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Scraped Surface Heat Exchanger for Dairy Industry- A Review

J. B. RAOL[1] AND A. G. BHADANIA [2]

Department of Dairy Engineering, S. M. C. College of Dairy Science,
Anand Agricultural University, Anand-388 110 (Gujarat)

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ABSTRACT

Scraped surface heat exchanger (SSHE) is more suitable for heat transfer for viscous and heat sensitive products in dairy industry. It is easier to control time, temperature and pressure in a SSHE than in a kettle. The use of SSHE for the manufacture traditional Indian Dairy Product helps in reducing man power and improving quality as well as shelf life of the product. SSHE of various design are being used for manufacture of TIDP as well as for western product such as icecream, cheese etc. The choice and design of heat exchanger depends on Flow rate of both streams, Heat sensitivity and corrosivity of the fluids, Terminal temperatures, Properties of both streams, Operating pressure and temperature, Pressure drop, Fouling tendencies, Type and phase of fluids, Material of construction, Heat recovery, Flow arrangement etc. The scraping action of the blades rotating within the heat transfer tube continuously removes the product film from the heat exchanger surface and prevents burning-on, scaling or crystal build up on the wall. This type of heat exchangers can be used for batch or continuous heating or cooling of products. The major advantages of SSHE include short residence time in heated zone so heat sensitive product can be conveniently processed, high heat transfer coefficient, narrow residence time distribution, wide viscosity range, minimum surface fouling. SSHE basically consists of a cylindrical rotating shaft within a concentric hollow stationary cylinder so as to form an annular region along which the process fluid is pumped. In a typical SSHE there are usually two or four blades located periodically around the rotor throughout the product tube, though sometimes they are axially staggered in order to improve mixing. Liquid-full operation and thin-film operations are very commonly used in SSHE. Thermal and electrical energy are required in operations of SSHE. The electrical energy required for driving the rotor is very small as compared to the thermal energy required to evaporate the water. Structural design of SSHE includes the calculation of size, shape and strength of each component of the SSHE to handle the product efficiently, material of construction require to meet the requirements from the view point of food hygiene and sensory attributes of the product, the finish of the surface and the mechanical power to run the unit successfully and efficiently. More advanced designs of SSHE are available in the market for various applications. There is a good scope for SSHE to prepare indigenous milk products *viz.,* basundi, peda, khoa, halava or in general any khoa based sweets on commercial basis.

Key words : Scrape surface, dairy, heat exchanger.

Heating and cooling are among the most important unit operations of the dairy and food industry since almost all the food material is heated or cooled for a variety of reasons in one stage or the other during processing.

These operations are carried out to get the desired properties of the food material during processing for enabling the efficient operations as the properties of the material are temperature dependent, to increase or decrease the reaction rate, to preserve the food material by lowering the temperature or moisture content as the microbial growth and decay as well as chemical and biochemical reactions depend on the temperature and moisture content, to remove heat developed in mechanical operation, to get the desired characteristics of final product, to assist further processing operations, etc. (Kumbhar *et al.*,1985).

The equipment which are generally used to transfer thermal energy through a separating wall or by direct contact between two or more fluids are called heat exchangers. Scraped surface heat exchanger (SSHE) is more suitable for heat transfer for viscous and heat sensitive products. The mechanical action on the heating surface safe guards against fouling which

[1.] Assistant Professor, [2.] Professor and Head reduces the residence time distribution (RTD) and facilitates processing of difficult products. Flow patterns, mixing effects, residence time distribution, heat transfer and power requirements are the major parameters for design and performance evaluation of SSHE (Abichandani *et al.*, 1987 and Harrod, 1990). It is easier to control time, temperature and pressure in a SSHE than in a kettle (Alam, 1988). This makes it possible to achieve more even and improved quality in cooking of highly viscous products.

In India, many un-organized sectors manufacture indigenous milk products like basundi, peda, khoa etc. in open pan which involves lots of labour in preparation of these products. The use of SSHE for the manufacture of such product helps in reducing man power and improving quality as well as shelf life of the product (Rajshekhar *et al.*, 2001). To a great extent SSHE has replaced kettles for processing of fruit juices, jams, margarine, sugar concentrates and many other food products. It is reported that SSHEs are suitable for processing liquid food having suspended solid, high viscosity and non-Newtonian rheology (Christie and Shah, 1992; Dodeja *et al.*, 1992). Dodeja *et al.* (1989) reported the use of SSHE for the manufacture of UHT milk.

