Solar Thermal Energy Utilization in Food Processing Industry in India.

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ABSTRACT

Food processing is an important industry in every economy, and India is no exception. In the Indian Food Processing Industry, sweetmeat production covers a wide area and sweetmeats are widely popular with consumers both in the country and abroad. This industry can be identified as a prospective area for the application of solar thermal energy systems because the relatively lower temperature at which the processes are carried out here can be achieved easily through solar heating. Again, since solar radiation is available in abundance in the country, this is a quite feasible solution.

Considered from the point of view of cleanliness, which is a vital requirement in the food processing industry, the application of solar energy could be a big advantage for this industry. In this study, the possibility of application, importance, and advantages of using the solar thermal energy systems for heating purposes in the Indian sweetmeat industry has been explained.

From many aspects, a solar thermal system that is tailor-made for the sweetmeat industry would prove to be quite beneficial to the industry. The thrust of the study is on the technical side in order to make the system functionally acceptable. The design modification for the purpose of cost reduction has also been taken care of.

A brief thermal and economic analysis has also been presented here. The payback period, which is a crude one, along with the Net Present Value and Internal Rate of Return, which is more of a financial indicator, has been calculated for a specific discount rate over a 10 year period of time for the system. In the thermal analysis part of this study, recorded temperatures have been plotted as against the radiation available for different months, rather than in a direct calculation of heat available at the heat exchanger against heat energy incident on the concentrator.

(Keywords: food processing industry, solar parabolic concentrator, thermal system, heat exchanger, solar radiation, sweetmeat)

INTRODUCTION

The food processing industry in India plays an important role in the country's economic development as a result of the vital linkages and synergies that it promotes between the industrial and the agricultural sector, the two most important sectors in the Indian economy. Presently, the world's second largest producer of food products second only to China, India has the potential of being the largest producer, thereof surpassing China, given that India's food and agricultural sector contributes are around 26% of the country's annual GDP.

The Indian food processing industry has shown signs of potential for higher growth and profitability in the coming years. According to an estimate, there will be a phenomenal deployment of capital, human resources, modern technology, and finance of over INR 140 billion in this industry in the next decade [1].

Production of sweetmeat is an important area of traditional food processing industry in India. Apart from generating huge employment to the people, especially in the rural areas, the sweetmeat industry in India also contributes to the national economy by producing high sales turnover every year. But as of now, sweetmeat production is principally confined to the small scale sector in the economy. For ages, a significant proportion of India's production of milk has been used in the country for preparing a wide variety of dairy delicacies and sweetmeats. In order to overcome the basic limitation of milk, that is, its perishable nature, various methods of milk processing have been introduced in the country over the past centuries, all of which help in extending the shelf-life of milk.

In the process, diverse methods of preparing and preserving milk products have been developed. It has been estimated that 50 to 55% of the milk produced in India [2] annually is converted into a variety of traditional sweetmeats and other milk products by the use of various processes like coagulation, desiccation, and fermentation. But over the centuries, these processes have largely remained unchanged and undeveloped, being totally in the hands of halwais or the traditional Indian sweetmeat makers, who form the core of this small scale industry.

Milk is a major, if not indispensable, ingredient of Indian sweetmeats. The major Indian sweetmeat delicacies like rasagolla, sandesh, burfi, kulfi, kalakand, shrikhand, gulabjamun, chumchum, halwa, etc,. are all milk-based items. Concentrated items like Basundi, Kheer, Khurchan, Payasam, Rabri, etc., are also prepared by drying out water from milk.

Milk in India is mostly produced in the rural areas. It is quite evident that if treated and processed properly, it can be a good source of income for the rural producers. In the production of sweetmeats, 'Khoa', a product prepared from milk [9] is a vital and quite common ingredient. This Khoa is a highly concentrated form of milk having high nutritional value and capable of being preserved as such for several days. It is used as an ingredient in making different kinds of traditional Indian sweetmeats like Burfi, Gulabjamun, Kalajam, Kalakand, Lalmohan, Peda, etc. It is estimated that some 900,000 tonnes of Khoa valued at INR 45,000 million is presently produced in the country.

