger and necessary measuring as well as control devices. The insulated incubation room was constructed using Poly Urethane Foam (PUF) panels. These panels were selected having stainless steel plate on both the sides with PUF as insulating material sandwich between SS plates. The water to air heat exchanger (Finned type) was installed in the incubation room to transfer the heat from water to air. The schematic diagram of the experimental system is shown in Figure 1.

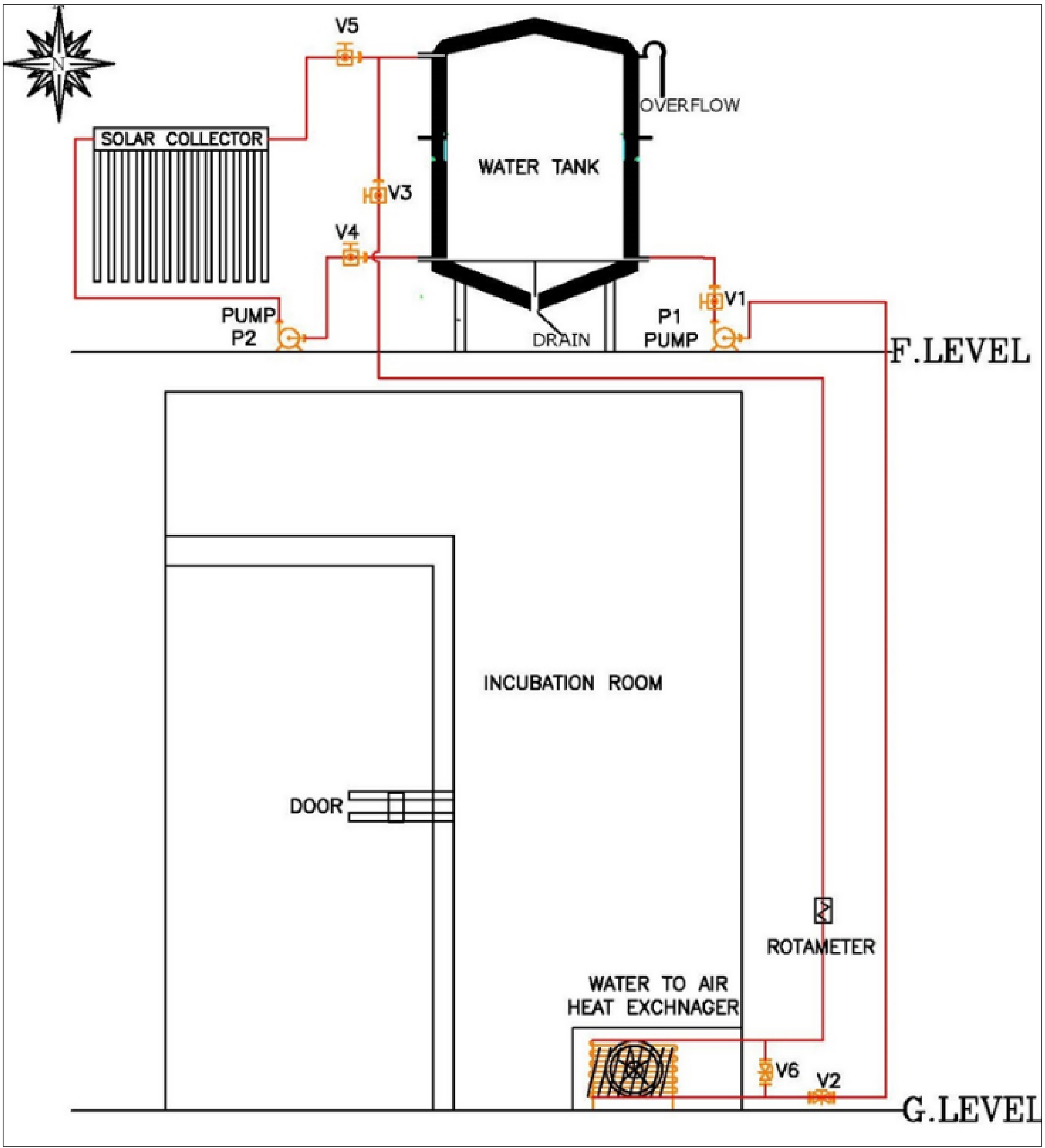

Fig 1: Schematic diagram of the experimental system

2.1 Dimensions of the experimental incubation room

The size of the incubation room depends on the storage capacity of the fermented products. The dimensions of the experimental incubation room are based on the incubation capacity of 100 crates. The incubation condition required for manufacture of curd (*dahi*) was selected as the fermented milk product for experimental trials as it is widely manufactured in organized dairy plants. In the industrial process for the manufacturing of curd, standardized curd milk after addition of starter culture is packaged in pouches which are kept in plastic crates and these crates are transferred in the incubation room where required temperature is maintained. The normal size of the crate used for curd pouches is 471 mm x 378 mm x 168 mm (L x W x H).