Application of SSHE for dairy industry

SSHE of various design are being used for manufacture of TIDP as well as for western product such as icecream, cheese etc. Manufacturing of various dairy products using scraped surface processing plant increases their shelf life (Rajorhia *et al.*,1991). The manufacturers of various SSHE have described the constructional and application of SSHE. (Anonymous, 1985). They include the coolmix (Fryma-Maschinen AG, Switzer land), Thermutator (Cherry- Burrel), Contherm (Alfa-Laval), Consistator (de Gesternberg, Denmark), Rota-pro(APV Crepa co), Fran Rica (USA) and Spiraflow (Heat Recovery System Ltd.,Watford UK). Applications claimed include UHT treatment of milk(Ready and Mathur,1991; Lewis,1993; Kjaerulff,1998), heating and cooling of various food products, protein concentrates, reconstituted milk, cream, ice cream, cheese, chocolate sauces and other viscous products (Abhichandani *et al.*,1989b; Ohlsoon, 1989), cooling molasses (Broadfoot *et al.*,1990), whey solids (Anon,1978), asceptic processing of fruits for yoghurt and icecream (Anon,1980, Smittcamp *et al.*, 1981), manufacture of khoa based sweets like gajar halwa, dudhi halwa, kheer (Upadhyay *et al.*,1993) and indigenous products like khoa, ghee(Bector *et al.*,1996). manufacture of ghee (Abhichandani *et al*, 1978, Savita and Dodeja, 2011), khoa (Dodeja *et al*, 1990a; Dodeja and Nand kisore,2011; Bhadania *et al.*, 2004a), UHT sterilization of milk (Abhichandani et al, 1978), Basudi (Rajshekhar *et al*, 2002; Patel Sunil, 2007; Dodeja; 2013), Milk evaporation(Kohli and Abhichandani, 1994), Rabri and Barafi (Dodeja, 2013), Sandesh (Patel and Bhadania,2004), Halwasan (Patel Sunil,2013).

Classification of heat exchangers and SSHEs

A large numbers of heat exchangers are available for heating and cooling operations in different industries such as dairy, food, chemical, pharmaceutical, etc. These heat exchangers can be classified in a number of ways such as according to transfer processes, degree of heat transfer, surface compactness, construction features, flow arrangements, number of fluids and heat transfer mechanism (Shah, 1981). In a direct contact type heat exchangers the heat is transferred through direct contact between hot and cold fluids; whereas in an indirect type, heat is transferred from hot fluid to cold fluid through a separating wall (Kumbhar *et al.*,1985). SSHEs are classified based on several ways such as scraper arrangement, blade clearance, design of product tube, etc. Abhichandani *et al.*, (1978) gave the detailed classification of SSHEs employed in dairy and food industries.