The value of Khoa and Chhana, a solid product prepared from milk by the process of fermentation, produced in the country every year is estimated to be twice the value of all milk handled by the organized sector. According to another estimate, the value of Khoa and chhana-based sweets produced in the country could possibly exceed INR 13 billion [3]. Khoa is at present being prepared by using conventional fuel, to be more specific, fuel wood in rural areas and liquified petroleum gas (LPG) or electricity in the urban areas,depending upon the position of the producer on income based ladder [4]. However, as solar radiation is available everywhere in India in abundance, as an alternative to the above conventional systems, solar thermal systems can be used even in the rural areas.

Mention may be made here of the fact that in India, any place in average receives solar radiation of 3000 to 3200 hours per year, delivering about 2000 kWh/m^2 of solar radiation on the horizontal surface per year [5]. The technological advances in the field of solar hot water applications have led to a high degree of maturity of current commercially available systems. However, the performance and the reliability of solar hot water systems will be always at the mercy of a number of design and construction parameters, some of which are well known, whereas others are still not adequately understood.

Good engineering practices are facilitated by packaged systems. However, due to the unique features of a particular application, a system tailored approach has frequently to be taken for each design and installation. Impressive performance improvements may be obtained in some existing systems by successfully employing simple measures or devices, as a result of a physical understanding of the system's operation.

While the numerous design tools and analytical models available are indispensable for the proper design of solar systems, it is the view of the author that equal consideration should be given to all practical features pertaining to their installation, operation, and durability, particularly when such features cannot be readily incorporated as parameters in analytical models. Energy is the main ingredient of small scale as well as large scale industries. In India, the use of conventional energy dominates the industrial scenario, both in the small scale and the large scale sector. However, India's oil reserve is only 700 million tonnes as compared to the world reserve of 1,42,700 million tonnes [6]. This being the background, the oil import bill of India has presently reached as high as INR 800 billion [7].

Small scale food processing units, commonly known as sweetmeat shops are in very large numbers in India and their annual sales turnover is estimated to be INR 150 billion [8]. Many of the food items are based on milk and this includes many deep fried varieties. Concentrated semi-dried milk Khoa is produced by prolonged boiling of milk in shallow pans and drying it to a total solid amount of about 70 percent through a process of rapid evaporation of its water content. It takes time and a good amount of energy to dry the water which constitutes a big part of the total volume of the milk. A slow boiling of milk is usually preferred in the production of Khoa and the temperature required is not very high, around 1,000C.

While producing Khoa in this traditional manner, a lot of heat energy goes to waste, but this can possibly be recovered in a system with a built-in waste heat recovery mechanism. It is also worth mentioning here that evaporation of milk in a typical Indian karahi[1] consumes almost five times more energy than in a vacuum evaporator. Alternatively this heating of the milk for producing khoa can also be done by using concentrated solar radiation which not only keeps the environment clean but is also completely emission free. In this study the application of solar thermal systems by using parabolic concentrators in the production of Khoa has been taken up and discussed in detail.

PARABOLIC CONCENTRATOR SYSTEM

By using parabolic concentrators, the aperture required to attain the working temperature of a heat-transfer fluid can be computed and the required heat flow can also be determined, which together would determine the overall size of the concentrator. Industrial process heat using this parabolic concentrator has already been developed earlier in many countries.

In order to deliver the required temperature with good efficiency, a high performance solar collector is required. Systems with light structures and low cost technology for process heat applications up to 2,500C could complete the variety of solar thermal collectors [10]. Parabolic trough collectors (PTC) can effectively produce heat at temperatures between 500C and 4,000C. The biggest application of this type of system is in the Southern California power plants, known as Solar Electric Generating Systems (SEGS), which have a total installed capacity of 354 MWe [11].

[1] Karahi is a big deep bottom pan typically used in Indian households and shops for frying food products in oil.

During 1999-2000, another Direct Steam Generation Process under real solar conditions for more than 3,000 hours was implemented at the Plataforma Solar de Almeria (PSA) [12]. Another Solar Electric Generating Systems model based on the absorber wall temperature rather than fluid bulk temperature in order to predict the performance of the collector with any working fluid has been tested at Sandia National Laboratory for measuring the thermal performance of a trough collector using Syltherm 800 oil as the working fluid.

An efficiency equation for trough collectors was developed and used by Odeh et al. [13] in a simulation model to evaluate the performance of direct steam generation collectors for different radiation conditions and different absorber tube sizes. Other applications of PTC collectors are reported by Bakos et al. [14] and Kalogirou et al. [15]. After a period of research and commercial development of the parabolic trough collectors in the 1980s, a number of companies had entered into the field of producing this type of collector.