It is considered that 10 crates can be conveniently stacked which gives the stack height of about 1.68 m (168 mm x 10). Thus, the floor area required for the one stack is 0.178 m² (L x W = 471 mm x 378 mm). The incubation room has been designed for 10 stacks each of 10 crates which require 1.78 m² (0.178 x 10 = 1.78 m²) floor area. As per design consideration for cold storages and incubation room, the ratio of space for product storage to free space for movement is kept 60:40. Applying the same consideration, the free space requirement would be 1.19 m². Therefore, the total floor space required for incubation room is 2.97 m² ~ 3 m².

As the temperature of air increases, it rises upward and low temperature air goes downward. Looking to this phenomenon, it was decided to install air heater adjacent to one of the walls of the incubation room. Radiator type water to air heat exchanger was used for heating of air inside the incubation. The hot water generated in solar collectors was used for heating the air. It was necessary to keep about 1 m² floor area for installation of air heater in the incubation room. Therefore, total 4 m² floor area is required for incubation requirement of 100 crates for the manufacture of curd. The maximum stack height of the crates is 1.68 m but the standard height of 2.5 m was kept for the circulation of air and convenience of movement. Thus, the dimensions selected for the incubation room were 2 m x 2 m x 2.5 m (L x W x H).

2.2 Selection of material for construction of incubation room

The temperature of air and food material in incubation room is maintained at around 40 °C to 45 °C which is usually higher than the average indoor surrounding atmospheric temperature. In addition to this, the temperature difference between incubation room and environmental air becomes larger during winter months. Therefore, it was decided to use insulated panels for the construction of the incubation room. The pre-fabricated PUF (Polyurethane Foam) panels were used for construction of incubation room. These panels are light in weight, durable and having good insulating and water barrier properties. The specifications of PUF panels used for the construction of the incubation room are given in Table 1 [5].

Table 1: Technical specifications of PUF panels

Sr. No.	Parameters	Description
1	Insulation Material	Polyurethane foam
2	Average PUF Density	40 ± 2 kg/ m³
3	Temperature range	+ 90 °C to - 60 °C
4	Dimensions of panels used in walls	1 m × 2.5 m
5	Dimensions of panels used in ceiling	1 m × 2 m
6	Dimensions of panel used in door	1 m × 2 m
7	Fire Resistance	FR Grade (Fire Resistance Grade)
8	Wall & Celling Panel Facing material	SS sheet, Grade 304, 0.50 mm
9	Core thickness	50 mm
10	Material of sealant	Silicon

As PUF panels with SS sheet on both the sides are available, it was decided to use AISI 304 stainless steel PUF panels for construction of walls and ceiling of the incubation room for ease of cleaning and sanitation. The thickness of PUF was 50 mm having 0.43 W/m²K overall heat transfer coefficient of the PUF panel [5]. The door size was kept 1 m x 2 m (W x H) fabricated from the same type of PUF panels. The technical drawing of incubation room is provided in Figure 2.

2.3 Solar based Heating System for Incubation Room

The hot water generated in the array of solar collectors was being circulated in the heat exchanger placed in the incubation room. The estimation of energy required for the incubation room is necessary to select the capacity of the heat exchanger.

2.3.1 Thermal Energy Requirements for Incubation Room

Thermal energy required to maintain the temperature of incubation room mainly depends on the heat losses from the incubation room, temperature of the product entering in the room and surrounding environmental conditions. The calculations for heat energy required are based on the incubation temperature between 40 °C and 43 °C.

