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Design and Modelling of a Milk Cooling and Storage Unit Based on Peltier and PV Panels

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Highlights: The paper addresses the “We used the finite element method for energy calculations to analyze the design of the developed model and is important because it is a single piece of Peltier module that can cause failure in the cooling unit.

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ABSTRACT - Companies and individual entrepreneurs which takes the milk from dairy storage points and dairy farms to distribute in the city centers, use milk cooling units mounted on pickup chassis. Cooling units are manufactured using stainless steel, 1st class Tungsten Inert Gaswelded, with a capacity of 200 to 5000 L, designed to remain no liquids inside. Cooling units are required for milk to be delivered to the customer without losing its freshness, without spoiling on the road, hundreds of kilometers on the vehicle. In this study, a milk cooling and storage unit based on a Peltier element with a capacity of 1000 L was designed. Energy calculations and finite element method was used to analyze the design of the developed model. As a result of the analyzes, it has been concluded that the milk can be cooled by three times less energy consumption with the Peltier Centric Cooling Unit developed.

Keywords: Milk tank, peltier, finite element method, ANSYS, milk cooling, energy harvesting, economic analysis

INTRODUCTION

Peltier cooler or thermoelectric cooler, which can be used as a cooler in recent years, has been used as an alternative to save energy (Tassou et al., 2009). The thermoelectric device can be used in two ways. First, when the temperature difference is applied to both sides of the device, the thermoelectric device can be used to generate electricity. In the second method; When electric (direct current) is applied to the thermoelectric device, one side of the device heats up, and the other side cools. When the cold side of the device is used in any application, this device can be defined as a Peltier cooler (Gouws and Jaarsveldt, 2012).

Peltier coolers operate as heat pumps and transport heat from one place to another within the device structure. These devices can also be defined as solid-state coolers. The use of Peltier in the refrigeration industry; is especially important in mobile applications where cooling is required. The absence of moving parts of these devices makes these devices suitable for mobile applications (Riffat and Ma, 2003).

In liquid cooling systems, gas compression cooling is the most commonly used method (Oró et al., 2012; Desai et al., 2013). The use of the Peltier can be considered an innovation for the cooling process. Thus, while the system becomes more digital, autonomous temperature control can be achieved (Riffat and Ma, 2003).

The Peltier is ideal for portable and compact designs thanks to the fact that it does not contain a moving element in its structure. Heat sensors, mass sensors, relays, current regulator, and thermostat to be added to the system allow the user to cool and store the milk in a stable condition at the temperature value entered by the user (Marafon et al., 2011; Tassou et al., 2010). Depending on the absorption and quality of the Peltier used, the cooling capacity can be increased in the system, and the amount of cooling can be changed (Bax, 2011).

In this study, a cooling tank with 1000 Lcapacity Peltier was designed for milk cooling. To calculate the energy and heat transfer needs of the developed design, a model has been developed by using finite element methods. The developed model is compared with the heat transfer calculation methods used in the literature.

MATERIAL AND METHODS

In this study, SolidWorks Software (Dassault Systèmes Americas Corp.,Waltham, MA, USA) is used for designs. In the SolidWorks environment, all the components that make up the system are designed in two-dimensional and three-dimensional.

Theoretical analysis of the system

Thermal conductivity (λ)

$\lambda = 0.025$ (W/m°C): Heat Conduction Coefficient of Urethane Foam
$t = 0.03$ (m): Thickness of Insulation Material

Surface area of milk reservoir (S)

$$S = 2*\pi*r*H + 2*\pi*r^2 = (2*\pi*0,25*5,1)+(2*\pi*0,25^2) = 8,4\ m^2 \quad \textbf{(1)}$$

Total heat transfer rate (K)

