HIGH TEMPERATURE SHORT TIME (HTST) CAMEL MILK PASTEURIZATION PILOT PLANT

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ABSTRACT

This paper reports on the design and fabrication of a High Temperature Short Time (HTST) camel milk pasteurization pilot plant. The objective of this project is to design and fabricate a low cost and practical camel milk pasteurization pilot plant which will work well in an agricultural setting in the Kingdom of Saudi Arabia. Fresh camel milk is a much sought after delicacies in the Arab world, usually sold directly by the farmer to the consumer without any further processing. However, this traditional method of milk handling has a few limitations where there is a possibility of milk contamination during handling, excess milk cannot be stored and the excess milk cannot be transported to other localities further away limiting the economic opportunities of the farmers. This pasteurization plant is based on High Temperature Short Time (HTST) continuous process where the raw camel milk will be indirectly heated to 72ºC via a heat exchanger. The milk temperature will be maintained at 72 ºC for 15s in a holding tube to kill most of the harmful microorganisms present in the milk. The pasteurized milk is then ready for consumption or can be refrigerated and stored for up to 21 days. With the introduction of this pasteurization pilot plant, it is hoped that the hygiene factor and the livelihood of the farmers will be improved where the camel milk can be stored longer and transported to stores safely to meet the demands of consumers.

Keywords: milk pasteurization; pilot plant.

INTRODUCTION

Camel milk is an important source of nutrition, especially for the Bedouin community in arid and semi-arid areas of Saudi Arabia. Although having less nutritional values compared to cow milk and ewe milk, camel can produce sufficient milk all year long compared to cow and ewe that needs plenty of drinking water for survival. Camel milk is believed to have medicinal and mystical properties. It is widely believed that drinking camel milk can clean ones digestive tract. In Ethiopia, camel milk is considered as having aphrodisiac powers. When camel milk is not consumed fresh it must be processed as soon as possible to prevent it from turning sour especially in the summer months where temperatures can go up to more than 50 °C. Camel milk does not sour at temperatures below 10 °C for up to 72 hours. However, at 30 °C camel milk sours in approximately 8 hours. Comparatively cow milk sours within 3 hours at 30 °C [1]. There is a lack of proper milk cold storage and processing facilities in the rural areas. Thus, the extra camel milk is curdled and soured reducing its economic value. Better milk processing facilities utilizing modern techniques, adapted to local conditions, are required to increase the quantity and improve the quality of fresh camel milk sold.

Microorganisms in the environment find their way to the hair and teats of camels and can move up the teat canal. Microorganisms can enter milk supply during the milking process, when equipments used in milking, transporting and storing raw milk is not properly cleaned and sanitized especially in desert environment which lacks supply of clean water. Pasteurization is an important process that can inactivate various dangerous microorganisms in the milk like Salmonella, Listeria, Yersinia, Campylobacter, Staphylococcus and E-Coli [2].

It is imperative that the proposed pasteurization plant to not only be well designed and well built but most importantly to meet the requirements of its intended users and operating environment. Most important requirement is the plant has to be portable that it can be transported on a pick-up truck through unpaved roads in the desert area. The design and built has to be rugged enough to withstand a harsh operating environment. The operation has to be simple enough to be operated by farmers with limited technical knowhow. Since the pasteurization plant will most likely be used in rural areas far from industrial center, it has to be easy to maintain with common spare parts available from local hardware stores.

PASTEURIZATION

Pasteurization is an established process invented by Louis Pasteur in 1864 [3]. He discovered that abnormal fermentation of wine and beer could be prevented by heating these beverages to about 57 ºC for a few minutes [4]. Pasteurization is a heat treatment process which applies sufficient heat to a particular food for a sufficient amount of time to kill certain microorganisms present in the food that will cause spoilage and disease. Fortunately, most of the harmful microorganisms present in foodstuff are not very resistant to heat. Besides beer and wine, pasteurization process is now being used to prolong the life span of a variety of foodstuffs like various juices, liquid egg [5], milk and milk products. The most common types of milk pasteurization process are Batch Pasteurization, High Temperature Short Time (HTST) and Ultra High Temperature (UHT). In milk pasteurization process, raw milk is heated rapidly to the required temperature for certain amount of time and then cooled down rapidly. Pasteurized milk will need to be refrigerated to maintain freshness. Table-1 summarized the various pasteurization temperature and its corresponding time according to [6].

Table-1. Pasteurization Temperature and time.

Temperature (°C)	Time
63	30 minutes
72	15 seconds
89	1 second
90	0.5 seconds
94	0.1 seconds
96	0.05 seconds
100	0.01 seconds

Batch Pasteurization

Batch pasteurization is also known as Low Temperature Long Time (LTST) is similar to heating up raw milk in a pot on the kitchen stove. Milk is heated to 63 °C in a large tank and maintained at 63 °C for 30 minutes. The milk has to be stirred constantly to ensure that each particle of milk is heated properly. This is a simple process easily done at home without using any sophisticated machines. The pasteurization process is done in batch and not continuously.