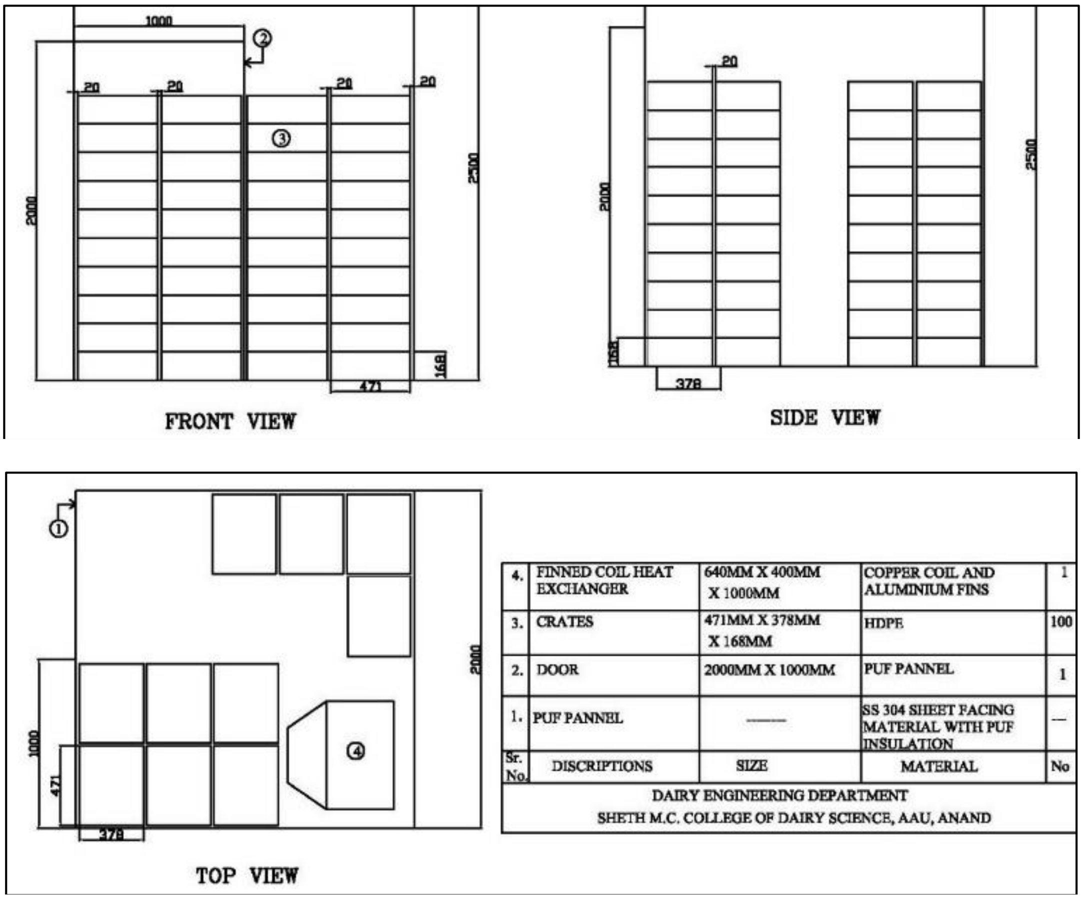

Fig 2: Technical drawing of incubation room

The thermal energy required is mainly for compensating heat losses from the structure of the incubation room and the heat needed to raise the temperature of the product to the incubation temperature. Therefore,

$Q_T = Q_a + Q_p + Q_c + Q_L$

Where,
Q_T = Total heat load required for incubation room
Q_a = Heat required to increase the temperature of air from room temperature to incubation temperature
Q_p = Heat required to increase the temperature of product
Q_c= Air change heat load
Q_L = Heat losses through walls of the incubation room

2.3.1.1 Determination of heat required to increase the temperature of air from room temperature to incubation temperature

In commercial dairy plants, incubation room is maintained at constant temperature and the incubated product on getting required acidity is transferred to cold storage while the new product is brought to the room for incubation. Therefore, heat loss from the structure of the incubation room and product load are contributing thermal energy required for maintaining the temperature of the air. In the present investigation, experimental trials were conducted batch wise and hence the thermal energy required to raise the temperature of the incubation room was also considered in each trials. Thus, the volume of incubation room will be 10.0 m^3 (V= L x B x H, i.e. 2 × 2 × 2.5)

Determination of mass of air in incubation room

$\rho_a = m_{a\,/\,V}$

Where,
ρ_a = Density of air = 1.23 kg/m^3 (Wikipedia)
m_a = Mass of air in incubation room (kg)
V = Volume of air in incubation room = 10 m^3
$m_a = \rho_a$ x V = 1.23 x 10 = 12.3 kg
The mass of air in the incubation room is 12.3 kg.
Now,

$Q_a = m_a \text{ x } s_a \text{ x } (T_2 – T_1)$

Where,
Q_a = Heat required to increase the temperature of air from T_1 to T_2.
m_a = Mass of air in incubation room = 12.3 kg
s_a = Specific heat of air = 1005 J/kg K (The Engineering Tool Box)
T_2 = Incubation temperature (°C)
T_1 = Initial temperature of air or atmospheric temperature (°C)