Factor affecting the selection and design of heat exchangers

The choice and design of heat exchanger depends on a large number of factors such as (1) Flow rate of both streams: The size-length, width, height, weight of any heat exchanger depends on the flow rates of both the streams. There may be limitations on the size of heat exchanger due to site requirement, lifting and servicing capabilities or inventory consideration. Therefore, accurate process flow are indispensable for sizing heat exchangers to meet required thermal thermal duties at the smallest pressure drop and to minimize capital cost (2) Heat sensitivity and corrosivity of the fluids: Some fluids are heat sensitive while some are corrosive in nature. Hold up volume, residence time and surface temperature are met by exchangers having good flow distribution, high heat transfer coefficient and small channel volumes. If the fluid is corrosive in nature, the corrosion resistant material should be used for construction. (3) Terminal temperatures: The performance of heat exchanger depends on the terminal temperature of the processed streams and is expressed in terms of number of heat transfer units. In general plate heat exchanger has more heat transfer units per pass than tubular heat exchanger. (4) Properties of both streams: Properties of fluid such as viscosity, thermal conductivity, density, specific heat etc. are used for determination of pumping and heat transfer rate. For low viscous fluid plate heat exchanger and for high viscous fluid SSHE is the best choice.(5) Operating pressure and temperature: Mechanical design of the exchanger depends on the operating temperature and pressure(6)Pressure drop: Pumping cost and heat transfer depends on pressure drop (7) Fouling tendencies: Velocity of the fluid, temperature of the surface on which foul forms, bulk fluid temperature and composition of the fluid affects the deposition of solid on the heat transfer surface. (8) Inspection-cleaning and extension possibilities: Heat exchanger should permit easy cleaning and inspection for fouling, leakage and corrosion. It should be possible to extend the exchanger to accommodate increased capacity of the dairy/food processing plant with minimum installation change and cost. (9) Type and phase of fluids: The choice depends on the viscosity of liquid and suspended solids. If condensable gas is to be used, tubular heat exchanger is the obvious choice (10) Material of construction: The type of material used for the construction of exchanger depends on the properties of the liquids, operating temperature and pressure, welding ease, availability, conformance to all applicable laws, codes and cost. SS 302, 304, 316 are used for the construction of the parts of equipments which directly come in contact with dairy/food materials. (11) Heat recovery: For heat recovery in excess of 50 %, the tubular heat exchanger will be seldomly used while plate heat exchanger can be used conveniently upto 95% heat recovery. (12) Flow arrangement: Counter current flow arrangement is thermodynamically superior, produces minimum thermal stress, takes minimum advantage of maximum advantage of the heat transfer surface, recurring the least heat transfer surface for given duty and maximum heat recovery (13)Cost of heat exchanger.

Scraped surface heat exchanger (SSHEs)

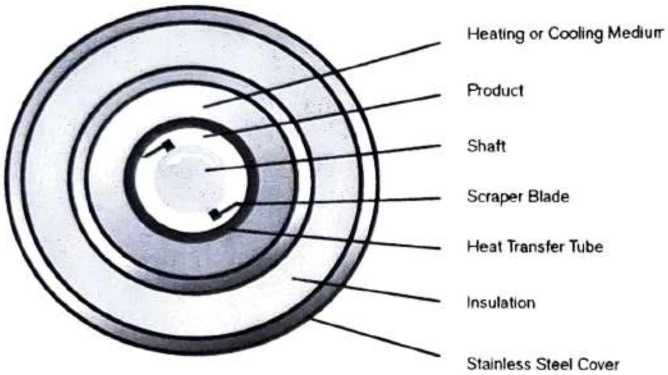
High viscosities and non-Newtonian behaviors of the processed fluids are often encountered in dairy and food field and tend to complicate their handling and to reduce the heat transfer rates in process equipment. In addition, the presence of solid food pieces causes additional problems related to the formation of solid deposits on hot surfaces. During heating, these deposits can eventually heat up to roasting temperatures altering the aromatic properties of the treated fluid. Some of these issues can be avoided or minimized by adopting a SSHE in place of shell and tubes or double-pipe heat exchangers. Unlike the simpler plate heat exchangers which are commonly used for low viscosity process fluids, SSHEs are designed to deal with the problems that arise when processing very viscous products. Foodstuffs such as margarine, ice-cream, chocolate, sauces, spreads, peanut butter, cream, caramel, purees, soups, salad dressings, yoghurt and jam are all routinely processed using SSHEs (Smith, *et al.*, 2010). The scraping action of the blades rotating within the heat transfer tube continuously removes the product film from the heat exchanger surface and prevents burning-on, scaling or crystal build up on the wall. During operation, the product is brought in contact with a heat transfer surface that is rapidly and continuously scraped there by exposing the surface to the passage of untreated product. More over the product is in contact with the heating surface for only a few seconds and high temperature gradient can be used without the danger of causing undesirable reactions. This type of heat exchangers can be used for batch or continuous heating or cooling of products with very high viscosity and solid contents up to 75 %. The major advantages of SSHE include short residence time in heated zone so heat sensitive product can be conveniently processed, high heat transfer coefficient, narrow residence time distribution, wide viscosity range, minimum surface fouling, liquids with foaming tendency can be easily handled, high capacity reduction-down to 10% of design throughput, low product inventory, waste heat recovery is possible for energy conservation, it is possible to use concentrated milk as feed which would increase the capacity substantially, efficient use of thermal energy, better process control and optimization (Abhichandani *et al.*,1978; Dodeja and Nand Kisore, 2011).