External Surface Heat Conductivity: $h_1 = 20$ (W/m^{2}°C)
Internal Surface Heat Conductivity: $h_2 = 200$ (W/m^{2}°C)

$$K = 1/\{(1/h_1) + (1/h_2) + t/\lambda\} \quad \textbf{(2)}$$
$$= 1/\{(1/20) + (1/200) + 0.03/0.025\}|$$
$$= 0,8\ (W/m^{2}°C)$$

Total Heat Amount Entered in Isolated Chamber (Q_1)

$$Q_1 = S*K*\Delta T \quad \textbf{(3)}$$
$$= 8,4 * 0,8 * (30-(2)) = 187,5\ W$$

Heat absorption required to cool milk (Q_2)
Cp: specific heat capacity of milk (kcal / kg.°C)
p: specific density of milk (kg / L)
v: milk volume (L)
$Q_2 = Cp*p*v*\Delta T$ **(4)**
= 0,94 * 1,033 * 1000 * (30-2)
= 27226,15 kcal

For 1 hour cooling of milk;
Q_2 = 27226,15 cal * 1,163 = 31664,02 (W)
(1 Kcal = 1,163 W)

Amount of heat absorption required Q;

It is not taken into account because the thermal load of water itself will not be significant. in this case
$Q_3 = 0$
$Q_a = Q_1 + Q_2 + Q_3$ **(5)**
Q_a = 187,5 + 31664,02+ 0 = 31851,52(W)

Q_T : Total amount of heat to be absorbed by adding 25% safety rate, **(6)**
Q_T = 39814,4 W

Peltier selection for cooling unit

As shown in Figure 1, it is theoretically confirmed that the point where the difference between the two surfaces of the Peltier (hot-cold) is about 30 ° C and the heat absorbed by approximately 33 W can be obtained from the module as a result of the application of 5.1 A current. **CP85-2** coded Peltier module can work in the direction appropriate to the system.

The total amount of heat to be absorbed in the designed milk cooling unit was determined as 39814.4 W in [1.7.1]. The CP85-2 module can meet approximately 0.08% of this value alone.

Thus, the required heat absorption in the milk cooling unit can be achieved by using 1207 of the selected Peltier module.