Different types of bacterial cultures are used for the manufacture of various types of fermented dairy products. The temperature of incubation room is required to be maintain in accordance with the optimum growing conditions for the starter culture. Mesophilic culture is used for the manufacture of curd from which different fermented dairy products like *Chakka*, *Chaas*, *Lassi*, etc. are manufactured. The optimum temperature for the mesophilic culture is around 37 °C. Yoghurt is very popular fermented dairy product all over the world which uses *Lactobacillus bulgaricus* and *Streptococcus thermophiles* culture having optimum growing temperature of 37 °C to 42 °C. In design calculations, 45 °C (T_2) was taken as incubation temperature. The ambient atmospheric temperature is seasonal which varies considerably. The ambient temperatures of Anand, Gujarat, India vary from 10 °C to 42 °C throughout the year and minimum temperature of 10 °C (T_1) was taken for design calculations. Therefore, the quantity of heat required to raise the air temperature from 10 °C to 45 °C of the incubation room,
$Q_a = 12.3 × 1.005 × (45 – 10) = 432.65$ kJ
The heat required to increase the temperature of air to incubation temperature is 432.65 kJ per batch. Though, it is applicable when the temperature of the incubation room after each trial comes to surrounding ambient temperature which will not be the case when the room is constantly maintained at required temperature and the products flow in and out.

2.3.1.2 Determination of Heat Required to Increase the Temperature of the Product

During the production of fermented dairy products, the milk is heated or cooled to the incubation temperature before inoculation of the starter culture. If the product enters at the incubation temperature, then thermal energy is not needed to raise the temperature of the product. However, there are chances of reduction in the temperature of about 2 to 5 °C during filling, packing and transfer of the product to the incubation room. It is considered that maximum temperature rise of product required is 5 °C to achieve incubation temperature. Thus,

$Q_p = m_p × s_p × (T_2 – T_1)$

Where,
Q_p = Heat required to increase the temperature of product from T_1 to T_2
m_p = Mass of the product in incubation room
s_p = Specific heat of product = 3.9 kJ/kg K
T_2 = Incubation temperature (°C)
T_1 = Temperature of the product when transferred in the room (°C)
The incubation room is designed for 100 crates (12 litre milk per crate). Therefore, the mass of the product,

$m_p = V_p × \rho_p$

Where,
V_p = Volume of the product = 12 × 100 = 1200 L
ρ_p = Density of the product = 1.035 kg/L
Therefore,

$m_p = 1200 × 1.035 = 1242$ kg

The mass of the product in incubation room is 1242 kg
Therefore,

$Q_p = 1242 × 0.93 × 5 = 5775.3$ kJ

The product load of the incubation room was 5775.3 kJ per batch of 100 crates.

2.3.1.3 Determination of air change heat load

The temperature of incubation room is normally higher as compared to immediate surrounding ambient temperatures. The air change load of the incubation room mainly depends on the frequency of door opening. In commercial large capacity incubation room the quantity of air change taking place is normally higher on account of transfer of product through service door. Leakage of air through the room is negligible as the room is air tight as all joints of walls and ceiling are properly filled. The actions of moving materials in or out of the cabinet, and persons going in or leaving incubation room causes air change load. Hence, the air change heat load is given by

$$Q_c = V \times A_c \times H_a$$

Where,
V = Volume of incubation room = 10 m^3
A_c = Air changes per 24 h = 29.5 [6]
H_a = Heat per m^3 = Q_a/V = 432.65 / 10 = 43.265 kJ
Q_c = 10 x 29.5 x 43.265 = 12763.18 kJ for 24 h
Normal incubation time for fermented dairy product varies from 3 to 4 h [7]. The incubation time has been taken as 4 h for design calculations. Therefore, the maximum 6 batches can be incubated per day and air change heat load of the incubation room would be 2127.2 kJ (12763.18 kJ / 6).

