Energy Efficient Solar Milk Chiller

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Abstract: Life stock is the major sector of agriculture which is of great importance for Pakistan. It has a major contribution towards the economy of Pakistan with a 55.9 % participation in agriculture sector. Pakistan is fourth largest country in milk production with 50.9 Billion tons per annum out of which only 5% is processed and pasteurized hardly and remaining milk is handled by milk men under non-hygienic conditions which causes milk borne diseases. Milk is perishable food having shelf life of few hours therefore milk processing is done to deactivate the microorganisms in the milk and increase its shelf life for future use. It is an energy intensive process and mostly conventional form of energy is used for this purpose. Solar power is the sustainable source of energy and there is an average solar global radiation of 5.3kWh/m^2/day persist in the country with more than 300 sunny days in a year. The objective of the study was to design and develop a solar assisted milk pasteurizer and to evaluate its performance. The developed solar assisted milk pasteurizer consisted of heating and cooling unit. Heating unit made of shell and tube type coil to heat up the milk up-to 730C for 15 seconds. Cooling unit has a chiller for sudden cool down the milk from 35^{0}C to 4^{0}C within 2 hours. Solar milk chiller had capacity of 200 liters, chiller semicircular pug mill type SS-304, a 2kWp PV system having eight PV modules each of 250Wp, a hybrid inverter 3kVA that convert 24V DC current into 220V AC current and two batteries 150Ah each as a backup source to meet weather fluctuations. One ton of vapor compression refrigeration system was filled with R410a refrigerant with inlet pressure of 118psi and the outlet pressure of 300psi was coupled with the chiller through coils at bottom side of the vessel. An agitator was installed with a lid on the tank to stir the milk continuously inside the chiller to make sure that homogeneous milk cooling to avoid freezing of the milk in the bottom of the chiller. Inverter technology was also coupled with the chiller to eliminate the torque load of 9-10 ampere to a uniform torque load of 3.2 ampere which is a big hurdle in using solar PV system. Efficiency of the system was achieved up-to 69%. The Coefficient of Performance (COP) of the system was found to be 3.18 and the cost of the processing milk was calculated1.17Rs/liter.

Index Terms: Renewable Resource, Hybrid Inverter, Capacitor Technology, Inverter Technology, Solar PV Module, Milk Chiller, Data Logger, Rotary Compressor, Reciprocating Compressor.

1 INTRODUCTION

PAKISTAN is 5th largest milk producing country in the world it is almost 45.6 million tons annually unfortunately 95% milk is handled by the milk man which unhygienic at high health risks especially lack of vitamins and essential nutrients and the remaining 5% is processed by the agro-based. Moreover, the farming community do not have a processing facilities at farm level to get proper price of milk. The pasteurized milk has long term its shelf life and market. The milk dairy processing is a rapid growing business but high energy running cost is a serious problem. After processing of milk, the shelf life is increased to 20 days with full of essential nutrients and vitamins. With this solar based technology milk is chilled with cheapest source of energy which is solar energy and rapidly available in Pakistan with more than 300 sunny days in a year. In normally, solar irradiance is 800 to 900 W/m². Torque load of the energy efficient solar assisted milk chiller is zero and the uniform load is 3.5 ampere and he milk is cooled down to 4ºC in the chiller within 2 hours (standard time by WHO). The processing cost of milk is Rs.1.17 per liter. The payback period of energy efficient milk chiller is 1.5 years.