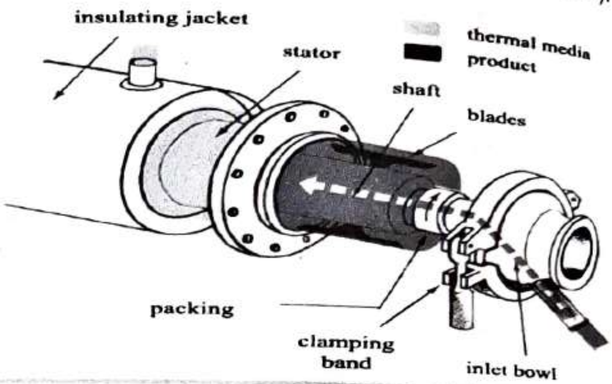
Parts and configuration of SSHE

SSHE basically consists of a cylindrical rotating shaft (the "rotor") within a concentric hollow stationary cylinder (the "stator") so as to form an annular region along which the process fluid is pumped.

1. Stator : The stator acts as the heat-transfer surface, and it is normally enclosed within another cylindrical tube which provides a gap through which a heating or cooling service fluid passes. Scraper fitted with two or more scraping blades mounted on the central shaft. The outer cylinder is covered with an insulated material to minimize heat loss to or heat gain from the surrounding. The stainless steel sheet with sealed joint is used to cover the insulation and protect it from mechanical damage. It is made up of stainless steel or mild steel lined with chrome nickel plating. The inlet and outlet ports for heating or cooling medium and liquid product are kept at the end of the cylinders.

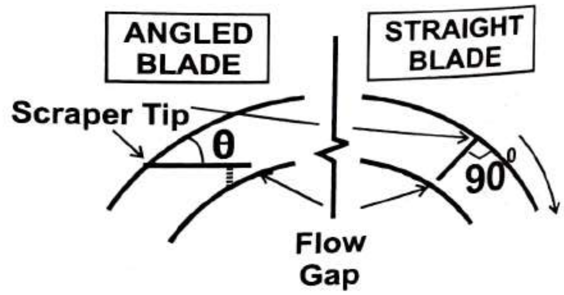
2. Rotor:SS rotor shaft at the center of the cylinder holds the scraper blades and connected to drive mechanism for rotation. Flow of milk through the pump can be regulated by varying the speed of feed pump and rotor speed can be controlled by with the help of variable frequency drive (VFD). Feed pump should handle viscous/non viscous fluids and pulped material in suspension, *viz.*, milk, cream, sugar syrup, beverages and fruit juices. It has a uniform pulse-free output in strict linear dependence on the rotational speed. SSHE must be insulated with glass wool or other appropriate insulating material of about 1-2.5 cm thickness. The dimensions of SSHE vary from 7.5 cm to 25 cm diameter and length of 120 to 180 cm (HE, 2012). Scraper assembly of appropriate design is configured for scraping action. Attached to the rotor are a number of pivoted blades each of which scrapes the heat-transfer surface, removing processed fluid and hence allowing unprocessed fluid to come closer to the stator. For maximum efficiency the product tube is manufactured from a material with a high heat-transfer coefficient. The blades themselves are usually made from stainless steel as well as Teflon material depending on the application (Smith, 1972).





Scraper Arrangement:

In a typical SSHE there are usually two or four blades located periodically around the rotor throughout the product tube, though sometimes they are axially staggered in order to improve mixing. The rotating scraper helps in improving efficiency, proper mixing and imparting desirable consistency and texture to the product. In ice cream freezer action of the blades helps to blend the fluid, air and ice crystals that are formed on the cooled stator surface, to produce a smooth consistency. The scraper may be grouped into fixed clearance scraper and variable clearance scraper. The fixed clearance scrapers are used for highly abrasive product such as sugar/fat mixture and are fitted with small clearance between the blades and the heat transfer surface of the inner cylinder. Variable clearance scrapers have floating blades which are forced towards the wall by spring, centrifugal force, hydrodynamic action of the fluid or a combination of these forces. The product velocity at the heat transfer surface depends on the speed of the scraper and the effective number of the rows of the blades and does not depend on the product flow rate. The overall thermal performance of the continuous *Khoa* making unit is improved by increasing the heat transfer rate with the help of blades by violently agitating the liquid, eliminating any channeling of liquid, decrease in apparent viscosity by shearing effect and forming a thin film of liquid on its heat transfer surface. The blade arrangement can be made in straight blades or staggered blades fashions. Dodeja *et al.*, (1987) reported that staggering of blades improved RTD and reduced power consumption as the flow is very close to plug flow that is free from bypassing, short circuiting and channeling. Kohli (1993) indicated that staggered blades for the concentration of milk are highly advantageous from viewpoint of heat transfer and hydrodynamics. It caused high turbulence due to more frequent interruption of fluid film by blades. Performance of SSHE machine with regards to heat transfer and product outflow for *khoa* have been reported (Bag, 1994).



Mode of Operation

Liquid-full operation and thin-film operations are very commonly used in SSHE. In liquid full operation, the vessel is filled completely with liquid products and it is almost always used in sensible heat transfer. In the liquid full vertical SSHE the product falls down along the inner side of vertical heat transfer tube by gravity. The heat transfer is promoted by rotation of blades that scrapes product off the surface of the heat transfer tube. Centrifugal force throws the product back on the tube. Evaporated vapour rises in the free space close to the rotor. The flow pattern in the liquid full scraped surface film evaporator cannot be expected to be similar to the flow pattern in an annulus with a rotating inner cylinder where the annulus is completely filled with liquid. In case of thin film operation, product tube does not run full, but the liquid flows in a thin film. This mode of operation is used when a change of phase takes place in the liquid product. Some time, it is necessary to operate SSHE under positive back pressure to get effective scraping action, to overcome product film viscosity or to keep the product in liquid state (Guevas, *et al.*, 1980). The problems like viscosity variation, heat sensitivity and foaming encountered during processing of food products can easily be handled in thin film SSHE. Heat transfer in thin film SSHE is very complex involving hydrodynamic of the liquid, several empirical relations and operating variables etc. (Rajshekhar *et al.*, 2002).

Operating/ process parameters

Time, temperature and pressure are easily controlled in SSHE than a kettle (Alam, 1988). The geometry and operating parameters play a major role in heat transfer performance and quality of the product. The maximum operating flow rate of 2.7×10^4 l/h, maximum operating pressure of 35 kg/cm^2, maximum operating temperature of 250^{0}C have been reported (Pelsoi, 1972, Kumbhar *et al.*,1985, HE, 2012). Pressure drop is extremely important parameter in SSHE design since pumping cost and heat transfer rate depend on the pressure drop (Alfa laval, 1985). The operating steam pressure during manufacture of batch type khoa making process (Bhadania, *et al.*, 2004b), continuous khoa making machine (Dodeja, *et al.*, 1990b), basudi making machine (Patel Sunil,2007), thermization of shrikhand (Dhotre *et al.*, 2009), sandesh manufacture(Patel,2004), halwasan making(Patel Sunil, 2013) using various types of SSHEs with different types of scraper assembly have been reported.

Heat transfer behaviour of SSHE (Thermal design)

Heat transfer behavior of SSHE is very complex phenomena, as several factors such as properties of fluid being handled and operating parameters like temperatures, batch size, rotor speed etc. are associated with heat transfer (Trommelen and Beek, 1971; Harrod, 1990, Dumont *et.al.*, 2000.; Rajshekhar *et al.*, 2002). The rate of heat transfer between the heat transfer medium and the product is controlled by two mechanism viz. the rate of heat conduction in to the thin product layer at the heating surface as well as the rate at which the thin product layer is removed and then mixed with the bulk product. The mixing step occurs at radial mixing, which enhances heat transfer. However, axial mixing with a certain amount of back mixing may also occur, which leads to reduction in driving force and affects the heat transfer coefficient. The flow is three-dimensional (comprising a transverse flow driven by the moving rotor and blades and a pressure-driven axial flow) and in certain circumstances it can be complicated by the formation of vortices. The flow is also non-isothermal and will typically involve conduction, convection and viscous dissipation within the process fluid; moreover, the thermal characteristics of the service fluid may also affect the heat transfer. The fluids that are processed are often non-Newtonian, inhomogeneous, viscoplastic, viscoelastic, contain particulates, possess temperature-dependent viscosities, and/or undergo phase changes during the cycle through the SSHE which have impact on rate of heat transfer (Trommelen and Beek, 1971; Harrod, 1990 and Dumont *et al.*, 2000).

