# Investigation of Energy Saving Potential of Bulk Milk Chiller by Waste Heat Recovery

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***Abstract*--In the age of globalisation energy saving has become significant. It has led to the increased energy and cost concern which encouraged an investigation of waste heat recovery from bulk milk chillers as a conservation alternative for reducing heat cost in diary industry. Milk chilling equipment used depends on the quantity of milk required to be handled. In coolers (BMC) ie. milk production practices the harvested milk is chilled from its initial temperature of 35 °C to 4 °C to arrest the bacterial growth and maintain the quality of milk. Milk chilling process by using BMC is energy intensive process. Hot water is used in dairy industry to clean all dairy processing equipment which is heated separately by using oil and gas as a fuel or electrical energy. This amount of energy required for water heating is saved by recovering and utilizing heat dissipated to atmosphere through condenser is recovered using a heat pump which saves the strain on the electric energy used to heat the water separately and eventually helped lessening the expenditure. An attempt has been made to design a tube in tube type heat exchanger capable to recover heat during the condensation process. Experimental investigations are done for water instead of milk which has nearly similar properties. In this paper energy saving potential in 150 litre capacity bulk milk cooler through heat recovery tube in tube type heat exchanger. It is revealed that there is considerable energy saving potential in bulk milk cooling systems. Significant improvements have been achieved and coefficient of performance (COP) of the system is about 2.73**

***Keywords* -- Energy Saving, Bulk Milk Chiller, Waste Heat Recovery, Tube in Tube Heat Exchanger**

## I. Introduction

Energy is one of the most important building block in human development and as such, acts as a key factor in determining the economic development of all countries. In an effort to meet the demands of a developing nation, the Indian energy sector has witnessed a rapid growth. Areas like the resource exploration and exploitation, capacity additions, and energy sector reforms have been revolutionized. However, resource augmentation and growth in energy supply have failed to meet the ever increasing demands exerted by the multiplying population, rapid urbanization and progressing economy. Hence, serious energy shortages continue to plague India, forcing it to rely heavily on imports.

- Driven by the rising population, expanding economy and a quest for improved quality of life, the total primary energy demand in India grows at 3.1% per annum on average in 2008-2035 and overall increase of 127 %.
- India's natural gas consumption is projected to rise from 8.5 % to 13 % in the period of year 2012-13 to 2021-22.The combination share of oil and natural gas in energy consumption was 24.7 % in 2011-12 and is expected to be same in 2021-22
- The use of coal for electricity generation in India is expected to increase by 1.5 %per annum during 2012-22, thus requiring an additional 66,600 MW of coal-fired capacity.
- Oil demand in India is expected to increase by 6-7% per annum during year 2012 - 25.

There is, therefore, an urgent need to conserve energy and reduce energy requirements by demand-side management and by adopting more efficient technologies in all sectors. One of the energy saving approach is thus by retrofitting a waste heat recovery system.

### *A. What does waste heat recovery means???*

Waste heat, in the most general sense, is the energy associated with the waste streams of air, exhaust gases, and/or liquids that leave the boundaries of a plant or building and enter the environment. It is implicit that these streams eventually mix with the atmospheric air or the groundwater and that the energy, in these streams, becomes unavailable as useful energy. The essential quality of heat is not the amount but rather its "value". The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. The absorption of waste energy by the environment is often termed thermal pollution.

In a more restricted definition, waste heat is that energy which is rejected from a process at a temperature high enough above the ambient temperature to permit the economic recovery of some fraction of that energy for useful purposes.

### B. *Waste Heat Recovery Opportunities in Industry*

Different industrial processes consume different amounts of energy and produce different quantities and qualities of waste heat. To take advantage of the potential of industrial waste heat, it is therefore essential to look into and analyse the industrial processes used in large energy consuming industries and to investigate what suitable waste heat recovery methods can be applied to the systems of each sector.

Following are some of the applications through which waste heat can be recovered.

1) *Iron and Steel Industry*: Iron and steel production is a resource and energy intensive process which involves extensive amounts of heat and raw material. Waste heat recovery in the iron and steel industry includes recovering heat dissipated from high-temperature sources such as furnaces used for sinter, coke, iron, and steel production, which is investigated to account for roughly 8% of the overall industrial energy consumption in the UK.