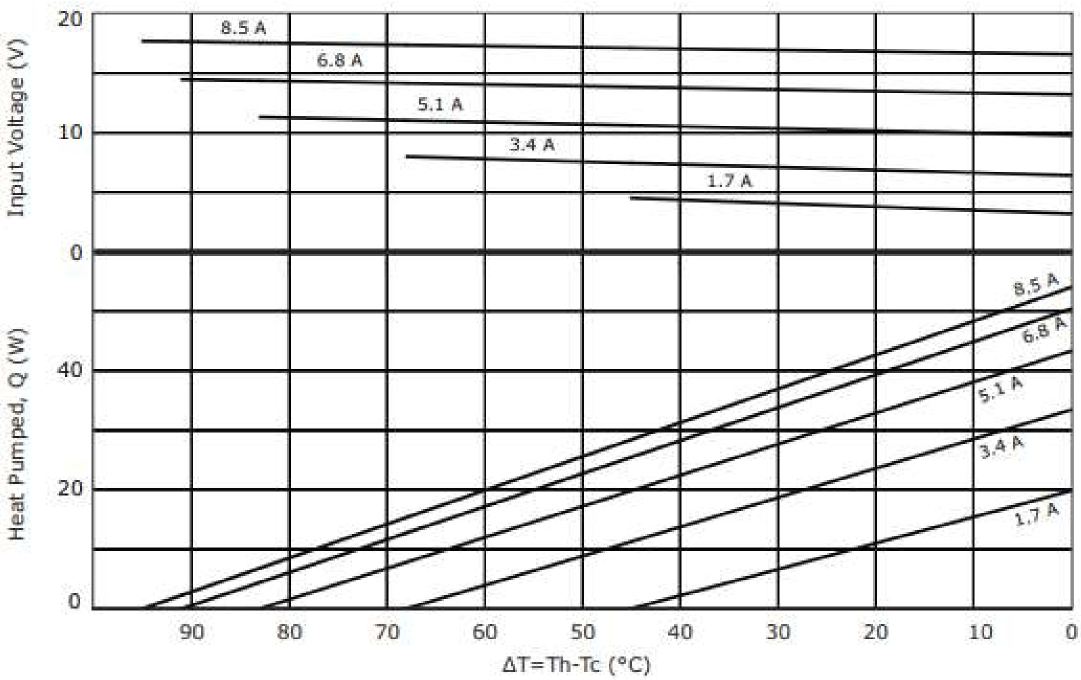

Figure 1. The behavior of CP85-2 Peltier according to different currents (Cui Devices, 2019)

The surface area of the photovoltaic panel required for cooling

All of the designed milk cooling unitsare considered to be full of milk, the energy needed to cool the milk for 1 hour to be met with the photovoltaic panel calculations have been made. For this purpose, the panel area was calculated from the following linear equation.

$E = A_T . r. H.PR$ **(7)**
$39814,4*1= A_T* 0,15*1300*0,75$
$A_T= 272,24\ m^2$

E = Energy (kWh)
A_T = Total solar panel Area (m²)
r = Solar panel yield (%)
H = Annual average irradiation on tilted panels (kWh/m².an)
PR = Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)

Economic analysis of the system designed with Peltier

Photovoltaic panels with a surface area of 1.63 m², with a purchase cost of \$ 118.4;

$$n = \frac{A_T}{A_1} = \frac{272,24}{1,63} \cong 168 \quad \textbf{(8)}$$

A_1: Area of selected panel (m^2)

Total cost of the system to be installed (P_T);

$P_T= n*P_1= 168*118,4= 19891,2\$$ **(9)**

P_1: Cost of selected panel (\$)

Annual electricity production;

$E_y=E_h*t*d= 39,8*8*240= 76416kW/yr$ **(10)**

E_y: Annual electricity production (kW/yr)
E_h: Hourly electricity production (kW/h)
t: Daily average working time of photovoltaic panel (h)
d: The number of days throughout the year that can be obtained electricity from photovoltaic panels conditions in Turkey

Estimated time to meet the amount of investment for photovoltaic panels (T_r);

$$T_r = \frac{P_T}{E_y \times C_h} = \frac{19182,2}{76416 \times 0,1} = 2,6yr \quad \textbf{(11)}$$

C_h:The hourly cost of electricity consumption (electricity conditions in Turkey kW / h cost \$ 0.1)
(1 \$ = 5.23 TL accepted.)

In this case, the system can pay for itself at the end of 3 years of spending \$ 500 per year for maintenance costs.

ANSYS Analysis

To perform thermal analysis with the help of ANSYS 15.0 (Dassault Systèmes Americas Corp., Waltham, MA, USA), the tank is modeled in 3D in the SolidWorks program. The model was imported and used for analysis on ANSYS. As shown in Figure 2 and Figure 3, the tank is designed to have one inlet and one outlet and also heat-absorbing surfaces closer to the interior (about 30 mm).

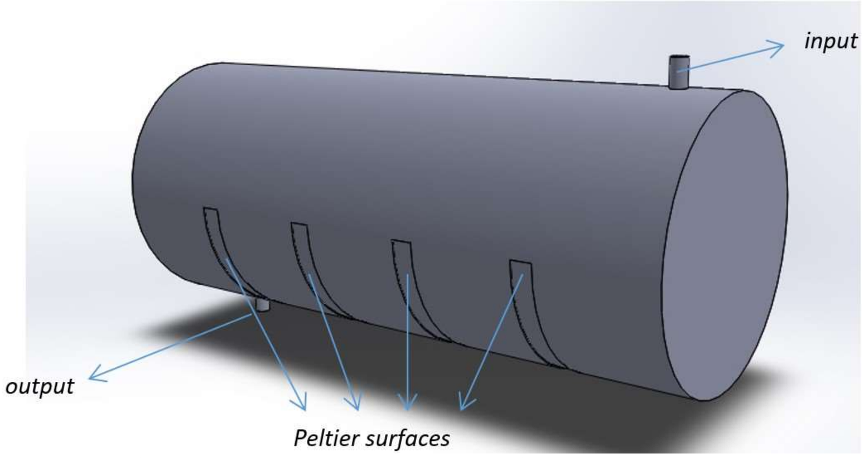

Figure 2. The initial design of the milk tank and the location of the surfaces in which the pelter touches

