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Design of a Solar Pond as an Energy Storage System for the Pasteurization process in Dairy Industry

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Abstract: ***The usage of solar energy started from the ancient time. After a remarkable increase in oil prices, various countries started extensive research and development in utilization of a solar energy. There are various methods to store this solar energy and solar pond is one of them.Solar ponds are nothing but pools of salt water which store solar energy. Salt water naturally forms a salient gradient in which low salinity water floats on high salinity water. High salinity water does not mix readily with the low salinity water above it. When bottom part of a pool is heated, convection occurs separately in two layers which results in a decrease in the heat loss. This phenomenon allows the high salinity water to increase the temperature of the water up to 90℃.In a dairy industry, the pasteurization process plays a crucial role. Pasteurization is a process which kills microbes and bacteria in food and beverages. This process was invented by French Scientist, Louis Pasteur in 1864. In this process food or beverage is heated at an appropriate temperature and held at that temperature for a certain time and then cooled. As the output temperature from solar ponds can be up to 80 ° C (176 F), the energy from a solar pond can be used for the pasteurization method in a dairy industry. In a dairy industry where daily production of milk is around 85000 liters, required pond area is 2172 m2. If an existing coal or a natural gas boiler system is replaced with a solar pond as an energy storage, 160 tons and 90 tons of carbon dioxide emissions can be reduced respectively per month.***

Keywords: Solar pond, Pasteurization process, Renewable energy, Energy storage

1. Introduction

1) Solar Pond

Solar Energy is an abundant and renewable source of energy. Average daily solar irradiance in India is 5 kWh/m2. Hence this energy can be collected over large areas. It is also an intermittent energy hence solar energy systems require an energy storage system in order to meet the energy needs during nights.

Solar ponds are nothing but pools of salt water which store solar energy. Salt water naturally forms a salient gradient in which low salinity water floats on high salinity water. High salinity water does not mix readily with the low salinity water above it . When a bottom part of pool is heated , convection occurs separately in two layers which results in reduction of heat loss . It allows the high salinity water to reach temperature up to 90℃. So this water can be used as the thermal energy storage.

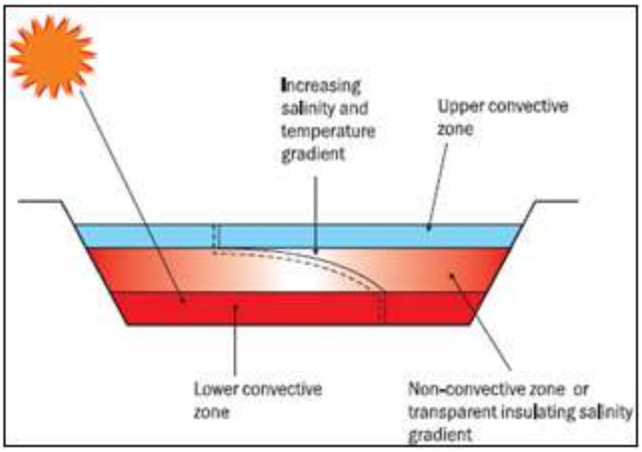

Figure 1: Zones of solar pond [22]

As shown in fig.1.1, solar pond consist of three zones. First zone is upper convective zone, second is non convective zone which is in the middle and acts as an insulating layer and third is a lower convective zone which acts as an actual thermal storage

There are three main categories to design this type of a thermal storage system. The first step is to calculate the required area of a pond according to the requirement. The second step is to fix the constructional dimensions of a pond including salt dissolution. The last step is to analyse the thermal behavior of a solar pond. These steps are explained in detail as below,

2) Construction

The steps followed for the construction of a solar pond are,

3) Site planning and excavation

There are several requirements for a site to be considered suitable for a solar pond.

- Access to water
- Access to salt
- Low wind speed
- Relatively flat site
- Soil with good cohesion for walls

4) Lining of a solar pond

The lining of a solar pond plays an important role in the thermal behavior of the system. Most common materials used for the lining are clay, LDPE film and bricks. Usually after excavation, the thick layer of clay is applied in the pond. This layer is followed by LDPE film which is fixed with thermally welded joints. It is followed by another layer

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of clay and finally bricks lining on the side of slopes filled with cement.