2.3.1.4 Determination of heat losses through the incubation room

The heat loss through wall, ceiling and floor of the incubation room is govern by overall heat transfer co-efficient of the wall and ceiling, surface area of the wall and temperature difference between incubation room and temperature of surrounding environment. Thus,

$$Q_L = U \times A \times (T_2 - T_1)$$

Where,
U = Overall heat transfer coefficient or heat transmission coefficient ($W/m^2 K$)
A = Area of heat losses through wall, ceiling and floor (m^2)
T_2 = Incubation temperature (°C)
T_1 = Initial temperature of air or atmospheric temperature (°C)
As per the specification of the supplier, the overall heat transfer coefficient value of the PUF panel used for the manufacture of the incubation room was 0.43 W/m^2 K. The overall heat transfer co-efficient value of the PUF panel was taken higher side as 0.5 W/m^2 K for determination of heat loss through the incubation room. The area of heat loss can be calculated as

$$A = 2 (2 \times 2) + 4 (2 \times 2.5) = 8 + 20 = 28 \ m^2$$

$$Q_L = 0.5 \times 28 \times (45 - 10) = 490 \ W = 0.49 \ kJ/s = 1764 \ kJ/h = 7056 \ kJ \text{ for } 4 \ h$$

The heat losses through the incubation room was calculated as 7056 kJ per batch
Therefore,

$$Q_T = 432.65 + 5775.3 + 2127.2 + 7056 = 15391.15 \ kJ \sim 15500 \ kJ$$

The total heat required in incubation room is 15500 kJ per batch. Considering 6 batch per day, the total heat required in incubation room is 93000 kJ per day (15500 x 6).

Therefore, the estimated heat energy required to compensate structural heat load for the incubation room was 93000 kJ/day.

2.3.2 Selection of heat transfer fluid

There are different fluids which can be used as service fluid in chemical and other industries. But, in dairy and food industry, water is widely used as service fluid for heating requirement as it is safe in dairy and food industry. It is efficient in heat transfer and having high specific heat capacity. In addition to this, water has high thermal conductivity, low viscosity and low thermal expansion coefficient. The hot water generated in solar collectors was circulated in water to air heat exchanger installed in the incubation room.

2.3.3 Design and development of the hot water storage tank

The storage of thermal energy is one of the very essential requirements to maintain the temperature of incubation room. The hot water produced in solar collectors during day time was used to maintain required temperature of the incubation room during day and night time. For this purpose, the hot water is required to be stored for its use during night time as well as during morning and evening time when solar radiations are not adequate. The hot water storage tank was fabricated and was install on the terrace of Dairy Engineering Department, SMC College of Dairy Science, AAU, Anand. The heat losses through the tank takes place due to temperature difference between hot water in the tank and surrounding ambient temperature together with higher velocity of air on the terrace. Stainless steel AISI 304 grade was used for fabrication of hot water tank due to its advantages in terms of corrosion resistant, contamination, strength, useful life and cleanability as compared to any other metal. Glass wool of 100 mm thickness was used as an insulating material for the cylindrical tank. Aluminium sheet was used for cladding material over the insulation.
The size of the tank is an important point for deciding the thermal storage capacity of the system. Higher hot water storage capacity increases the heat storage capacity which increases the backup time to maintain incubation temperature of the room. Estimating thermal requirement during night hours, it is decided to fabricate water tank having 2000 kg (2000 L = 2 m^3) water storage capacity. The tank was fabricated using 3 mm thick SS 304 sheet. The technical specifications of the hot water tank are given in Table 2. It was necessary to provide ten ports on the insulated storage tank. The description of these ports is given in Table 3. The technical drawing of the hot water tank is shown in Figure 3.

Table 2: Technical specifications of the hot water storage tank

Sr. No.	Particulars	Description
1	Height of the bottom conical part of the tank (h_1)	254 mm
2	Height of the cylindrical part of the tank (h_2)	1500 mm
3	Height of the top conical part of the tank (h_3)	152.4 mm
4	Internal diameter of the tank (d_i)	1268 mm
5	Outer diameter of the tank (d_o)	1274 mm
6	Material for insulation	Glass wool
7	Thickness of the insulation	100 mm
8	Number of ports	10

Table 3: Description of the ports of hot water storage tank

Sr. No.	Particulars of the ports	Numbers	Diameter (mm)	Location in the tank
1	Ports for provision of auxiliary electric heater	03	63.5	Bottom part of the cylindrical shape of the tank
2	Ports for Inlet and overflow	02	25.4	Top part of the cylindrical shape of the tank

3	Ports for outlet (one for incubation room and one for solar collectors)	02	25.4	Bottom part of the cylindrical shape of the tank
4	Ports for sensors	02	12.7	Centre part of the cylindrical shape of the tank
5	Port for drainage of high TDS water or for cleaning purpose	01	25.4	Bottom part of the tank