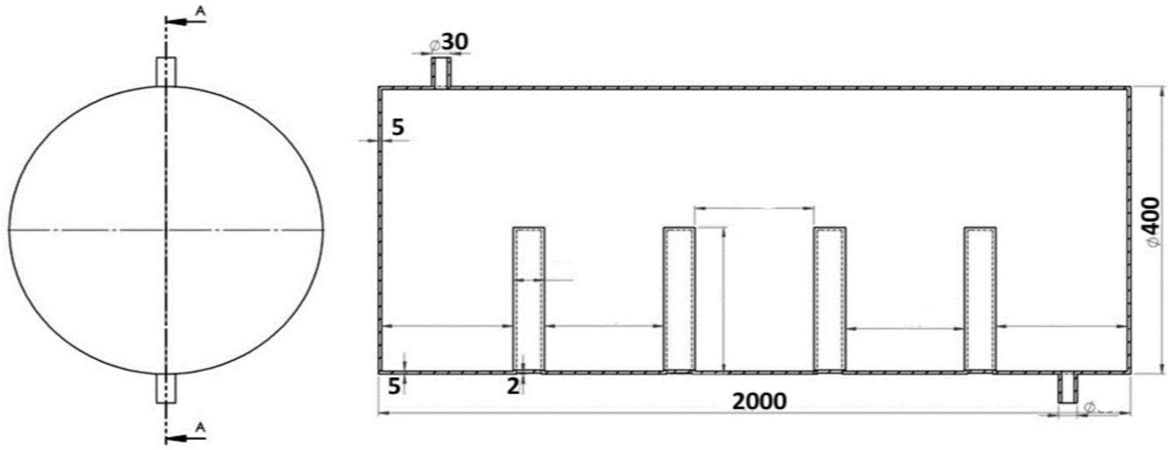

Figure 3. Technical drawing and details of the design

Evaluation of the first analysis

In the system within the cycle, the input of the milk into the tank at a speed of 20 m/s and a temperature of 286 K was calculated. 296 K and Peltier contacted to the system by contacting the outer surface temperature of the liquid with urethane and aluminum additions. As seen in Figure 4, the minimum temperature in milk as a result of the analysis and 100 iterations 277,6 K. Also, the milk temperature was 284 K in the tank. Figure 4 shows the analysis of the ANSYS Fluent environment.