2 MATERIAL AND METHOD

2.1 Methodology

The trends of using renewable resource to fulfil energy demand is becoming increasingly popular both in developed and developing countries. Different technologies have been developed to extract maximum power out of these renewable resources but very less attention has been paid to demonstrate the true potential of these resources and how effectively these resources can substitute the conventional resources of energy. The following study has been carried out to compare a solar assisted milk chilling unit using reciprocating compressor with R22 refrigerant and rotary compressor with capacitor technology and with inverter technology with R410A refrigerant. This research was conducted in three phases in the first phase solar hybrid system was developed in the workshop of Faculty of Agricultural Engineering and Technology, University of Agriculture Faisalabad. Galvanize steel frame is fabricated to installed solar PV modules of 2kWp system of 8 PV modules each module with 250Wp at the angle of 310, hybrid inverter having 3kVA capacity and built in charge controller to convert Direct current (DC) into Alternating current (AC) and battery bank of 300Ah for backup source, in the hybrid inverter there is a multiple source are required i.e. primary source is solar energy, secondary source is battery and last source is utility and also have a choice to rearrange the source priority as per requirement to continue the processes without any interception. This system was used to operate the milk chilling unit, at farm level where there is no electricity. The second phase of the research was adopted to different techniques to optimize the load of the milk chiller. In this phase first we use reciprocating compressor then we installed rotary compressor with capacitor technology and then we installed rotary compressor with inverter kit. Last phase of the research was parametric study of solar assisted milk chiller. In this phase data acquisition system is used to study different parameters like Ambient temperature (^{o}C), Solar Irradiance (Wm^{-2}), PV Voltage (DC Volts), Battery Voltage (DC Volts), Electricity Voltage (AC Volts), Electricity Current (AC A), PV Module Current (DC A), Battery Bank, Charging and Discharging Current (DC A), Chiller Unit Load Current (AC A), Milk Temperature (^{o}C), Radiator Out Temperature (^{o}C), Condenser Out Temperature (^{o}C), Capillary Out Temperature (^{o}C) etc.

2.2 Development of Solar Assisted Milk Chiller

Cooling unit has a chiller for sudden cool down the milk from 35^{0}C to 4^{0}C within 2 hours. Solar milk chiller had capacity of 200 liters, chiller semicircular pug mill type shape to increase the area to volume ratio, made up of fine food grade (SS-304). One ton of vapor compression refrigeration system was filled with R410a refrigerant with inlet pressure of 118psi and the outlet pressure of 300psi was coupled with the chiller through coils at bottom side of the vessel. An agitator was installed with a lid on the tank to stir the milk continuously inside the chiller to make sure that homogeneous milk cooling to avoid freezing of the milk in the bottom of the chiller. The main component of efficient milk chiller is rotary compressor having

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mechanical efficiency is 0.8, which has two lobes attached to the driving shaft by the prime mover. These lobes are displaced with 90 degrees to one another. If one of the lobe is in horizontal direction the other lobes will be exactly positioned at 90 degrees. The air gets trapped from one end and as the lobes rotates the air gets compressed and then compressed air is delivered to lines. Inverter technology was also coupled with the chiller to eliminate the torque load of 9-10 ampere to a uniform torque load of 3.2 ampere which is a big hurdle in using solar PV system. Efficiency of the system was achieved up-to 69%. The Coefficient of Performance (COP) of the system was found to be 3.18 and the cost of the processing milk was calculated1.17Rs/liter. The average temperature decrease rate of rotary compressor with inverter kit was 0.210C/min.

Fig. 1 *Energy Efficient Solar Based Milk Chiller Unit*

2.3 Data Monitoring System

To analysis the performance and parametric study of solar assisted milk chiller data logger is attached with this system. Data logger of Agilent 34970A will be used to collect the real-time data of after every 10 minutes. All the instruments or sensors or via external instruments and sensors will be connected to data logger used in this research. Data Logger Switch Unit consists of a three-slot mainframe with a built-in 1/2-digit digital multi-meter, equipped with the pyranometer (One SP Lite2 can be used under all weather conditions), thermocouple (sensitivity of approximately 41µV/°C, its range is -200°C to +1260°C / -328°F to +2300°F range), amperemeter, current adapter and volt crafts for real time data monitoring.