The Industrial Solar Technology (IST) Corporation is one of the leading producers of Solar Collectors in the United States. It erected several process heat installations in the United States with up to 2700m^2 of collector aperture area [16]. The performance equation of the collector as given by the manufacturer is:

$$n = 0.762 - 0.2125\left(\frac{\Delta T}{G_b}\right) - 0.001672\left(\frac{\Delta T}{G_b}\right)^2$$

where ΔT = temperature difference (Tin-Ta);
Gb = beam solar radiation (W/m2);
Tin = collector inlet temperature (°C);
Ta = ambient temperature (°C).

Experimental Set up

The Research and Development program of the solar parabolic concentrator under study involves the developments of a low cost solar heating system for food processing industry, in general, and in sweetmeat industry, in particular. Working in association with the local sweetmeat production units, it was ascertained that the operating temperature required for preparation of sugar juice and Khoa is in the range of 95^{o}C to 101^{o}C while for heating oil for the preparation of fried sweetmeats like Jelabi, Amriti, etc., the temperature required is 180^0C to 190^0C. Field measurements have been carried out with an infrared thermometer. The solar heat is conducted to the evaporating container or frying pan with the help of a heat-transfer fluid which. After transferring, the heat returns again to the concentrator [18] forming a closed heating-loop where contamination can easily be prevented. It is necessary to have an efficient heat exchanger but it is equally important to shape it in such a way as to accommodate the traditional boiling/frying-pan for user friendliness. Being highly diffused, the solar radiant energy generally needs concentrating systems even for temperatures above 100^oC.

A typical shell and tube heat exchanger which is one of the most critical components of the system has been designed after a thorough literature survey [22-26]. The heat exchanger so developed works well and further improvements have been done. Heat transfer is always better and quicker for higher temperature differentials, but production of higher temperature through solar thermal system involves the concentration of radiation over a larger area thereby increasing the cost of the concentrator.

At lower temperature differentials, the heat flow rate would be lower would require additional processing for an equivalent amount of energy. After cost-benefit analysis, it has been decided to develop a system with a temperature differential in the range of 50^0C initially, and progressively increase using the same design and operational experience. A Parabolic Trough Concentrator with a heat collector in the form of a coated copper tube carrying a heat transfer fluid, transfers heat to the processing container (essentially a flat bottom pan) through a heat exchanger. This has the advantages of the facility of controlling temperature as well as heat flow rate and secondly higher system efficiency.

Coated copper tube is provided with a glass jacket to reduce convective heat loss but no attempt has been made for evacuated jacketing of the absorber tube so that the cost of the system may be kept low. A heat transfer fluid called Therminol 55 is pumped through the absorber tube that is connected in zigzag fashion under the cooking pot for exchanging heat to the item being cooked. Therminol 55 is a unique, synthetic heat transfer fluid designed to provide reliable, consistent heat transfer performance over a long life.

This heat transfer fluid is a superior cost-performance alternative to common mineral oil-based heat transfer fluids. Its optimum use range is from -25°C to 290°C [17]. On sunny days, when average solar radiation is 600W/m², the temperature rises above 150°C in the collector tube and the input temperature at the cooking pot can set at a level suitable for processing milk for sweetmeat production. On the basis of calculation made the concentrator and the heat exchanger were designed. The concentrator and heat exchanger specifications are given below:

Concentrator material:	Anodized aluminum
Length of the concentrator:	2.4 m
Collection area:	2.88 sq.m
Reflectivity of the concentrator:	0.85
Receiver tube material:	Copper with black chrome coating
Receiver tube diameter:	40mm
Outer Glass tube (jacket) diameter:	65 mm
Amount of thermic fluid in pipeline:	24 litre
Concentration ratio:	32
Inclination angle:	22.50

The arrangements for a single axis manual tracking are required to be provided to optimize the solar energy collection and the tubes are to be kept at an inclination of local latitude for the same purpose. Three RTD sensors (accuracy ±0.10C) TK1, TK2, and TK3 are installed to measure the temperature at different points in the fabricated system; one at the inlet of the absorber tube TK2, one at the outlet of the absorber tube TK1, and the third after the heat exchanger TK3, as given in the Figure 1.