Salt dissolution

The most commonly used salts for solar ponds are Sodium Chloride and Magnesium Chloride. In this method, the top layer of a pond is pumped in the mixing tank then salt is added in the mixing tank. This concentrated brine is again pumped in the bottom part of a pond. (Fig.1)Hydrochloride acid and copper sulphate is also added in the brine for algae control [8]

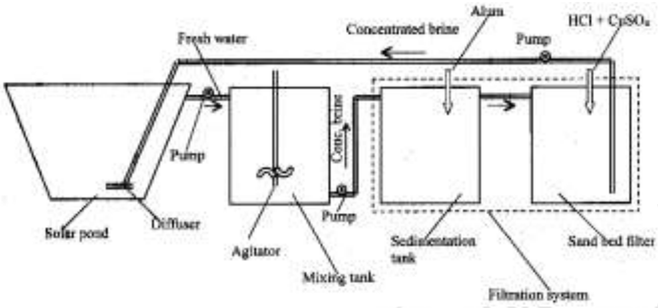

Figure 2: Salt dissolution and filtration system [8]

5) Thermal behavior

Thermal behaviour of a solar pond includes input solar radiation, absorption of solar energy in salt water, heat flow in the pond, thermal efficiency of pond and heat losses. Heat loss is most important factor in terms of performance.

6) Pasteurization Process

In a dairy industry, pasteurization process plays a crucial role to kill microbes, bacteria from milk to increase the shelf life of a product. Most commonly used pasteurization process are batch pasteurization and HTST (High temperature short time) pasteurization [6]. In batch pasteurization milk is heated at 62 ˚C for 30 minutes and in HTST pasteurization milk is heated at 75 ˚C for 15 seconds [12]. Generally energy required to heat milk is provided by boilers by burning non-renewable energy sources like oil, wood, coal etc.

As there are harmful environmental impact of using non-renewable energy, the whole world is heading towards the maximum use of renewable energy [21]. Hence to meet the requirement of energy load for pasteurization process also renewable energy source can be used.

2. Literature Survey

The concept of solar pond first appeared in the scientific literature in 1902. Kalecsinsky [1] observed Medve Lake in Transylvania, Hungary and he wrote the first report on the natural Solar Lake. Medve lake had the temperature around 70 ° C,at depth of 1.3 m. M. Rozsa [2] later confirmed the salinity gradient measurements and explained the temperature phenomena and seasonal temperature variation.

Research on artificial solar ponds started in 1950 by Dr. R. Bloch [3] , research director of the Dead Sea Works in Israel. In 1970, solar pond activities were reviewed and became national project. Since 1970, four solar ponds have been constructed in Israel. In the USA, Prof. Nielsen [4] initiated research in 1974. He solved many practical problems regarding the construction of the ponds including the problems of internal convection, the insulating layer and algae growth.

In 1999 Amit Kumar and V.V.N.Kishor presented constructional and operational experience of a 6000 m2 pond with analysis of constructional parameters and materials for the lining of a solar pond including various methods for protection of a pond from algae and wind disturbance.[8] In 2005, M.M.O.Pah and A.Belghith studied the temperature and salinity profiles development of a solar pond in a laboratory and presented the salt concentration range required for the maximum recovery of a heat from a solar pond. [10]

Currently there are various solar pond systems which are running in various parts of the world. For example, Israel- 21000 m2, India- 6000 m^2, Egypt-10000 m^2, Australia- 3000 m^2, USA- 3200 m^2. These countries are doing research and developing highly efficient solar ponds. [8][13][14]

3. Methodology

Steps followed in this paper to design a solar pond are as follows,

1) Production estimation- Firstly the total production of a system has been estimated according to the available equipment specifications for pasteurization process.
2) Calculations of heat requirement of a system - The heat required for a process of a estimated amount of milk has been calculated.
3) Available heat calculations - The available heat at an assumed location has been calculated according to the radiation data.
4) Calculation of area of a pond - Area of a pond has been calculated using heat requirement and available heat.
5) Dimensioning of a pond- Solar pond dimensions have been calculated according to the available information.
6) Salt concentration- The required salt concentration has been calculated for a pond.
7) Thermal efficiency- The thermal efficiency has been calculated using available formulas.