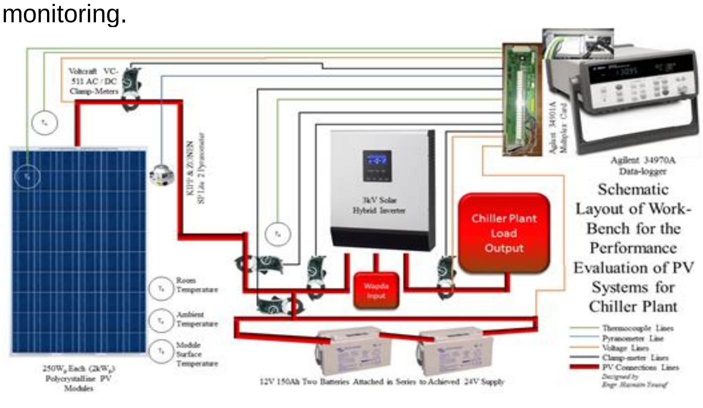

Fig. 2 *Data Acquisition System of Solar Milk Chiller*

3 RESULTS

To optimize the compressor with solar system there were three different types of compressor technologies utilized. To check the performances of these technologies 200-liter water as a sample was used in the solar assisted chiller unit instead of milk. Because the milk was so expensive to perform multiple experiment on the solar assisted chiller unit and the thermal properties of water was approximate same as milk, so in this research water was use instead of milk.

1. Compressor with Capacitor Technology
2. Compressor with Convectional Technology
3. Compressor with Inverter Technology

3.1 Compressor with Capacitor Technology

In the first step of this research the rotary compressor in which R410a refrigerant is filled with two capacitors one is running capacitor and second is starting capacitor. With this system temperature from 30^{0}C to 4^{0}C is achieved.

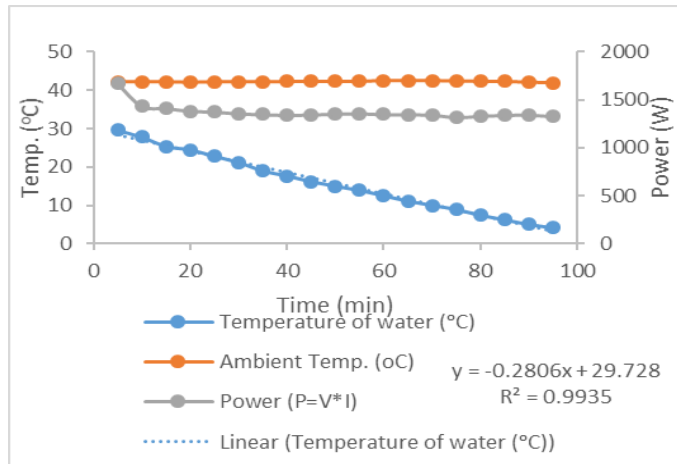

Fig. 3 *Comparison between Water Temp., Ambient Temp. and Power using Capacitor Technology*

The above fig. shows that comparison between water temperature, ambient temperature and power using capacitor technology. By using this technology, the initial temperature was recorded as 29.6^{o}C and final temperature was recorded as 4.1^{o}C. This compressor took 95 minutes to achieve 4.1oC from 29.6^{o}C. The temperature was decreasing at the rate of 29.45^{o}C per minute by using this technology. The compressor takes 1668.78W torque load as starting after that take 1350W as running. The average ambient temperature was recorded as 42oC. The equation and r-square value of the linear trend line was recorded as