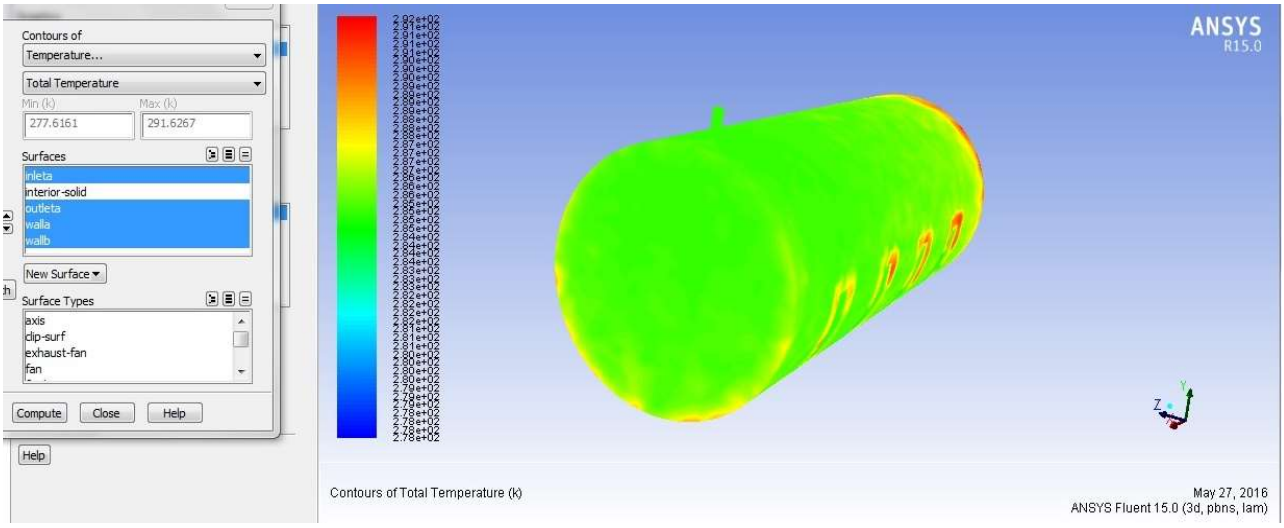

Figure 4. The results of ANSYS analysis with input values of the first design.

To bring the system to even better cooling capacity, the same size, and the same amount of Peltier is used in optimization, and a second design is created (Figure 5).

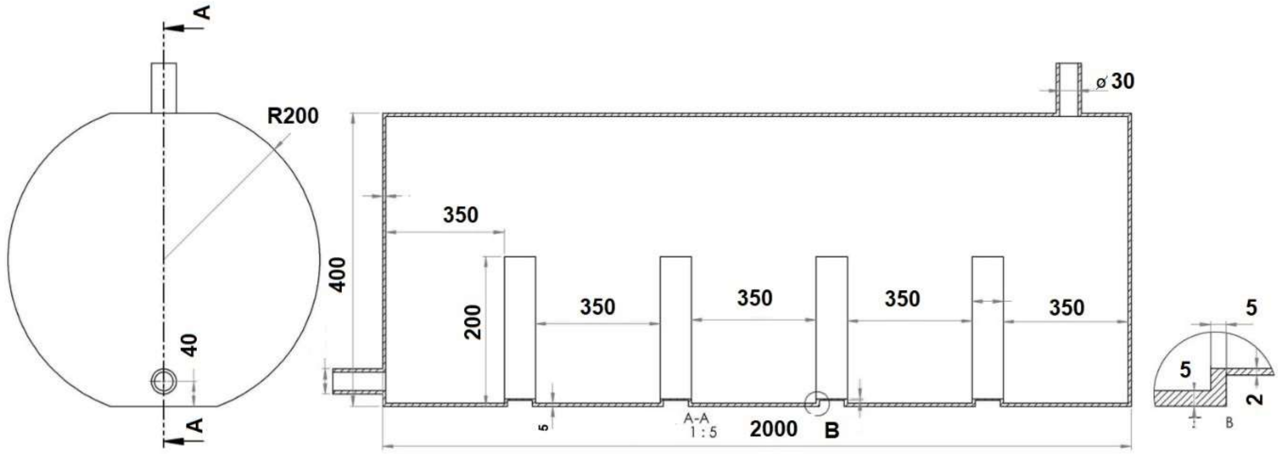

Figure 5. Technical drawing and details of the second design

The most significant difference from the first design is that the Peltier contact surfaces are closer and deeper to the milk (Figure 5 - Detail B). Thus, while the heat transfer is facilitated, the amount of heat absorbed is increased.

In the second analysis, the values accepted in the previous analysis were taken. In other words, the milk entry into the tank is assumed to be at a speed of 20 m/s, and a temperature of 286 K. 296 K and Peltier contact with the outer surface temperature of the liquid and urethane and aluminum additions were applied. The number of iterations for the analysis was limited to 50. In addition, changes in the milk inlet and outlet positions into the tank are made, as shown in Figure 1 - section A-A.