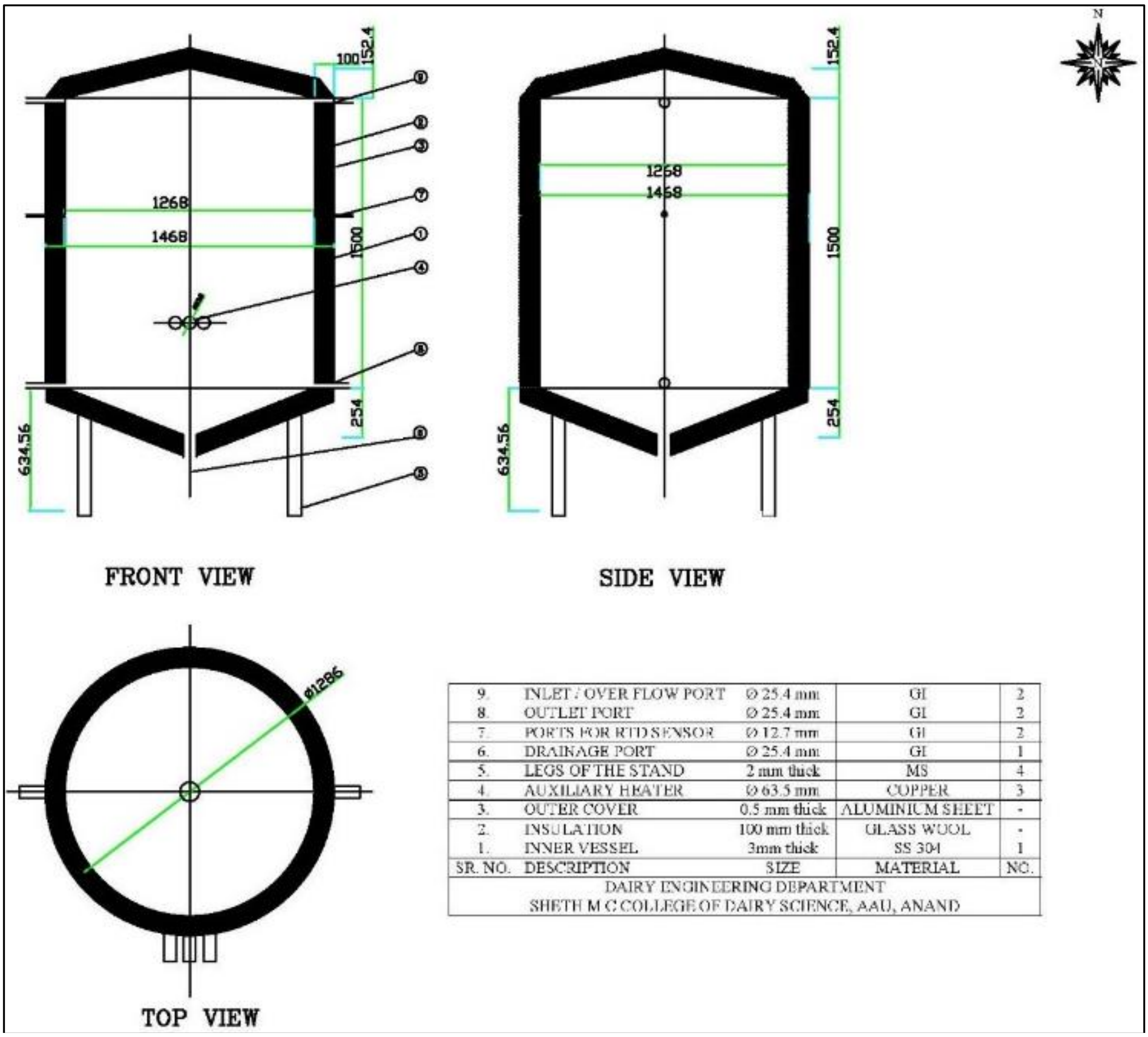

Fig 3: Technical drawing of the hot water storage tank

2.3.4 Selection of type and capacity of solar collectors

Looking to advantages of evacuated tube (ET) over flat plate collector (FPC) in terms of higher collector efficiency and minimum maintenance, ET solar collectors were selected. Evacuated tube collector (ETC) with heat pipe gives higher temperature in hot water generation as compared to ETC without heat pipe even at lower solar radiation. Considering the average solar intensity of the area and requirement of heating water from as low as 10 °C in winter season to around 70 °C, ETC with heat pipe system was selected for the incubation room system.

The capacity of the solar collector depends on the efficiency of the solar collector and total heat requirements of the system. The total requirements of the heat energy is the sum of heat energy required in the incubation room, heat losses through the wall of the hot water storage tank and heat energy losses through hot water circulation system.

It is estimated that minimum 70 °C temperature of hot water is necessary to achieve to avoid uninterrupted supply of hot water to the incubation room throughout the night even in winter to maintain required temperature.