$$y = -0.2806x + 29.728$$
$$R^2 = 0.9935$$

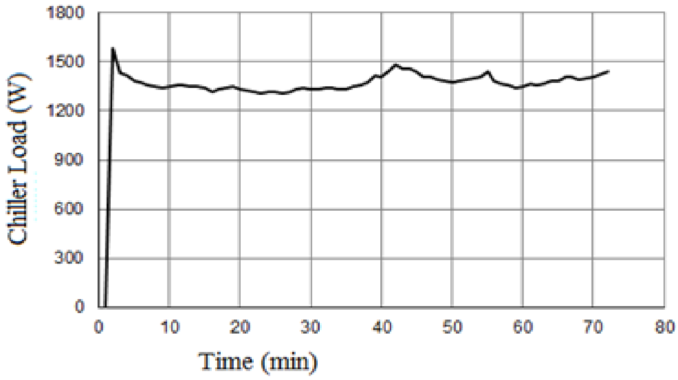

Fig. 4 *Comparison between Chiller load and Time using Capacitor Technology*

In this type of technology, the rotary type compressor was installed with environment friendly R-410 refrigerant was used in the same vapor compression refrigeration technique. This system was installed with the conventional type of two capacitors one for starting the capacitor and other for running the compressor continuously. The data recoded with this type of technology was quite satisfactory, however the torque load was still recorded as about 1.7kW and running load was recorded above 1.2kW. This was an acceptable solution but still running such system on PV can reduce the performance of the system and heavy amount of backup system is needed to run such type of systems as shown in Figure 4. The figure also shows that the time required to bring milk temperature to 4°C was recorded to be 72 min.

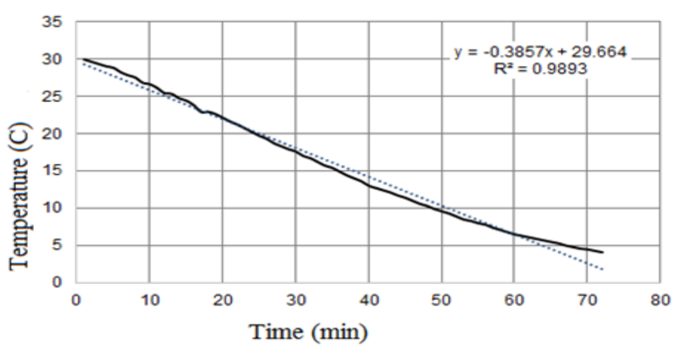

Fig. 5 *Comparison between Milk Temperature and Time using Capacitor Technology*

The graph shows that comparison between milk temperature and time to achieved the desired temperature using capacitor technology. By using this technology, the initial temperature was recorded as 300C and the finial temperature was recorded as 40C. This compressor took 73 minutes to achieve the desire temperature. The equation and r-square value of the linear trend line was recorded as

y = -0.3857x + 29.664
$R^2 = 0.9893$

3.2 Compressor with Conventional Technology

In the second step of this research the compressor is exchange with reciprocating compressor in which R22 refrigerant is filled. With this system temperature from 30°C to 4°C is achieved.

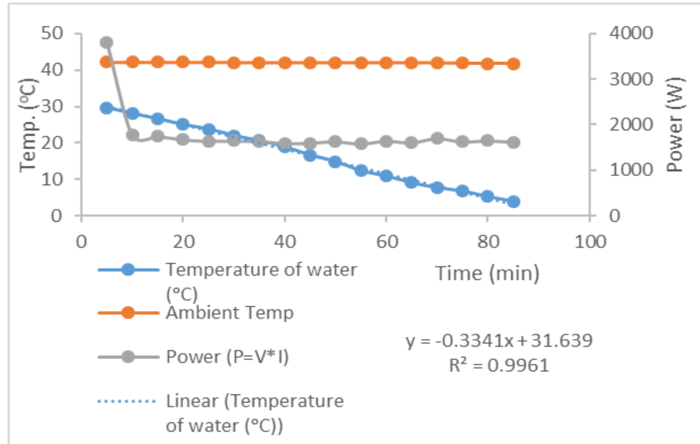

Fig. 6 *Comparison between Water Temp., Ambient Temp. and Power using Conventional Technology*