Evaluation of second analysis

As a result of the iterations, the milk in the tank reached a minimum temperature of 278.8 K, and the temperature in the tank was found to be stable at an average value of 281 K in Figure 6. However, according to the prescribed and rule 0 of thermodynamics, even though the two systems are interacting with each other, if their situation remains unchanged, it can be said that these two systems are in balance with each other. If the two systems are open to interaction, there is no net energy transfer (heat transfer), except for energy transfer (work) with mechanical interaction between them. These two systems are in thermal equilibrium.

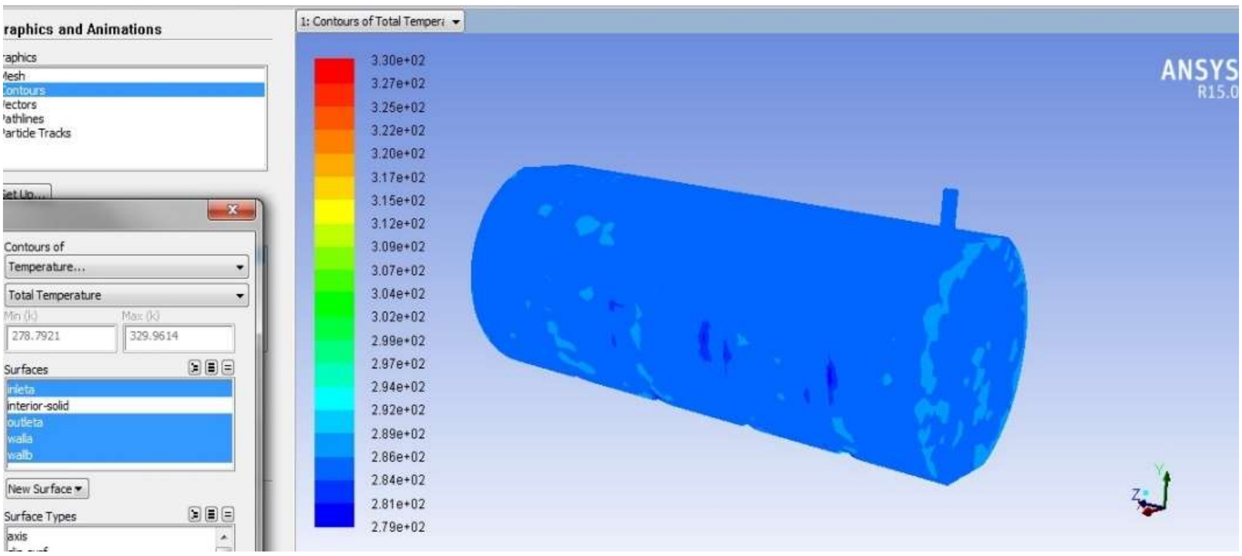

Figure 6. ANSYS analysis results of the second design

Results and Discussion

The designed system consumes more energy for cooling 1000 liters of milk than the existing milk cooling tanks available in the market (Figure 7). In Figure 8, the difference between these values is seen. In the following days, the increase in photovoltaic panel efficiency, developments in semiconductor technology, as well as for small volume fixed or portable applications, such designs can become economical.

Figure 7. Essential parts and layout of the system

(A) MILKOL Single Phase 1000 L Milk Cooling Tank

1 mixer 0.07 kW / h, 1 unit Ekovat 2.2 kW / h, 2 fans 0.4 kW / h: 2.67 KW / h

(B) İSST 1000 L 2B1 Class Horizontal Half Cylindrical Milk Cooling Tank: 2,83 kW / h