Overall heat transfer coefficient (U-value)

The overall heat transfer coefficient represents the intensity of heat transfer from one fluid to another through a wall separating them expressed as W/m^2 ^{0}C. The U-value is dependent on steam side film heat transfer co-efficient (ho), product side film heat transfer co-efficient (hi) and wall heat transfer coefficient (hw) (Patel and Bhadania, 2004). The value of hw is constant as it is fixed with the design of the SSHE. The resistance of heat transfer will be greater on product side than on condensing steam side (Mc Admas, 1954; Cuevas and Cheeryan, 1982). Heat and mass transfer equations are used in order to calculate the U-values of SSHEs (Kessler, 1981; Patel and Bhadania, 2004; Savita and Dodeja, 2011). The equation correlating operating temperature, TS, velocity of fluids, and number of blades for determining U value during evaporation of milk have been reported (Dodeja and Nand Kisore, 2011; Abhichandani, 1985).

The equation for calculating U value during preparation of khoa and evaporation of milk have been reported for cylindrical SSHE (Cuevas and Cheryan, 1982, Bhadania *et al.*, 2004a). The U value is a function of blade rotational speed and mass flow rate, number of blades, temperature, feed rate, steam pressure etc. (Cuevas and Cheeryan, 1982; Dodeja *et al.*, 1989; Dodeja *et al.*, 1990a; Punijrath *et al*,. 1990; Patel, 1990; Bhadania *et al.*, 2004b).

Calculation of hi value

The calculation of inner side(product side) film heat transfer coefficient(hi) during heating, evaporation of water using different type of SSHEs have been reported (Kessler, 1981, Patel and Bhadania, 2004, Savita and Dodeja, 2011). The product side film film heat transfer coefficient depends on various operating conditions of the SSHE such as scraper speed, concentration of the milk, design of the scraper etc. (Bhadania *et al.*, 2004a).

Dimensional Analysis

Dimensional Analysis is a mathematical technique used to develop correlation among various variables involved in a forced convection phenomenon in SSHE like film co efficient, dynamic viscosity, diameter, density, velocity, specific heat of fluid, thermal conductivity of fluid. If the number of variables involved in a physical process are known, then the relation among the variable can be determined (Bansal, 1983). This method can be adopted to all types of fluid resistance, heat flow problems and many other problems. The equation produced by this method also gives non dimensional constant, which governs the problem under consideration (Kessler, 1981; Patel, 2007). As the convection heat transfer is very complex, it is possible to investigate the combined effect of various operating parameters using dimensional analysis (Trommelen and Beek, 1971). Various researchers have developed different corelationships of variables based on dimensional analysis for evaluating the heat transfer behavior of SSHE (Skelland, 1958; Lateinen, 1958; Harriot, 1959; Das and Verma,1985; Abhichandani and Sarma, 1988a; Dodeja, 1987; Dodeja *et al.*, 1990b, Badshah ,1999). Krischbaum and Dieter (1958) developed corelationship for evaporation process and showed that scraped heat transfer coefficient decreased with increasing "T at constant rotor speed, low flow rate and higher value of "T. The study conducted by Reay (1963) showed that, heat transfer coefficient dropped by 20% when clearance was doubled and increased by 20% when clearance was decreased by 80%. It has been suggested that axial flow velocities were a better marker of thin film operation than rotational velocities (Bott and Sheikh 1966; Bott and Azoory; 1969; Azoory and Bott, 1970). Abichandani (1985) evaluated the heat transfer performance of water, buffalo milk and cream at different flow rate, scraper speed, number of blades and operating steam temperature. Goede and Jong (1993) predicted higher heat transfer coefficients due to scraping action than predicted by penetration theory. Dumont *et al.* (2000) studied the influence of flow regimes on temperature heterogeneity in a SSHE. Using non-Newtonian and Newtonian fluids, they observed large heterogeneities for laminar flow and progressive homogenization of temperature from inlet to outlet for high rotational speeds.