4. Measurements and calculations

4.1 Requirement of a system

Assuming available pasteurization equipment – Dairy Heritage 500 Gallon pasteurizer [12]

Hence the total milk production per batch = 500*3.78 = 1890 liters.

As a time per batch is 30 minutes. The total number of batches per day including time for a charging and discharging of a milk from a pasteurizer can be 45 batches.

Total milk production of plant is 1890*45= 85050 liters.

Heat required to raise the temperature from 4˚C to 62˚C can be calculated as,

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$$q = m * Cp * \Delta T$$

$$q = 85050\,kg * 3950\frac{J}{kg\,{}^{\circ}C} * 58^{\circ}C$$

$$q = 19484.9\,MJ$$

$$q = 5412.47\,kWhperday$$

Total heat required for the process,

As general effectiveness of a heat exchanger is between 0.6 to 0.9 so assuming a total 30% heat loss in the heat exchanger,[15]

$$Q = q + q(0.30)$$

$$Q = 5412.47 + 5412.47(0.30)$$

$$Q = 7036.211\,kWhperday$$

Now area of a pond can be calculated as,

$$Areaofpond = \frac{Heatrequired}{Heatavailable}$$

Heat available can be calculated as,

Total Heat Gain by LCZ-NCZ Interface

$$Qin = Ho * \mathrm{h}(x)$$

Ho = Solar irradiance

H (x) = Fraction of solar irradiance received at depth (x) from top of pond

Now,

Ho = 5.34 kWh/ m^2 per day

= 667.5 W/ m^2 – Assuming 8 sun hours daily.

Using equation which gives amount of solar radiation reaching a certain depth, [9]

h(x) = 0.28-0.08 ln(x)

h(2.1) =0.28-0.08 ln(2.1)

= 0.2206

Therefore,

$Qin = 667.5 * 0.2206$

= 147.25 W/ m^2

Therefore,

$$Areaofpond = \frac{7036.21\,kWh}{147.25\,W/m2}$$

$$Areaofpond = \frac{293175.41\,W}{147.25\,W/m2}$$

$$Areaofpondrequired = 1991.004\ \mathrm{m2}$$

Hence Area of pond required for lower convective zone – Non convective zone interface is approximately 2000 m^2

4.2 Construction and lining of a solar pond

Based on the requirements of a solar pond area, barren land in the state of Gujarat (Solar irradiance- 5.34 kWh/m^2 per day), [11] India has been selected for the construction of a solar pond. The total area of 2000 square meter for Lower convective zone- Non convective zone interface is fixed (50 m * 40 m).

By analyzing the construction of the established plants, the following data is assumed for the construction of this design project. [8]

Depth of the plant - 3 m

Layer of clay- 40 mm

LDPE film thickness- 60 mm

Layer of mixed clay- 50 mm

Bricks lining on both slopes - 45°

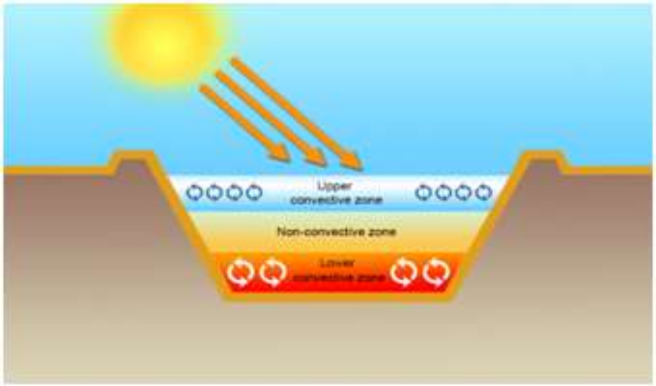

Figure 3: Zones of a solar pond [16]