High Temperature Short Time Pasteurization

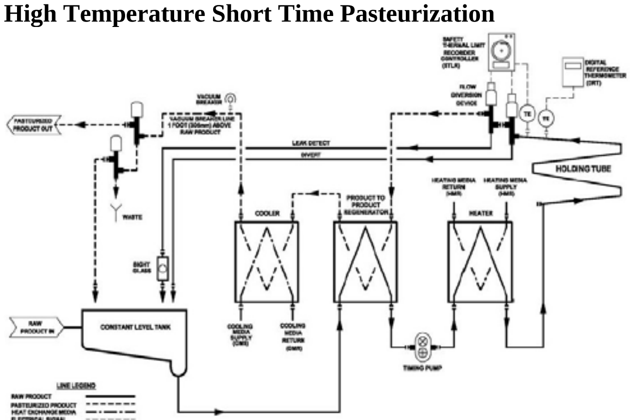

Figure-1. Diagram of a Typical HTST Pasteurizer [6].

HTST pasteurization process is also known as flash pasteurization. HTST is the most common pasteurization method used in the industry. The standard US protocol for HTST pasteurization of milk, 71.7 °C for 15 seconds, was introduced in 1933, with a result of 99.999% or greater reduction in harmful bacteria [7]. HTST pasteurization which is a continuous process is faster and is suitable for higher volume processing in the industry. HTST pasteurization is more energy efficient than batch pasteurization, where the energy from the pasteurized milk can be partially recovered to preheat the raw milk before being channeled to the heat exchanger. However, with a higher temperature used compared to batch pasteurization, the milk may give a slightly cooked flavor.

Ultra High Temperature Pasteurization

In Ultra High Temperature (UHT) pasteurization process, raw milk is heated rapidly to 135 °C and maintained at 135 °C for a very short time, typically between 2s to 5s [8], then the milk is cooled down rapidly to room temperature. The UHT pasteurized milk once sealed properly in a sterilize condition can be kept in room temperature for up to nine months without refrigeration. The main advantage of UHT milk is easy and cheaper storage and delivery without the need of refrigerated trucks and refrigerated display shelf.

PASTEURIZATION PILOT PLANT

The main components of the pasteurization plant consists of a raw milk tank, a boiler, a heat exchanger, a thermally insulated holding tube, a set of diverter valves, raw milk pump, hot water pump, a variable frequency drive, three J-type thermocouples, and a control box to control the entire pasteurization process. The components are all placed on a trolley with wheels for mobility.

The HTST pasteurization pilot plant is shown in Figure-2 while the Process and Instrumentation Diagram of the plant is shown in Figure-3. In the HTST pasteurization plant, the raw milk flow rate is kept constant by the raw milk pump's constant speed and a hand valve. The hand valve can be used to adjust the desired raw milk flow rate. First, raw milk is preheated to 42 °C by an electric heater in the raw milk tank. Hot water is maintained at constant 100 °C by the boiler. Preheated milk is pumped to the heat exchanger to be heated to the required 72 °C. The heated milk temperature set point in the heat exchanger is achieved by regulating the flow rate of hot water in the boiler tank into the heat exchanger. The heated milk output from the heat exchanger flow to the insulated holding tube. At the holding tube, the heated milk is maintained at 72 °C while flowing through its entire length for 15s. At the end of the holding tube, the milk temperature is measured again where the milk that does not meet the required temperature is diverted back into the raw milk tank while the pasteurized milk is packed and cooled down for storage.

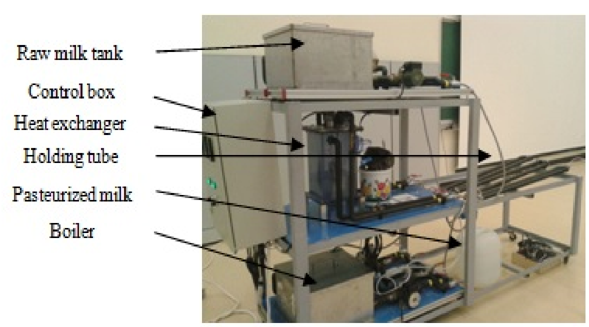

Figure-2. The Pasteurization Pilot Plant.

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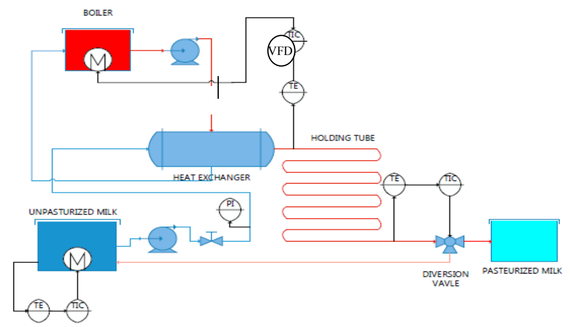

Figure-3. Process & Instrumentation Diagram of the Pasteurization Pilot Plant.