TABLE I
Comparison of different WHR methods

| Process | Description | Observations and remarks |
|---|---|---|
| Solid slag impingement process | In this process, the stream of liquid slag is fragmented and turned into granules and particles through striking the stream into previously solidified particles. The recycled particles with the slag granules are then fed to a fluidised bed, where heat recovery is conducted. | The heat is recovered through adjusting the product temperature to 500-800°C by controlling the ratio of recycled to liquid slag in the fluidised bed. This process generated steam with a temperature up to 250°C and a heat recovery rate up to about 65%. |
| Mechanical stirring process | This process includes striking and crushing the molten slag with the use of rotating blades or moving sticks. Through this action, heat is recovered in a container by radiation and conduction to water pipes. Then the crushed particles are discharged into a fluidised bed to recover additional process. | With the use of a waste heat boiler in the final stage of the process a recovery efficiency of up to 59% through this method can be achieved. |
| Rotating drum process | Through this process, a stream of molten slag is broken up into particles as it is poured onto a rotating drum. The particles are then fed into a fluidised bed where heat is recovered. | This process has been tested in full scale and has been proven to recover 50-60% of the slag heat into a hot airflow. |
| Rotating cup atomiser (RCA) process | The process contains a high speed rotating cup which generates a centrifugal force and surface tension that can cause the breakup of the high temperature slag into particles. In this process, high temperature slag is gradually poured into the rotating cup and at the same time air is blown to recover heat from the hot particles. | The process produces hot air and solid granules which are then dropped into a fluidised bed for further heat recovery. This process has been tested commercially and has proven to recover 59% of the slag heat and cool down the slag particles to 250°C. |

2) *Food Industry:* Most baking processes in the food manufacturing sector involve use of gas-fired ovens. Only about one-third of the total energy used in these ovens adds value to the final product. The remaining two-thirds is discharged with the exhaust gases at 150-250oC and thus represents an opportunity for heat recovery. However, the low temperature range, fouling and presence of corrosive materials in the exhaust streams make heat recovery technically challenging and uneconomical. The existing low grade heat recovery technologies mostly use gas to liquid heat transfer to produce hot water for use in other areas of the manufacturing plant. The performance of these systems is governed by hot water demand in the factory and is therefore not recommended if there are frequent fluctuations in demand or if a more efficient technology, such as combined heat and power, is already in place. This study involves design, manufacturing and testing of a novel low-temperature gas to gas heat recovery system using an array of heat pipe heat exchangers, for industrial-scale baking ovens at a large confectionary manufacturing plant. Unlike gas to

liquid heat transfer, a gas to gas heat transfer system provides direct savings in oven fuel consumption, independent of the hot water and other energy demands elsewhere in the plant. The heat recovery potential of the system is estimated using a thermodynamic model developed based on energy and mass balance for the ovens. The design enables recovery of up to 50% of the energy available through the exhaust stack, increasing the energy efficiency of the overall process to 60% and reducing food manufacturing costs by one third.

3) *Automobile Industry:* Increasing production of automobiles is the key driver for the growth of this market. Since the production of automobiles involves the generation of waste materials, many manufacturers are now recycling these waste materials as it helps to resolve supply shortage during the manufacturing process. Automotive waste management involves the reuse and recycling of waste materials like metal, solvents, batteries, plastic, and glass. Recycling of these materials helps vendors to address environmental concerns and also allows them to address the issue of resource depletion.

### *C. Why bulk milk chillers?*

A bulk of milk in India flows from the farmers to the processing plants via intermediate milk chilling centers. These are establishments which collect milk primarily from farmers, cool it down and then send it over to the main processing facility. Typical capacity in India varies between 20,000-50,000 liters of milk per day (there are much larger Chilling Centers as well). At the milk chilling center, milk is collected in cans from farmers, and cooled using a chiller. These cans are then cleaned using hot water (typically 45ºC) and then sent back. If cold water is used, the fat/oil is not adequately removed, and can lead to poor quality milk and microbial growth. Hot water at 80ºC is also required for doing CIP (cleaning-in-place) of the receiving tank, like a bulk milk chiller.