The main task in the constructional design of a solar pond is to establish the thicknesses of zones (Fig.2). These thicknesses have been established by the previous research done by the other existing plants. [8] [9]

Establishment of an upper convective zone (UCZ) thickness:-

For maximum solar energy collection upper convective zone thickness could be between 0.2 m to 0.4 m. [8] [9]

Establishment of a lower convective zone (LCZ) thickness:-

Lower convective zone depth has been found to have a value of 0.9m for UCZ thickness of 0.4 m. [8] [9]

Establishment of a non-convective zone (NCZ) thickness:-

As the total depth of a plant has been selected as 3 m, thickness of non-convective zone becomes 1.7 m. [8] [9]

4.3 Dimensions of a solar pond

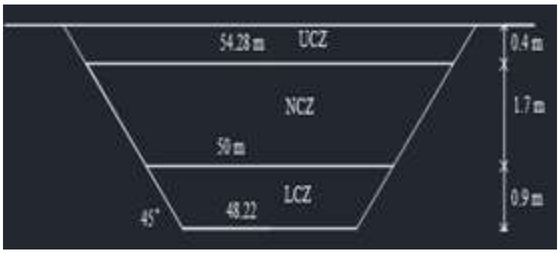

Figure 4: Dimensions of a solar pond [20]

As shown in Fig.3,

LCZ-NCZ interface area = 2000 m^2 = {50.m*40m}

Bottom floor area = 40 * (50-2*(0.89))

= 1928.8 m^2 = {48.22 m * 40m}

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Top surface area= 40*(50+2(2.14))
= 2171.2 m^2 = {54.28m*40m}
Hence total surface area required is 2171.2 m^2

Slope of the sides of a pond is 45°

$$TotalVolumeofpond = L * H * \frac{A + B}{2}$$
$$= 40 * 3 * \frac{48.22 + 54.28}{2}$$
$$= 6150 \text{ m3}$$

4.4 Salt dissolution

The sodium chloride salt is selected for the system. Concentration of 27 % is assumed for the process. The reason behind this is, for solar ponds, required salt concentration is 20 % to 30% [10]. To get 0.27 Kg salt/Kg solution, mass of a salt required is given by

$$ConcentrationofSalt\% = \frac{\text{Mass of salt}}{Massofsalt + Massofwater} * 100$$

$$Massofwater = 6150 \text{ m3} = 6150000\text{liters}$$

$$Massofsalt = 2274657\ Kg = 2275\ Tonnes$$

4.5 Thermal efficiency

The thermal efficiency of a pond is calculated as

$$\eta = \frac{Qu}{I}$$

Q_u =Useful Heat Extracted
I =Solar Energy incident on the pond
I= 5.34 kWh/ m^2 * 2171.2 m^2 = 11594.208 kWh

Therefore,

$$\eta = \frac{293.17\ kW}{1449.27}$$

$$\eta = 0.2022 = 20.22\%$$

5. Working

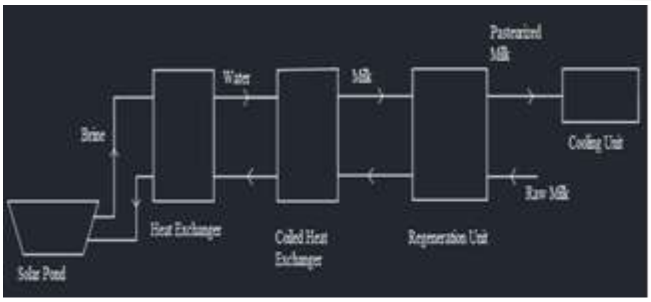

Figure 5: Schematic diagram of system [20]

As seen in (fig 4) this system consists of a solar pond as an energy storage including two heat exchangers and a regeneration unit. Once a solar pond is fully charged, the system will start and water will run through the heat exchangers. The reason behind using two heat exchangers is, it will eliminate the chance of spoiling the whole batch of milk if there is some leakage. Once the required temperature is achieved, the flow stops and temperature is maintained. If temperature goes below required range, the flow starts and required temperature is achieved. Raw milk is preheated in regeneration unit using the heat from the pasteurized milk. After going through regeneration unit, the pasteurized milk goes to cooling unit for further process.