The graph shows that comparison between water temperature, ambient temperature and power using conventional technology. By using this technology, the initial temperature was recorded as 29.6°C and final temperature was recorded as 4.0°C. This compressor took 85 minutes to achieve 4.0°C from 29.6°C. The temperature was decreasing at the rate of 31.30°C per minute by using this technology. The compressor takes 3808.48W torque load as starting after that take 1640W as running. The average ambient temperature was recorded as 42.1°C. The equation and r-square value of the linear trend line was recorded as

y = -0.3341x + 31.639
$R^2 = 0.9961$

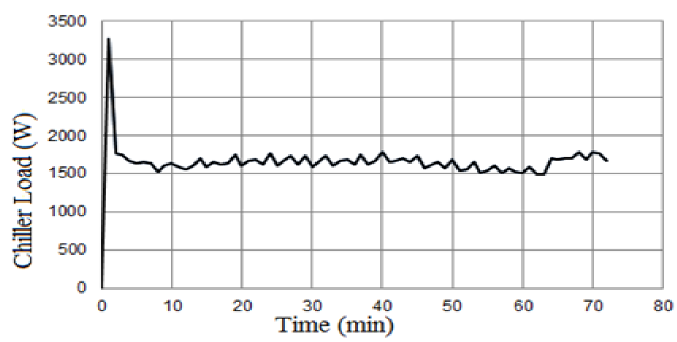

Fig. 7 *Comparison between Chiller load and Time using Conventional Technology*

Conventional reciprocating compressor was used with R22 refrigerant. The system performance was satisfactory in terms of meeting the temperature requirement of the milk from ambient temperature 30°C to 4°C which is the requirement of WHO. The major drawback was the high initial torque load (3.7kW) which was not feasible and economical to couple with solar PV system for the on-farm applications. The overall average load was recorded was above 1.5kW as shown in the Figure 3. The below figure also shows that the time required to achieve a temperature of 4°C was found to be 72 min.

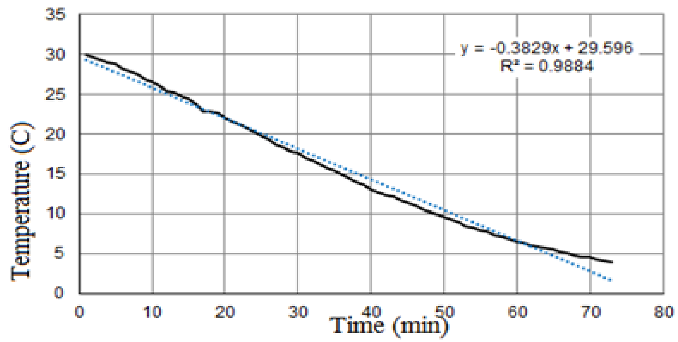

***Fig. 8** Comparison between Milk Temperature and Time using Conventional Technology*

The graph shows that comparison between milk temperature and time to achieved the desired temperature using capacitor technology. By using this technology, the initial temperature was recorded as 300C and the finial temperature was recorded as 40C. This compressor took 73 minutes to achieve the desire temperature. The equation and r-square value of the linear trend line was recorded as

y = -0.3829x + 29.596

R^2 = 0.9884

3.3 Compressor with Inverter Technology

The third phase rotary compressor is used with R410a refrigerant and inverter kit is used to controlled the compressor according to the ambient temperature. With this system temperature from 30°C to 4°C is achieved.