A radiation pyroheliometer (accuracy ± 2%) is placed on the horizontal plane for measuring the direct solar irradiance. The effectiveness of insulation of the pipeline follows the law of decreasing returns and an increased thickness being uneconomical as it can not be recovered through small heat savings. An economical thickness of insulation is thus calculated. The entire bare pipeline has been insulated at this thickness with glass wool.

RESULTS

The data obtained from the experimentation with the Solar Parabolic Concentrator and the data supplied by a local manufacturer of sweetmeat products give us the following results:

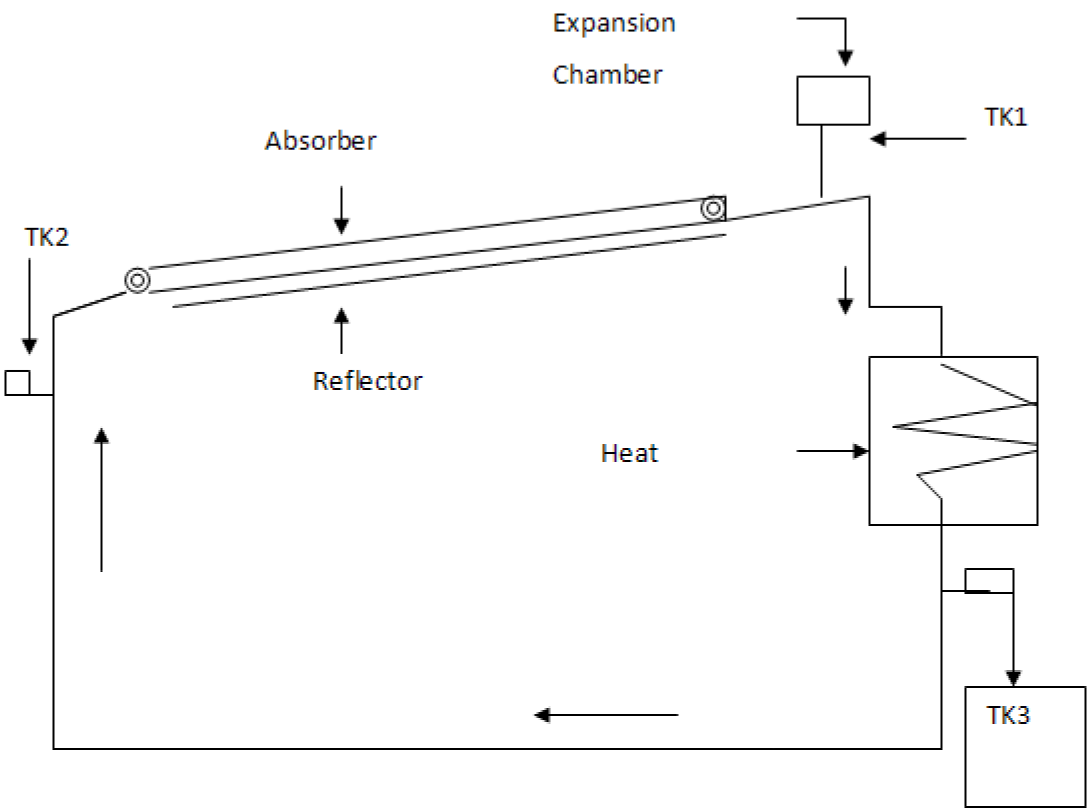

Figure 1: Flow Diagram of Concentrator-Heat Exchanger System.

Analysis

LPG burner replaced:

1kg of LPG emits 3.20 kg of CO_2, and 0.0056 kg of CO in the atmosphere [19].

No of cylinder used(per day)	LPG content per cylinder (Kg)	LPG used per day(Kg)
4	17	68

Considering 250 days of operation in a year:

LPG used (Kg/yr)	CO2 emitted (yr)	CO emitted (yr)
17000	54.4 tons	0.42 tons

Economic Analysis

LPG used per day (Kg)	No. of pieces Sweets produced (per day)	Average price (INR)	Daily turn over (INR)	Yearly turnover (Million INR)
68	10000	2	20000	7.2

Considering total turnover is INR 200 billion in sweetmeat industry

Yearly turnover (Million INR)	CO2 mitigated (Ton)	CO mitigated (Ton)
7.2	54.4	0.42
200000	1510000	11600