Calculation of ho value

Film heat transfer coefficient of working fluid side (ho) has been studied by various workers (Sativa and Dodeja, 2011; Kessler, 1981). Nusselt theory is applied to find the steam side film heat transfer coefficient (Kreith and Bohn, 1986; Patel and Bhadania, 2004, Bhadania *et al.*, 2004). Many research workers have reported values of ho during preparation of various indigenous dairy products using steam as heating medium (Dodeja, *et al.*,1990b; Patel, 2004; Patel Sunil, 2007; Dhotre *et al.*, 2009).

Energy Requirement for SSHE

Thermal and electrical energy are required in operations of SSHE. The manufacture of Traditional Indian Dairy Product involves heating and concentration of milk which require considerable amount of energy (Bhadania *et al.*, 2013). The electrical energy required for driving the rotor is very small (<0.5%) as compared to the steam (thermal energy) required to evaporate the water (Cuevas and Cheryan., 1982; Abhichandani and Sarma, 1988b&c; Dodeja *et al.*, 1989). The consumption of heat energy for the SSHE was 35147.8 W and electric power requirement was 324.48 W which was just 0.92 % of the thermal energy used during manufacture of khoa.(Bhadania, *et al.*, 2005).

Power required driving the rotor

The power required to drive the rotor of SSHE under various operating conditions have been reported by several workers (Trommelenand Boerema, 1966; Bhatacharya, 1970; Abhichandani and Sarma, 1988b&c; Abhichandani and Sarma, 1989a). The electric power requirement is associated with several factors like properties of material, speed of rotation, weight of scraper blades, geometry of SSHE, tension of springs, etc.(Bhadania, *et al.*, 2005). Abichandani and Sarma (1988b&c and 1989a) developed a relationship to predict the power requirement for SSHE using mathematical model. Altiokka (1992) found that the power consumption of SSHE is proportional to the rotational speed of the shaft and SSHE with no clearance had approximately 30% more power consumption than one with standard clearance. Electrical energy was found 0.10 to 0.25 kWh per kg water evaporated from milk for manufacture of khoa and 4 kWh for 50lit/h milk capacity (Bhadania, *et al.*, 2013).

Thermal energy requirement

In SSHE, vapour removal from the product is likely to accumulate on the top surface at the exit. The provision of induced draught system will quickly remove the water vapour from SSHE exit. Kohli and Serma (1990) reported heat consumption per kg of butter was maximum 187 kcal/kg in falling film SSHE as compared to 293 kcal/kg in case of jacketed kettle. Energy requirement for ghee making was 0.35 kg of steam/ kg of ghee in continuous process as compare to 0.68 kg of steam per kg of ghee in traditional method (Pandya,1998). The steam consumption in horizontal SSHE for sandesh making ranged from 1.795 to 6.75 kg steam /h in different operating conditions (Patel, 2003), 1.2 to 1.3 kg steam/kg of water evaporated for manufacture of khoa (Dodeja *et al.*, 1989) and 1.368 kg steam per kg water evaporated (Bhadania *et al.*, 2005).The steam consumption of continuous basudi making machine was 1.2 kg steam per kg water evaporated (Patel, 2007). The reported value of LPG consumption for thermization of Shrikhand ranged between 0.5 to 1.25 kg/h (Dhotre *et al.*, 2009).

Mass transfer in SSHE

Mass balance is carried out to determine the rate of evaporation of water from each stage and amount of steam consumption for each stage of SSHE. Mass balance is done on solid side and liquid side for the product (Abhichandani and Sarma, 1988a; Bhadania *et al.*, 2013).