The total area of the hot water tank was calculated from the following formula

Total area of tank = Area of the bottom conical part of the tank + Area of cylindrical part of the tank + Area of the top conical part of the tank

$$A_T = A_{LC} + A_C + A_{TC} = \pi\, r_m\, (h_1^2 + r_m^2)^{1/2} + 2\, \pi\, r_m\, h_2 + \pi\, r_m\, (h_3^2 + r_m^2)^{1/2}$$

Where,

A_T = Total area of the hot water tank (m²)

A_{LC} = Area of the bottom conical part of the tank (m²)

A_C = Area of cylindrical part of the tank (m²)

A_{TC} = Area of the top conical part of the tank (m²)

r_m = Mean radius of the hot water tank = $(d_i + d_o)/4$ = 0.6355 m

A_T = 8.656 m²

Therefore, the surface area of the hot water tank 8.656 m² was taken in design calculations. Preliminary trials were conducted to determine the U value of the insulated storage tank and it was found to be 0.8 W/m²K.
The heat loss (Q_L) through the surface of hot water tank was calculated from the following formula.

$$Q_L = U \times A \times (T_2 - T_1)$$

Where,
U = Overall heat transfer coefficient or heat transmission coefficient = 0.8 W/m²K
A = Surface area of the hot water tank = 8.656 m²
T_2 = Temperature of water in hot water tank = 70 °C
T_1 = Atmospheric temperature of air on terrace where tank was installed = 10 °C
Q_L = 415.488 W = 35898 kJ per day
The heat losses through the hot water circulation system was taken as 5 % of total heat losses.
The total heat requirements from solar collectors = (93000 + 35898) x 1.05 = 135342.9 ~ 135000 kJ/day
The average global solar irradiation play an important role in calculation of area of solar collector. The average solar irradiation is taken as 500 W/m² in Anand, Gujarat region for calculation of area of solar collectors [8].
Now,

$$\eta_c = Q_T / (A_c \times G_t)$$ [9] [10] [11]

Where,
η_c = Efficiency of solar collector = 70% = 0.7 [12]
Q_T = Heat energy to be supplied by collector or required by the system = 135000 kJ/day = 3409 W (Considering 11 hour sunshine per day)
A_c = Aperture area of solar collector (m^2)
G_t = Global solar irradiation in different seasons (W/m²) = 500 W/m².
Therefore,

$$A_c = 9.74 \sim 9.75 \text{ m}^2$$

The commercially available ETC-HP tube having 1700 mm length and 47 mm diameter has 0.25 m² (0.125 m² aperture area) solar radiation collector area per tube. Therefore, the number of ETC-HP required are 78 (9.75 m² area) to meet the requirements of the incubation room. The supplier of the solar collectors provides 20 tubes per system. Therefore, 4 systems (80 tubes with 10 m² aperture area) were selected for the experimental solar collector system.

2.4 Design and development of water to air heat exchanger

The rate of heat transfer from hot water to air is a basic requirement to achieve desirable temperature of air in the incubation room. A mechanical draft water to air type heat exchanger was selected for heating of air in incubation room with the help of hot water produced by solar collectors. The heat transfer in the heat exchanger is very complex phenomenon affected by several factors such as flow rates, Reynold's number, area of heat transfer, type of fluid used as heating media, type of fluid to be heated and many other inter related factors. Finned coil type heat exchanger is generally used for heating or cooling of air. Looking to application of the finned coil type heat exchanger, it was decided to use induced draft finned coil type heat exchanger for heating of air in incubation room.
The selection of material for fabrication is also very important criteria for design and development of the heat exchanger. The thermal conductivity of copper is high and in majority of evaporator and condenser in domestic refrigeration system, copper is used as a material of construction for coil. Therefore, copper and aluminum were selected as material of construction for the coil and fins respectively.

2.5 Design and development of the hot water circulation system

Hot water circulation system is very important part of the solar based incubation room. The water circulation system requires one pump and pipeline for circulation of water from hot water storage tank to solar collectors to increase the temperature of water. One another pump is also required to circulate the hot water through heat exchanger of incubation room to increase the temperature of the air in the incubation room.
The pipelines are required to circulate the hot water through pump, hot water tank, solar collectors and finned coil heat exchanger. The composite piping system with insulation was used for the system as it is flexible with strength, low frictional coefficient, ease of application, long life and low heat conductivity.
The composite pipes are having pressure rating of 13.8 kg/cm² at 23 °C and 11.0 kg/cm² at 60 °C. The composite piping system can safely be used for 6 kg/cm² pressure at 80 °C working temperature.