3D CAD Design

The mechanical structure is designed using SolidWorks 3D Computer Aided Design (CAD) software. First, all the off the shelf components like the control box, controllers, sensors, indicator lamps, tanks, pumps, heaters, hand valves, bolts, washer and nuts are drawn in 3D. Then, the steel structure is designed. Next, all the 3D components from the smallest to the largest are assembled to the steel trolley. Numerous adjustments are made to the components' and tanks' placement to obtain the best placement by taking into account the piping and wiring route. By using 3D CAD software designers can make sure that all the components can be installed without any obstruction, the screw holes fit properly and there is enough space for tools and installer's hand. Ergonomic aspects like the visibility of all sensor readings and the accessibility of all hand valves are taken into considerations. Once all the design works and drawings are finalized and approved, it is sent to external vendor for fabrication. Finally, all the components and accessories can be installed on the trolley followed by the piping and wiring works.

Holding Tube

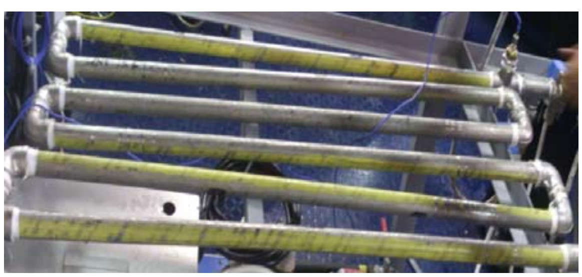

Figure-4. Holding Tube.

The heated milk from the heat exchanger output is channeled through an insulated holding tube. The holding tube is designed to keep the milk at the required temperature for the required time. The difference between the hottest and coldest milk in the holding tube at any time of the holding period should be less than 0.5 ^{o}C. The length of the holding tube required to hold the milk for a length of time is given by Equation. 1 and Equation. 2 below.

$$V = \frac{Q \times HT}{3600 \times \eta}\ dm^3 \qquad (1)$$

Where:
V = Volume of milk in liter or dm^3
Q = Flow rate at pasteurization, liter/hour
HT = Holding time in seconds
η = Efficiency factor

$$L = \frac{V \times 4}{\pi \times D^2}\ dm \qquad (2)$$

Where:
L = Length of holding tube in dm
D = Inside diameter of holding tube in dm
V = Volume of milk in liter or dm^3

Based on calculations using Equation. 1 and Equation. 2, the required length of holding tube to maintain a holding time of 15s is approximately 7m.

a) Control

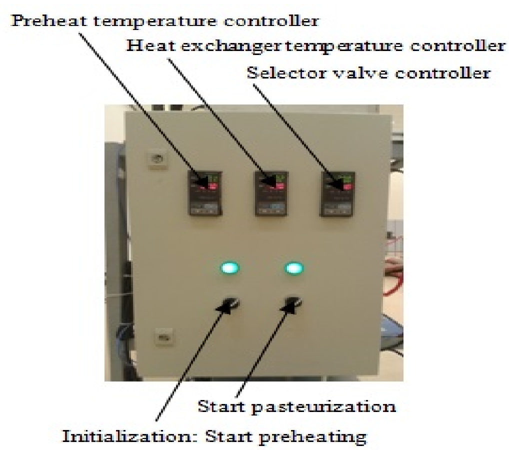

Figure-5. Control Box.

The control box is the heart of the pasteurization plant. There are three Yokogawa UT321 digital temperature controller to maintain the raw milk preheat temperature, heat exchanger output temperature and pasteurized milk temperature output after the holding tube. J-Type thermocouples are used to measure temperature of the raw milk, heat exchanger output and pasteurized milk output. Thermocouple is a suitable type of temperature sensor because of its ability to measure high temperature range. The measured temperatures are feedback into the temperature controllers, which use the feedback temperatures to decide on suitable control actions. Variable frequency drive is used to convert the output signal from the heat exchanger's temperature controller to drive the pump at variable speed. The other components in the control box are indicator lamps, selector switches, circuit breakers, relays and connectors.

There are two temperature control loops in the system. The control loops are the raw milk tank

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temperature control and the heat exchanger temperature control. The raw milk tank is running on discrete On/Off control mode while the heat exchanger temperature control is running on continuous PID control mode. On/Off control for the raw milk tank is simple to be implemented and suitable for slow process like temperature control. The thermocouple measures the raw milk temperature to gives input to the temperature controller. The heating element acts as the final control element. The thermocouple measures the milk temperature output and feedback to the heat exchanger's PID temperature controller. The controller gives continuous output to the inverter to vary the pump speed to manipulate the flow of hot water into the heat exchanger.