Structural design SSHE

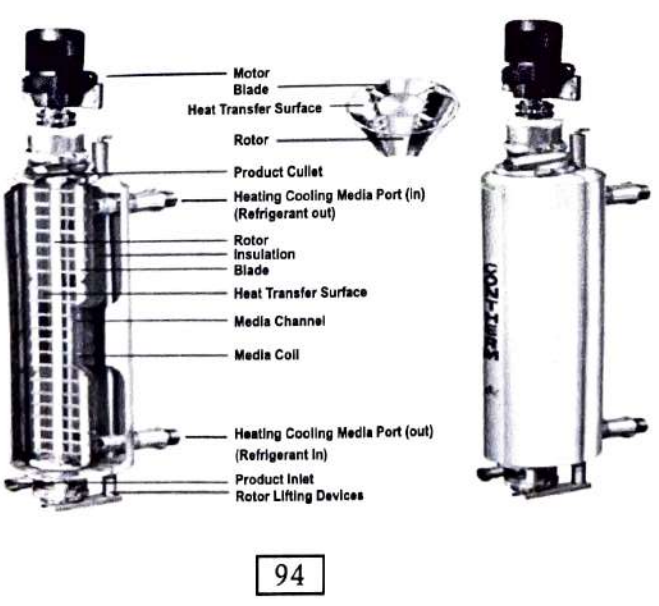
It includes the calculation of size, shape and strength of each component of the SSHE to handle the product efficiently, material of construction require to meet the requirements from the view point of food hygiene and sensory attributes of the product, the finish of the surface and the mechanical power to run the unit successfully and efficiently (Dhotre *et al.*, 2006). Shaft diameter, torque, cylinder thickness and motor power requirement can be calculated by applying various mechanical design principle /theory (Pandya and Shah, 2002; Khurmi and Gupta, 1992). The material for Product tube: SS 304 or 316 grade, Shaft:SS ,Blade: SS and Teflon ,Insulation: Glass wool and PUF is generally used.

Maintenance of SSHE

All the metallic parts that come in contact with the product should be made of SS and the non metallic parts coming in contact with product should be nontoxic, non-corrosive to product as well as cleaning solutions. The joints and welds of the system should be precise especially of the jacket. The entire corner should be well ground and polished. (Dhotre *et al.*,2006). The vertical installation requires less floor area as horizontal SSHE. Rajshekhar *et al.* (2001) has reviewed maintenance aspects of various components and accessories of SSHEs.

Advances in SSHE

More advanced designs of SSHE include features such as holes in the blades (which reduce power consumption), oval stators (which reduce "channelling" in which fluid passes through the exchanger relatively



unprocessed), and non-centrally mounted shafts (which enhance mixing and prevent material from building up on the underside of the blades).Forward and backward tapering and Step arrangement of SSHE cylinder is also an advance design of SSHE. Rotating disc or cone type (Screw type) with advanced instrumentation (Magnetic flow meter, pressure gauge, I/P converter, Transmitters, Pneumatic valves, Air pressure indicators, Digital panel meter, Process controller)plays an important role in process control and automation for continuously monitoring the process variables in SSHE. The latest version of industrial SSHEs are CONTHERM, CENTHERM, CONVAP and VOTATOR advanced design features are being manufactured by different manufacturer for dairy and food products.

CONCLUSION

Efficient heating or cooling of complex fluids is an important requirement for several operations in dairy and food industry. SSHE is more suitable for heat transfer to viscous and heat sensitive products. It is easier to control time, temperature, speed and pressure in SSHE as compared to other type of heat exchangers. This makes it possible to achieve more even and improved quality in cooking of products. The scraping blade continuously removes fouling and eliminates burn-on problems as well as improves heat transfer rates. Manufacture of various dairy and food products using scraped surface processing plant increases their shelf-life. Due to its vast application the importance of SSHEs is increasing day to day. Various researchers have used various theory and principles to established various operating parameters relationship for thermal design and power requirement of SSHE for dairy products. It is very important to improve the thermal efficiency to get overall economy of the SSHE system. There is a good scope for SSHE to prepare indigenous milk products *viz.,* basundi, peda, khoa, halava or in general any khoa based sweets on commercial basis. For improving the performance of SSHE follow the recommended procedure for manual as well as CIP cleaning. Adopt preventive maintenance schedule for bearings and other components of the SSHE. Follow the burr removal procedure periodically and replacement of blades. Adopt preventive maintenance schedule for bearings and other components of the SSHE. O-ring of the flanges should be cleaned with alcohol, clean O-ring groove with a wire brush. Replace the worn and damaged O-rings in pairs. For leakage proof operation, the running surfaces are precision lapped or polished, absolutely flat and parallel and the pressure holding the running surface should be sufficient.

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