2.6 Instrumentation and process control system

The operation of the incubation room at specific temperature is very difficult without instrumentation and control. It is necessary to incorporate required sensors and controls in order to maintain set value of temperature in the incubation room. The operation of the hot water pump is regulated based on the temperature of the room. Resistance temperature detector (RTD) as well as control panel which control the temperature in the room by starting and stopping of the hot water circulation pump. Performance evaluation of the system requires data logger to know the on and off cycles of the pump and other parameters. The specifications of the data logger with sensors are shown in Table 4.

Table 4: Specifications of the data logger and different sensors

Name of the item	Specifications
Digital multi-channel data logger	Digital microprocessor based 16 channels (12 channels for temperature, 3 channels for relative humidity and one channel for solar intensity) data logger to record the data from different types of sensors. Facility for storage of data, membrane keyboard for easy selection and programming, built-in clock and calendar, real time data recorder, sampling time can be set from 1 second to 3600 seconds.
Air temperature sensors (3 numbers)	Pt_{100}, 0 °C to 199 °C temperature range with required length of cable.
Water temperature sensors (5 numbers)	Pt_{100}, 0 °C to 199 °C temperature range with length of cable.
Relative humidity sensors (3 numbers)	0 to 99 % RH range with necessary cable length.
Solar Intensity sensor (1 number)	Measuring unit W/m^2. Cosine corrected < 5 % for angle 60°.

2.7 Installation and commissioning of the system

It is necessary to install all the components of the system in appropriately for proper working and ease of operation of the system. The Figure 4 shows the installation of actual Solar hot water heating system with ETC-HP installed on the terrace of the Dairy Engineering Department, SMC College of Dairy Science, AAU, Anand, Gujarat, India. The Figure 5 shows the incubation room fabricated in one of the laboratories the department located on first floor below the solar water heating system.

3. Result and Discussion

The performance of the designed solar based incubation room was evaluatted in term of solar fraction (SF). The solar fraction is the ratio of amount of thermal energy supplied by the solar thermal system to the total energy required for the incubation room [13]. The value of SF for any heating system in which a part of the thermal energy is supplemented by auxiliary heating varies from 0 to 1. It is obvious that higher value of SF is desirable as it indicates higher amount of solar energy available in comparision with the total thermal energy required for the heating system. When total energy required is achieved from solar thermal system, the value of SF becomes one and it is zero when entire thermal energy required is used from auxiliary heating arrangement. The values of solar fraction of the incubation room during experimental period from April 2017 to March 2018 as shown in Table 5. The solar fraction of the system ranged from 0.81 to 1.00 throughout the experimental period.

Fig 4: Solar hot water heating system with ETC-HP

Fig 5: Incubation room

The solar yield per day in different months during experimental period ranged from 82.6 to 116.2 MJ/day. The solar intensity in summer months (March to June) is higher but the solar yield per day is lower as compared to winter season (November to February) due to less heat requirements in incubation room as the atmospheric temperature is higher which causes less heat losses. The average solar intensity in monsoon season (July to October) was lower which resulted into lower solar yield per day. The auxiliary heating requirements is the difference between total heat requirement for the solar based incubation room and solar yield. Table 5 shows the auxiliary heat requirements which ranged from 0.0 to 25.1 MJ/day which was supplied by the electrical heater installed in the hot water tank.

Table 5: Solar fractions in different months of experimental study

Sr. No.	Month	Solar Yield per Day (MJ)	Auxiliary Heating Requirement per Day (MJ)	Solar Fraction
1	April – 17	96.2	0.0	1.00
2	May – 17	101.3	0.0	1.00
3	June – 17	91.2	0.6	0.99
4	July – 17	84.3	10.1	0.89
5	August – 17	82.6	11.2	0.88
6	September – 17	88.7	6.4	0.93
7	October – 17	107.2	3.0	0.97
8	November – 17	112.5	4.2	0.96
9	December – 17	106.1	25.1	0.81
10	January – 18	116.2	10.5	0.92
11	February – 18	112.8	5.3	0.96
12	March – 18	94.3	0.0	1.00

4. Conclusion

The solar thermal system can be used to generate hot water during day time and that can be utilise to maintain the temperature of incubation room. The designed solar based incubation room is working good in all season with solar fraction of the system during experimental period ranged from 0.81 to 1.00 respectively. It was found that supplementary thermal energy was not required for nearly 4 months of the year while during remaining months supplementary thermal energy requirements was 8-9 % of the total thermal energy required to maintain desirable temperature of the incubation room.

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