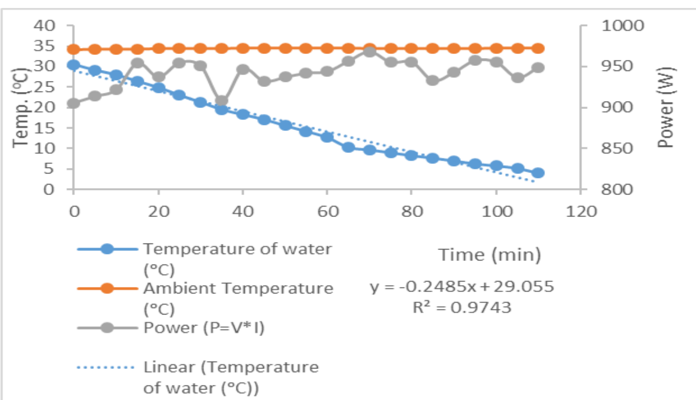

***Fig. 9** Comparison between Water Temp., Ambient Temp. and Power using Inverter Technology*

The graph shows that comparison between water temperature, ambient temperature and power using inverter technology. By using this technology, the initial temperature was recorded as 30.5°C and final temperature was recorded as 4.0oC. This compressor took 110 minutes to achieve 4.0°C from 30.5°C. The temperature was decreasing at the rate of 28.81°C per minute by using this technology. The compressor takes 905.73W torque load as starting after that take 950W as running. So, it has been seen that there was no any difference between torque load and running load of the compressor by using inverter technology. Infect that the compressor take start from the zero-torque load, after five minutes the compressor runs on full load. The average ambient temperature was recorded as 34.4oC. The equation and r-square value of the linear trend line was recorded as

y = -0.2485x + 29.055

R^2 = 0.9743

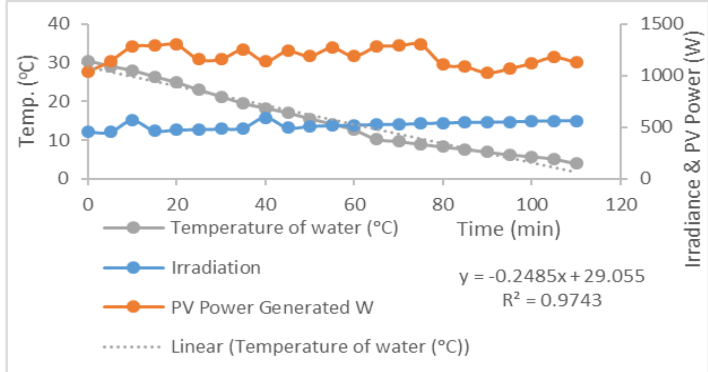

***Fig. 10** Comparison between Water Temp., Irradiance and PV Power using Inverter Technology*

The above graphs of inverter technology with rotary compressor and R410A refrigerant shows the comparison between water temperature, irradiance and solar power using inverter technology. By using this technology, the initial and final average temperature of water was recorded as 31.3oC and 3.9oC respectively and temperature was decreasing at the average rate of 0.2110C/min. The average irradiance is approximately 560W.

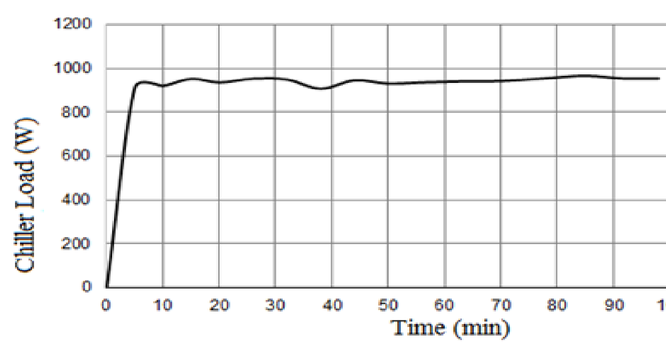

***Fig. 11** Comparison between Chiller load and Time using Inverter Technology*

In this phase of this research was conducted to optimize the system to run perfectly with hybrid solar PV system. To reduce the torque load of the chiller, an inverter technology was used which successfully eliminate the torque load as well as the running load of the chiller was also reduced up to 20%. The overall average load was recoded below 1 kW which is 45% less than the first phase of the research as shown in the Figure. The results show that a temperature of 4°C was achieved within a time of 100 min which is within the standards of WHO. There was a linear relation of temperature versus time in all the cases as determined by regression analysis (R2= 0.95). This optimized system can run smoothly and efficiently with only less than 1kW of load without compromising on COP of the system.