1) Current Scenario: For producing hot water, existing systems include boilers, hot water generators, electric heaters and solar heaters.

- Wood boilers are quite common, but availability of wood, maintenance is a major challenge, and it is quite common that because of the above two problems, close to 30-50% of the days, the boiler is not operational, and the cans are cleaned using normal water.
- Electric heaters are quite stable and generate reliable output, but there is a dependency on reliable grid connection, in the absence of which, diesel gensets are run to support the electric heaters, which are quite expensive. Further, many electric heaters are used in dangerous conditions, with exposed elements, and the danger of electrical shocks is not trivial.
- Solar heaters are very unreliable and depend heavily on atmospheric conditions. They tend to work only 7-8 months a year, 8 hours a day, and during the seasons where heat is not really a challenge. Most solar thermal installations in the country for this particular application haven't really been useful.

As milk collection centres run all year round and considering above factors it will be more beneficial to recover the waste heat from bulk milk chillers, so preferred.

## II. System design & description

### *A. Proposed solution*

The basic setup of BMC plant have been modified and shown in below figure.

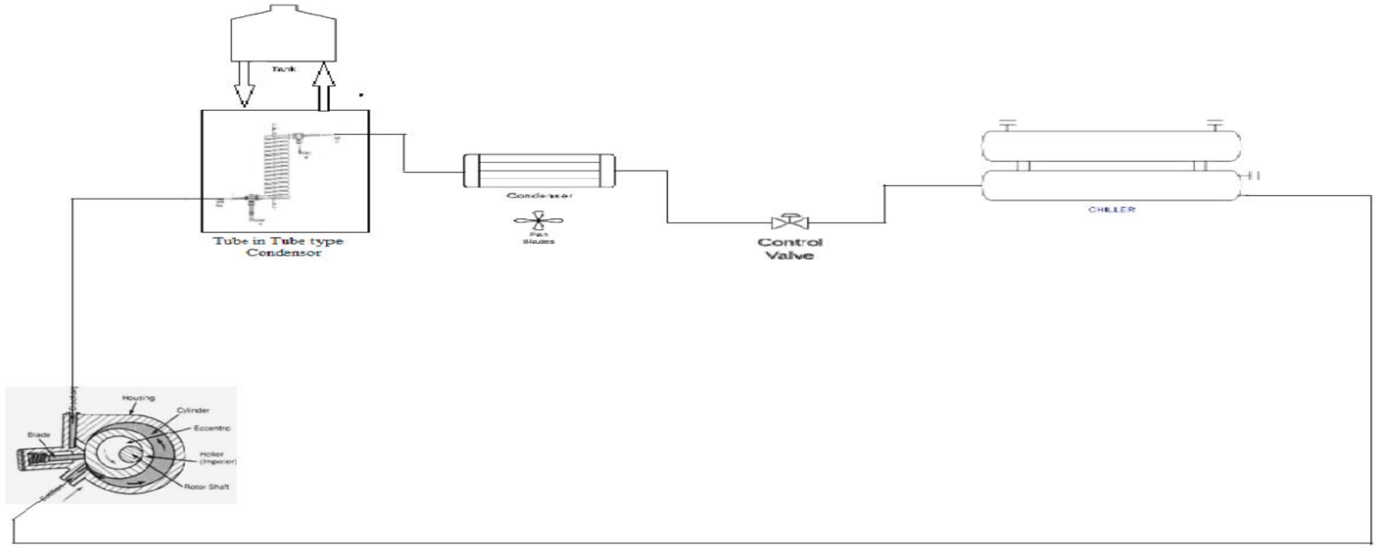



Fig. 1: System Setup

### *B. Various Components & their selection*

1) Scroll Compressor
2) Tube in Tube HX
3) Finned Tube HX
4) TXV
5) Chiller

*1) Scroll Compressor:* Scroll compressor has a moving scroll which creates pressure. Scroll compressors are more efficient as their operation is quieter and smoother than reciprocating ones. Also they are highly reliable and less prone to mechanical failures. Hence as per the system requirement a scroll compressor is used.