Cost Benefit Analysis of Solar Heating System [20]

A	Collection area	2.88 m2
B	Solar insolation available	5.5 kWh/sq.m/day
C	Temperature of hot milk	100 °C
D	Ambient temperature	25 °C
E	Assumed market rate of return	8%
F	Cumulative discount factor @ 8% for 10 years	6.709
G	Cost of electricity	INR 4/kWh

H	Efficiency of electrical heater	80% ~ 90%
I	Efficiency of solar system	50%
J	Life of the system	10 yrs
K	Heat available from Solar System	5.5´2.88´0.5 kcal/day
L	Saving in electricity consumption per day	7.92/0.9 = 8.8 kWhr
M	Cost of electricity saved	8.8´250´4 = INR8800.00
N	Total savings during 10 years of system's life (INR 8800´6.709)	Total savings during 10 years of system's life (INR 8800´6.709)
O	Cost of the solar system	INR 35000.00
P	Yearly Cost of Therminol 55 (Heat transfer fluid)	INR 2400.00
Q	Yearly maintenance cost @ 2 man day per year	INR 700.00
R	Total yearly expenditure on the solar system	INR 3100.00
S	Total expenditure on the system during 10 years (INR 3100´ 6.709)	INR 20797.00
T	Present Value of Total outflow (S + O)	INR 55797.00
U	Present value of Total Inflow	INR 59039.00
V	Net Present Value (U – T)	INR 3242.00
W	Pay back period (O/M)	4 years approx
X	Internal Rate of Return	9.3 %

Benefits

In the above Cost-Benefit Analysis, considering the present market scenario in India, the market rate of return has been assumed to be 8%. This means that on a general investment made in the market, the investor can reasonably expect a return of 8%. This also implies that any decision to invest an amount of money into an alternative venture will depend upon whether or not the alternative venture gives the investor a higher return. The efficiency of solar systems is 50% and their life is expected to extend over 10 years. The temperatures (T1, T2, and T3) recorded in the RTDs installed in different months have been given in Figures 3, 4, 5 and 6 against total global radiation. Here T1 is the highest recorded temperature, T2, and T3 are almost equal with T2 being a bit lower than T3. The wind speed has not been taken into consideration here as the insolation might have fluctuated due to this. The evaporation rate against the length of the heat exchanger in the use phase has been plotted in Figure 2.

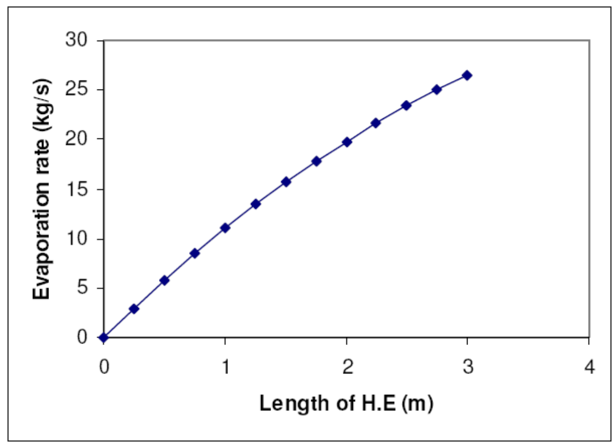

Figure 2: Evaporation Rate vs. Heat Exchanger Length.

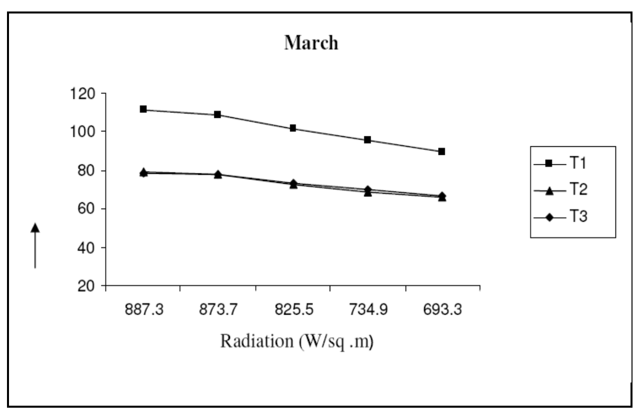

Figure 3: Temperature at Three Sensors Against Radiation in March.