(C) Peltier Central Milk Cooling Unit 1000 L: 39.814 kW / h

(D) PSYO-1 1000 L Horizontal Type Cooling Tank: 2.67 kW / h

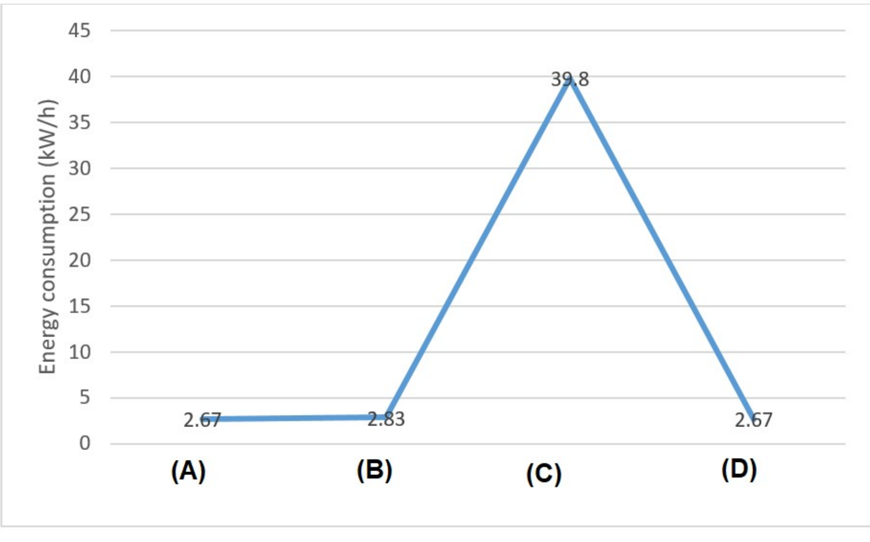

Figure 8. Comparison of Peltier Central Milk Cooling System with Other Models

According to the Turkish Food Codex, the raw milk production facility to be used in the production of drinking milk should be cooled to a temperature not exceeding 6° C and kept at this temperature until it is not processed within 4 hours after the acceptance of the milk (Munsch-Alatossava et., 2017, Nagaraj et al., 2018). The total number of bacteria determined by direct or indirect tests in raw milk, which is not heat-treated within 36 hours after acceptance, should not exceed 300.000 pieces/ml (Hou et al., 2013; Brodziak et al., 2017).

The tanks, which can keep milk from freezing to a specific temperature, are called milk cooling tanks. The EN 13732 standard for milk cooling tanks has been introduced by the European Union for milk cooling tanks to keep the milk in the desired characteristics (Chambers, 2002).

Built-in farms for milk production, there is a significant amount of milk production in the plateaus. Milk should be stored at +4 ° C is specially manufactured tanks to deliver milk to the processing plant or the consumer in a healthy way (Cui Devices, 2019).

Many beneficial and harmful bacteria can be found in milk (Chatzidakis et al., 2007; Stetca et al., 2004). If the cooling is not carried out immediately after milking about an hour, the number of these bacteria may increase by two to three times.

Although solar panels have recently been introduced in rural areas for milk cooling, milk transport to dairy farms is generally used for fossil-fueled transport vehicles (Günhan et al., 2006; Estrada-Flores et al., 2009). That, together with the increasing energy prices, imposes a considerable burden on economically small enterprises.

CONCLUSION

Based on the traditional cooling principle, it was observed that the Peltier-centered system was cooling with almost 15 times more energy consumption than conventional milk cooling units. From this point of view, the design which is designed with today's technology will take too long to pay for itself, and the design is no longer economical. However, an alternative to electricity use in rural areas with at least 240 sunny days can be considered as a low-maintenance solution, especially where the electricity supply from the grid is difficult.

The system can be made autonomous by PLC (Programmable Logic Controller). By integrating a software-supported monitor on the system, it is easy to control the situation for the user. Since there are no moving parts in the site, the noise generation in the typical cooling system has been eliminated with this new system. It can also be used as a portable cooling system or as a fixed position. It is a single piece of Peltier module that can cause failure in the cooling unit. This provides us with a longer life span, as well as the prices of the modules used to make it possible to complete the service maintenance with less cost.

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