*2) Tube in tube heat exchanger*: The equipment consists of a single tube mounted inside an outer shell tube, so that the product medium flows counter-current through the inner tube, with the service medium around it. The unit features a fully welded construction with a bellow-on-shell tube to absorb thermal expansion. The shell tube is always smooth while the product tube is either corrugated or smooth depending on the application. The installation is maintenance free, thus eliminating any need for spare parts. This unique, compact design prevents thermal fatigue, increases efficiency and reduces the overall size. It is ideal for high temperature, high pressure and low flow applications. The layout of tube-in-tube heat exchangers can be customised to fit the available installation foot print or other customer requests.


Fig. 2: Tube in tube HX

3) *Finned tube heat exchanger:* Finned tube heat exchangers have tubes with extended outer surface area or fins to enhance the heat transfer rate from the additional area of fins. Finned tubes or tubes with extended outer surface area enhance the heat transfer rate by increasing the effective heat transfer area between the tubes and surrounding fluid. The fluid surrounding finned tubes maybe process fluid or air.

Fig. 3: Finned tube HX

4) *TXV:* Thermal expansion valve or thermostatic expansion valve is a component used in the above system which controls the amount of refrigerant released into the evaporator, thus ensuring that the only phase in which refrigerant leaves the evaporator is vapour.
5) *Chiller:* This is the actual milk storage space which is a HX that chills milk from 35º C to 4º C & maintains it at that temperature.

### *C. Working*

As seen in the proposed solution, the main components are scroll compressor, tube in tube type of heat exchanger, fin tube type heat exchanger, bulk milk chiller section, TXV and storage tank. When hot water is desired, the heat is dissipated using tube in tube type heat exchanger and the working cycle is as follows:

High pressure, high temperature vapour refrigerant after being compressed by scroll compressor goes to the tube in tube type heat exchanger, where the hot refrigerant dissipates heat to the cold water and then it passes through TXV to the evaporator

When hot water is not desired and the system is in normal working condition, then the fin tube heat exchanger is active in the system and the working cycle is from compressor to the fin tube type heat exchanger, where heat is dissipated to the atmosphere by using force convection with the help of fan and thus low temperature liquid refrigerant goes to TXV followed by the evaporator.

### *D. Calculations*

1) Amount of energy required to heat 150 litres of water in 1 hour. Thus the mass flow rate is

$$\dot{m} = \frac{150}{3600} = 0.04166\ kg/sec$$

Thus the amount of energy required to raise the temperature of water by 30º C is

$$Q = \dot{m}\ Cp\ \Delta T$$

$$= 0.04166 * 4.187 * 30$$

$$= 5.2329\ kW$$

So, the temperature of circulated water lies in the range of 20-55º C.