6. Comparison

The total amount required to generate 1 kWh energy for a coal and natural gas is 0.00052 short tons and 0.01011 Mcf respectively. Presented system requires 162374.1 kWh per month. It means to fulfill this requirement, 84 tons of a coal or 1641.60 Mcf of a natural gas is needed. Coal emits 2.17 pounds of CO2 per kWh and natural gas emits 1.22 pounds of CO2 per kWh. [17]

If we use coal in this system, it will generate 160 tons of CO2 per month and if we use natural gas in this system, it will generate 90 tons of CO2 per month. Hence we can conclude that if we replace the coal or natural gas water heating system in the industry with a solar pond we can reduce 160 tons and 90 tons of carbon dioxide emissions respectively per month.[18] [19]

7. Conclusion

The concept of a solar pond as an energy storage system for industries has been taken for research by various countries. This design of a solar pond depends on the different factors like solar irradiance, wind velocity, ambient temperature and most importantly on the requirement of a system for which it is going to be used. Maximum efficiency can be achieved by analyzing the results of existing solar pond systems.

For a pasteurization process of a 85000 kg of milk, heat required is calculated and according to this requirement, area and dimensions of a pond are presented. Total area of 2171.2 m^2 is established for the system with LCZ, NCZ and UCZ thicknesses of 0.9 m, 1.7 m and 0.4 m respectively.

Sodium chloride is used in the system to get required salinity gradient in a pond. Salt dissolution system is used to dissolve 2275 tons of a salt in a solar pond. This system is compared with a coal and a natural gas boiler system, which gives the results that, if we replace these boilers with a solar pond, we can reduce 160 tons and 90 tons of carbon dioxide emissions respectively per month.

References

[1] A.V. Kalecsinsky, Ann. Physik IV 2, 408 (1902).
[2] M. Rozsa, Physik. Zeitachr. 1^, 108 (1915).
[3] H. Tabor, Electronics and Power 10, 296 (1966).
[4] Rabl and C. E. Nielsen, Solar Energy 1^, 1 (1975).
[5] Franz Soxhlet (1886) "ÜberKindermilch und Säuglings-Ernährung" (On milk for babies and infant nutrition), MünchenermedizinischeWochenschrift (Munich Medical Weekly), vol. 33, pages 253, 276.

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[6] Milk Pasteurization and safety: a brief history and update. V.H. Holsinger, K.T. Rajkowski& J.R. Stabel(1997)
[7] http://www.cdc.gov/mmwr/preview/mmwrhtml/mm4840b1.htm
[8] AMIT KUMAR and V. V. N. KISHORE (1999) CONSTRUCTION AND OPERATIONAL EXPERIENCE OF A 6000 m SOLAR POND AT KUTCH, INDIA
[9] Arumugam, S. (1997) Design, Construction, Performance and Heat Extraction Studies of a Full Scale Non-Convective Solar Pond, PhD Thesis, Gandhigram Rural University
[10] M.M.O. Dah, M. Ouni , A. Guizani , A. Belghith (2005) Study of temperature and salinity profiles development of solar pond in laboratory
[11] https://www.currentresults.com/Weather/India/annual-sunshine.php
[12] http://www.dairyheritage.com/vat-pasteurizers.php
[13] Jerome Godwin Egbe, Ahmed Hassan Khan, WongsakornWisatesajja (2013)
[14] Design of Solar Pond calculation and technique in Africa
[15] John Ralph Hull (1979) Physics of the solar pond
[16] http://cheguide.com/2015/12/heat-exchanger-analysis/
[17] http://www.solvay.com/en/asking-more/Solar-ponds-are-hot.html
[18] https://www.eia.gov/tools/faqs/faq.cfm?id=667&t=6
[19] https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11
[20] http://www.eia.gov/coal/production/quarterly/co2_article/co2.html
[21] Own image- AutoCAD
[22] The energy and resources institute (2016), "Salt-gradient solar ponds" [Online] Available at http://www.teriin.org/technology/salt-gradient

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