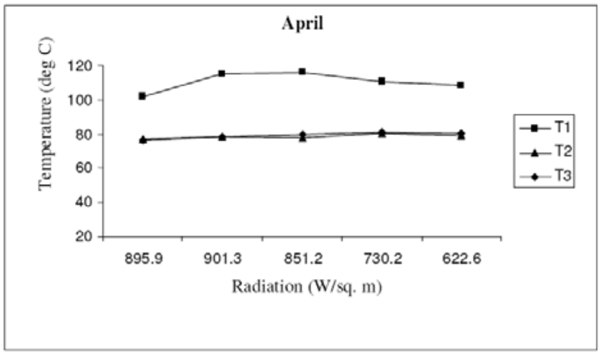

Figure 4: Temperature at Three Sensors Against Radiation in April.

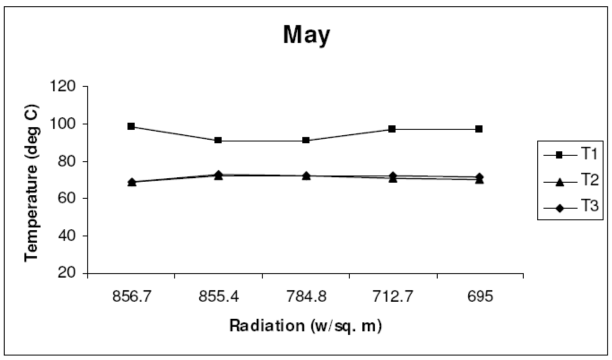

Figure 5: Temperature at Three Sensors Against Radiation in May.

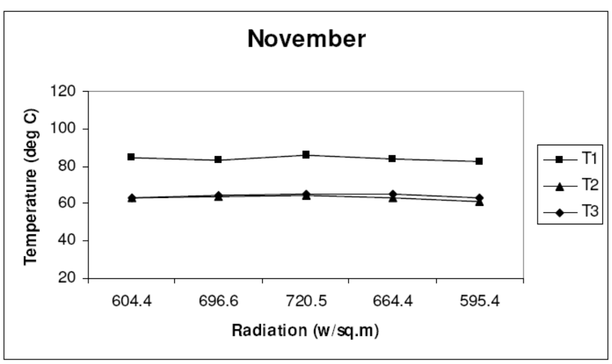

Figure 6: Temperature at Three Sensors Against Radiation in November.

Environmental Benefits

Problems associated with energy supply and use are related not only to global warming but also to other environmental impacts such as air pollution, acid precipitation, ozone depletion, forest destruction, and emission of radioactive substances [21]. Today, much evidence exists which suggests the future of our planet and of the generations to come will be negatively affected if human beings keep degrading the environment. It is true that solar systems are not inherently sustainable. The negative environmental impact of solar energy systems include land displacement and possible air and water pollution resulting from manufacturing, normal maintenance operations, and demolition of the systems. However, land use is not a problem when collectors are mounted on the roofs of buildings, the maintenance required is minimal, and the pollution caused by demolition is not greater than the pollution caused from demolition of a conventional system of the same capacity.

CONCLUSION

Solar energy is available abundantly in the country and can be used to good benefit in sweetmeat production. Ordinarily, insolation of around 600 W/m^2 is not considered to be sufficient for attaining the required temperatures. With the help of concentrators, higher temperatures can be achieved and solar heating systems with concentrators can be effectively used in this particular industry. This basic principle is very simple but the development of such systems in India for this particular area of application have so far been overlooked by the solar energy technologists.

There are undoubtedly many problems in the utilization of solar heating principally because of the hygienic conditions required to be maintained in the food processing industries. In this typical application, low temperature processing heat exchangers are considered to be the most critical component of the solar thermal system because the heat exchanger responsible for the easy transfer of heat is to be a very special one allowing efficient heat transfer and also allowing the use of traditional containers used in this industry.

Post heat cleaning and easy removal of the container after the heating cycles are important requirements of the heating system. As a result the heat exchanger should preferably allow heating from the bottom and there should not be any direct contact of the heat exchanger with the liquid under process, which has been taken as milk in this case, to avoid contamination. However, such heat exchangers will be of lower efficiency. The temperature differential also being low, the amount of heat finally transferred to the milk will be at a very slow rate. Temperatures attained at the RTDs are very satisfactory and the system will definitely attract the attention of the planners and it is expected that it will be used in a good number of areas in the near future.

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