2) Height of tube in tube heat exchanger

$$L = N\sqrt{(2 * \Pi * r)^2 + p^2}$$

Where,

L = length of HX

N = No. of turns of coil

p = Pitch

d = Diameter of tube

But $p = 1.5 * d$

& L = 1500mm $d = 15\ mm$

Thus, $p = 1.5 * 15$

$p = 22.5\ mm$

So $L = N * \sqrt{(2 * 7.5)^2 + (22.5)^2}$

$\mathbf{N = 28.72 \approx 29}$

Height (H) $= N * p + d$

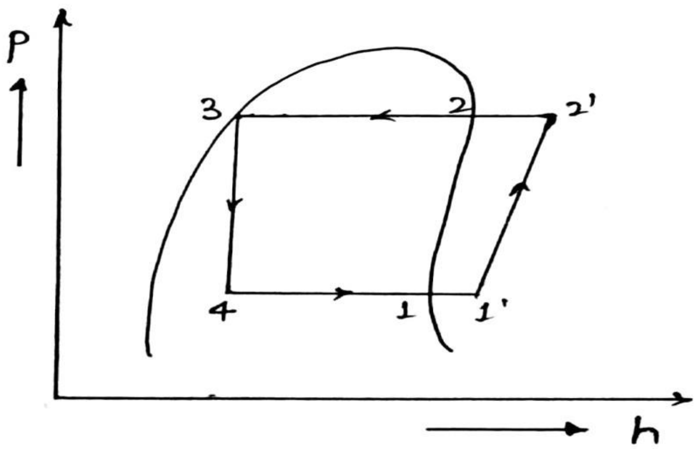
$= 29 * 22.5 + 15$

$= 667.5\ mm$

$\mathbf{H\ \ = 0.6675\ m}$

Thus the height of tube in tube HX is 0.6675 m

3) COP of the proposed solution



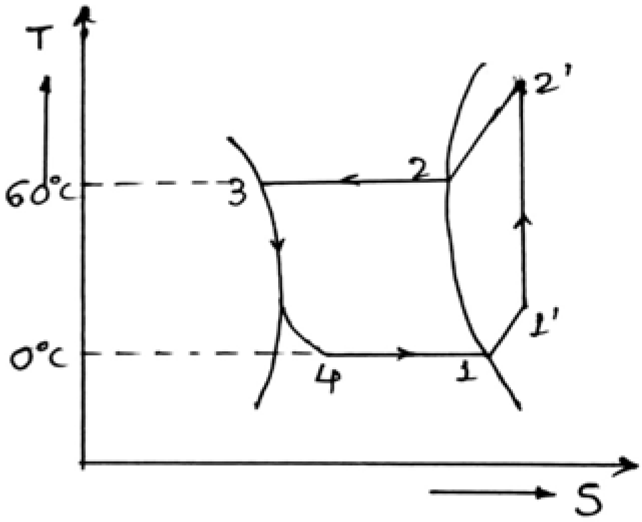




Fig.4 : Ph & TS diagram for proposed solution

TABLE II

Calculated values by using formulas & above Ph & TS diagram

| Refrigerant name | Properties | Value |
|---|---|---|
| 407c | $C_{pg}$ | 1.107 $\frac{kJ}{kgK}$ |
| | $C_{pf}$ | 1.533 $\frac{kJ}{kgK}$ |
| | $h_1$ | 424.973 $\frac{kJ}{kg}$ |
| | $h_2$ | 470.04 $\frac{kJ}{kg}$ |
| | $h_3$ | 302.2 $\frac{kJ}{kg}$ |
| | $h_4$ | 302.2 $\frac{kJ}{kg}$ |
| | $S_1$ | 1.8326 $\frac{kJ}{kgK}$ |
| | $S_2$ | 1.8326 $\frac{kJ}{kgK}$ |
| | $T_1 = T_4$ | 0° C |
| | $T_2 = T_3$ | 60° C |
| | $T_1^{'}$ | 10° C |
| | $T_2^{'}$ | 83.25° C |

The COP of the system is calculated as follow

$$\dot{m} = \frac{150}{3600} = 0.0416\,\frac{kg}{sec}$$

But Refrigerating effect $Q_E = \dot{m}\,(h_1 - h_4)$

$$= 0.0416\,(424.97 - 302.2)$$

$$\mathbf{Q_E = 5.1154\ kW}$$

Also work done, $WD = \dot{m} * (h_2 - h_1)$

$$= 0.0416\,(470.04 - 424.973)$$

$$\mathbf{WD = 1.8749\ \mathit{kW}}$$

Therefore, $COP = \frac{Q_E}{WD} = \frac{5.1154}{1.8749} = 2.73$

The COP of the proposed solution is 2.73

## III. Conclusion

From the above investigation, it has been perceived that by supplanting the normal bulk milk chiller by this system will vanguards to rescue cost on heating water. Thus saving energy which would have been utilized by electric heater, LPG gas , boilers etc. This not only saves the cost but also it bulwarks the environment by truncating global warming engendered because of heat dissipation to the atmosphere. Also, the hot water produced can be utilized for washing milk containers and other basic purpose. Thus it is advised to use waste heat recovery system wherever possible to increase the energy efficiency of bulk milk chillers.

**Acknowledgement**

We thank our colleagues from Department of Mechanical Engineering, Smt. Kashibai Navale College of Engineering who provided insight and expertise that greatly assisted the research.

We thank Prof. R. R. Yenare (Asst. Prof. Smt. Kashibai Navale College of Engineering) for assisting with his valuable guidance that greatly improved the research work. We would also like to show our gratitude to (Mr. Sahil Belsare & Youthcon Creative Solutions) for sharing their pearls of wisdom with us during the course of this research.

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