Figure-6. Control Box Wiring.

Operating Specifications

Table-2 summarizes the operating specifications of the pasteurization pilot plant. The raw milk tank and the boiler capacity is 30 liter, enough for a small scale farm operation. The length of the insulated holding tube is 7m to maintain the pasteurized milk at the required 72 ºC for 15s. The set point of the boiler is 100 ºC and the raw milk temperature at the raw milk tank is set to 40 ºC. These set points can be reset to different temperatures depending on the requirement of the farmers as needed. There are two heaters rated at 3kW each to heat the raw milk and the boiler. The pasteurization plant runs on 240Vac power source.

Table-2. HTST Pasteurization Pilot Plant Specifications.

Operation specifications:	
Raw milk tank capacity	30 lit
Boiler capacity	30 lit
Holding tube length	7 m
Milk holding time	15 s
Max. milk flow rate	3 lit/min
Recommended temperature set points:	40 ºC
Raw milk tank	100 ºC
Boiler	72.0 ºC
Milk at heat exchanger output	
Electrical specifications:	
Power source requirement	240Vac
Raw milk tank heater	3kW
Hot water tank heater	3kW

PROJECT MANAGEMENT

This section discusses on the project management aspect of the project. The development process includes managing the project workflow in different phases and identifying the man hour requirement.

Workflow

As illustrated in Figure-7, the project started with the conceptual and planning phase before proceeding to the mechanical design and fabrication works, followed by electrical design and wiring works, testing and commissioning and finally closure phase. The project starts by completing the conceptual design. A survey is conducted to estimate the cost of the major components in order to complete the proposed budget and proposal. Once the budget is approved the engineering work begins with the mechanical work like the structure design and fabrication, determine the type and sizing of the heat exchanger and pump, determining the length of the holding tube and the completion of the overall piping work. It is then followed by the electrical works which involves wiring work and selecting, installing and testing the temperature controllers, temperature sensors and other electrical components. The pasteurization plant is then tested for leak and functionality. In the closure phase, all documentations like the operation manual, service manual, wiring diagram, piping and instrumentation diagram, bill of materials and suppliers' information are properly documented for future references.

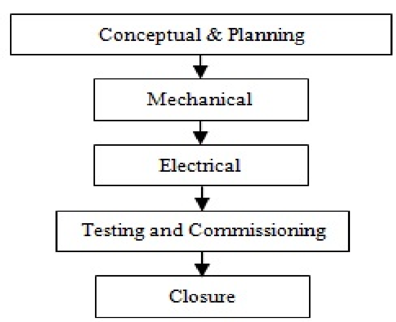

Figure-7. Project Workflow.

Man Hour Requirement

Table-3 summarizes the total man hour requirement of the project from the conceptual and planning to the closure phase. In total, the team took 1300 hours to complete the entire project. The team spent 200 hours in the conceptual design and planning phase. A total of 800 hours are spent executing the actual engineering work, split equally between mechanical and electrical design, fabrication and installation work. 50 hours are spent testing the completed pasteurization plant. A significant amount of time totaling 250 hours are spent completing and updating all the documentations including the operation and maintenance manual.

This is a new unique design with a steeper learning curve especially in identifying and sourcing for the components which took significant time. However, with experience gained, benefit of familiarity and by having the components suppliers identified, the next upgraded version can be completed in a significantly reduced time.

Table-3. Project Man Hour Requirement.

Task	Man hour (hrs)
Conceptual & planning phase: Gathering feedbacks from stakeholders Conceptual design Budgeting and approval	200
Mechanical phase: Mechanical 3D CAD design Sourcing and monitoring structure fabricator Heat exchanger selection and sizing Pump selection and sizing Piping and accessories installation	400
Electrical phase: Electrical design Components sourcing and procurement Components testing and installation Control box wiring Controller setting	400
Testing & Commissioning: Leak test Functionality test	50
Closure phase: Developing operating and service manual Documentation	250
Total	**1300**

CONCLUSIONS

The idea for this project came after observing the way fresh camel milk are handled by farmers selling camel milk by the roadside. Having a properly designed small scale pasteurization plant can ensure food safety and at the same time enhance the livelihood of the farmers. The HTST camel milk pasteurization pilot plant is successfully designed, built and tested. However, the current design is based on HTST pasteurization standards set for cow milk. The composition of fat, water and other enzymes and microorganisms in cow milk is different from camel milk. Further work needs to be done to determine the optimum temperature and time to kill the harmful microorganisms present in raw camel milk and also ensuring that the beneficial nutrients are not lost in the heat treatment process. The team hopes to improve the existing pilot plant by using food grade stainless steel and to conduct field trial in the near future.

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