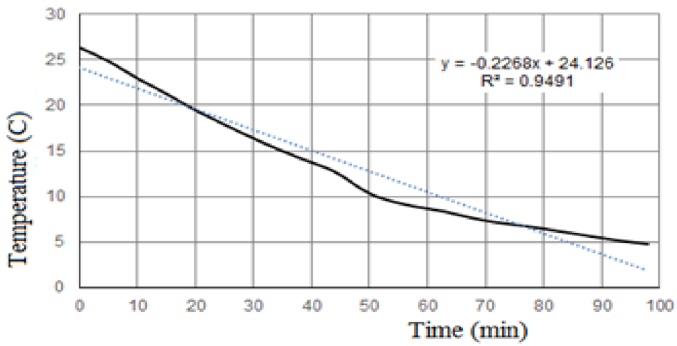

***Fig. 12** Comparison between Milk Temperature and Time using Inverter Technology*

The graph shows that comparison between milk temperature and time to achieved the desired temperature using capacitor technology. By using this technology, the initial temperature was recorded as 300C and the finial temperature was recorded as 40C. This compressor took 97 minutes to achieve the desire temperature. The equation and r-square value of the linear trend line was recorded as

$y = -0.2268x + 24.126$

$R^2 = 0.9491$

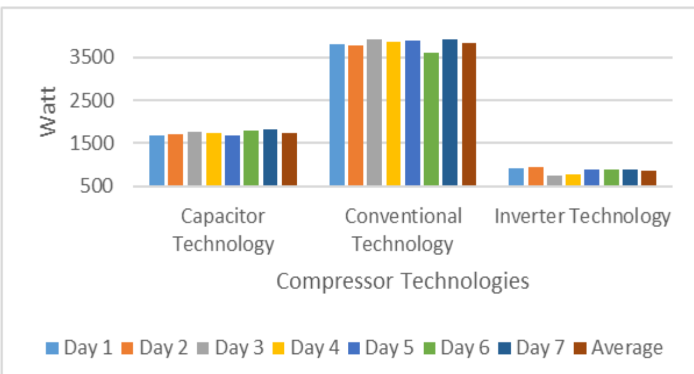

***Fig. 13** Technologies wise comparison of torque load between different compressor technologies (W)*

In the above graph shows the technologies wise comparison of the torque load between different compressor technologies. Capacitor technology has reciprocating type compressor with capacitor technology of average torque load of 1738.15W and the conventional technology has also coupled with reciprocating type compressor with average torque load is 3816.25W and the inverter technology is coupled with inverter kit and the rotary compressor with average torque load is 860.96W.

4. Conclusion

The feature like compact design and nature powered makes a solar assisted milk chiller system an ideal choice for the processing of milk at remote farm location. The system will help the farmer in processing their raw milk at farm level as soon as they are milked which will help farming community to produce good quality of milk at much cheaper cost which will benefit both farmer and consumer collectively. The following study addressed the question regarding the quality and quantity of chilled milk processed by solar assisted milk chiller to assess how well this system performs against conventional milk chiller when it comes to quantity and quality aspects of processed milk. Both solar and conventional system were put to quantitative and qualitative analysis under identical condition varying only by source of energy. The average milk processed yield observed in both solar and conventional chiller system were found statistically insignificant. Furthermore, the cost of erecting a solar milk chiller system was 0.5 million rupees and system will payback period is based on number of batch processed So, it can be summarized that solar assisted milk chiller system for milk processing not only has all the merits of conventional chilling system but is also capable of processing of milk because of utilizing solar energy as a source of energy which equally makes it a good choice for on grid and off grid farming community involved in milk trading.

4.1 Impact and Benefits of the Technology

1. No running or operational cost of the system
2. Environmental friendly source of energy supply which is free from harmful emissions
3. Little repair and maintenance is required
4. Opportunity for indigenization at cheaper rates
5. Possibilities of on-farm and commercial applications
6. Income generation and employment opportunities for farming community.