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# Heat transfer analysis of scraped surface heat exchanger

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**Abstract.** The main structure and the production theory of scraped surface heat exchanger was introduced. The heat transfer mechanism of heat exchanger is analyzed, and the mathematical model of heat transfer is established in this paper. There had three mode of heat transfer in Scraped surface heat exchanger. They were External heat transfer, Internal heat transfer ,Convection heat transfer, respectively, the mathematical model corresponding to them were established. On this basis, production equipment line with scraper heat exchanger as the core machine was improved.

## 1. Introduction

Scraped surface heat exchanger(SSHE)can be applied to viscous fluids and dilute fluid materials or granular liquids(Material sensitive to heat)Instant heating or instant cooling, SSHE has the advantages of continuity, closed processing, excellent heat transfer efficiency, etc. Besides, Compared to traditional tubular or frame heat exchangers, In the process of instantaneous heating or cooling, the scraped surface heat exchanger will not produce coking film or liquid crystal, Therefore, it is suitable for instant heating or instantaneous cooling in sauce, peanut butter, chocolate, jam, margarine, dairy products and other industries、Aseptic processing, etc. The use of scraped surface heat exchangers is a sensible choice for viscous fluids and particulate materials [1,2].

## 2. The Structure and production theory of SSHE

The scraped surface heat exchanger is usually used to thermally cool or heat viscous fluids with high viscosity. The fluid flow and heat transfer in SSHE is complex and have not been understood so far. Fig. 1 shows a schematic representation of an SSHE; two blades were considered in this study. The operating principle of SSHE is as follows: the heated or cooled fluid enters the exchanger through a flange (flow inlet), and is mixed by blades (sheared zone), and exits through another flange (flow outlet). During this operation, the treated fluid is brought in contact with a heat transfer surface (stator wall) that is rapidly and continuously scraped, thereby exposing the surface to the passage of untreated fluid. In addition to maintaining a good and uniform heat exchange, the scraper blades also provide simultaneous mixing and agitation. Heat exchange for sticky and viscous foods such as heavy salad dressings, margarine, chocolate, peanut butter, fondant, ice cream, and shortenings is possible only by using SSHEs. High heat transfer coefficients are achieved because the boundary layer is continuously replaced by fresh material. The enhancement of the thermal efficiency should be ensured by the blades scraping action. The main features of scraped surface heat exchanger is a stirring and scraping film, the material is not easy in the heat transfer wall fouling on the heat transfer, so it applies to viscous material, the slurry can flow, dilute fluid containing solid particles [3,4].

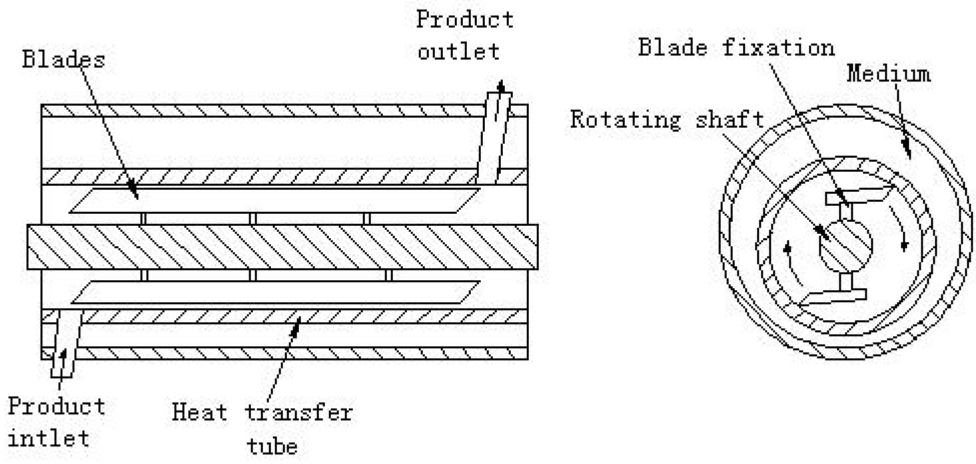


Figure 1. Schematic representation of SSHE, longitudinal and transversal cross-section.

## 3. Heat transfer model of SSHE

The heat transfer process of the scraped surface heat exchanger is the convection heat transfer between the material and refrigerant Freon respectively, In addition, there is a heat exchange between the shell of the tubular heat exchanger and the air, It is important to note that in the course of the study, the heat produced by shearing and crystallization is not considered in the process of the material passing through the heat exchanger. After the heat exchanger reaches a steady state of production, Keep the temperature gradient inside it not changing with time, Steady heat transfer occurs in the heat exchanger, in this article, the process of margarine production is taken as an example to analyze and study the model [5].

### 3.1 External heat transfer of heat exchanger

The temperature during margarine processing is generally no more than 50 degrees centigrade, Thus, heat losses due to thermal radiation account for only a small proportion of heat transfer, so ignoring the effect of thermal radiation is negligible, The shell of the heat exchanger is coated with polyurethane as insulation material, The heat insulation material is approximately closed to the shell of the heat exchanger, Convection heat transfer is very small, and therefore neglected, the heat convection does not take into account, Therefore, the heat transfer of the shell of the entire heat exchanger during operation is only caused by heat conduction, Can be seen as a cylindrical wall heat conduction model, Its heat conduction given by following equation:

$$Q_c = \frac{2\pi l}{\frac{\ln(\frac{r_{a1}}{r_{i1}})}{\lambda_1} + \frac{\ln(\frac{r_{i1}}{r_2})}{\lambda_2}} \times (\mathrm{t}_a - \mathrm{t}_i) \tag{1}$$

Where $Q_c$ is the heat of heat conduction, $l$ is the length of the cylindrical wall of the heat exchanger, ln is the natural logarithm, $r_{a1}$ is polyurethane outer diameter, $r_{i1}$ is the inner diameter of polyurethane, $r_2$ is the shell diameter of the heat exchanger, $\lambda_1$ is the thermal conductivity of polyurethanes, $\lambda_2$ is the heat conductivity of the heat exchanger, $\mathrm{t}_i$ is the temperature of the heat exchanger, $\mathrm{t}_a$ is the temperature of the polyurethane layer.

### 3.2 Internal heat transfer of heat exchanger

There are mainly three ways of heat transfer in the scraper type refrigerator, they were the composite heat conduction of the barrel wall of grease $\lambda_3$ ,Thermal conduction between scraper and grease boundary film $\lambda_4$ ,Heat transfer between grease film and inside of barrel wall $\lambda_5$ ,In the course of work, The scraper is tightly bonded with the inner barrel wall under the influence of centrifugal force, so the first two thermal conductivity coefficients can be considered the same, and the calculation method of each heat transfer coefficient were calculated using the flowing expression:

$$\lambda_3 = \frac{1}{\left[\frac{1}{\alpha_0}\left(\frac{D_i}{D_0}\right)+\frac{\delta}{\lambda}\left(\frac{D_0}{D_m}\right)+\gamma\left(\frac{D_i}{D_0}\right)\right]} \tag{2}$$

$$\lambda_4 = 1.24\lambda_3^{0.03}\bullet(\lambda_0\bullet Cp_0\bullet\rho\bullet N)^{0.516} \tag{3}$$

$$\lambda_6 = 1/(\frac{1}{\lambda_3}+\frac{1}{\lambda_4}) \tag{4}$$

Where $\alpha_0$ is the coefficient of evaporation heat release at the refrigerant side, $D_0$ 、 $D_i$ 、 $D_m$ are the outer diameter, inner diameter and diameter of the material barrel, $\delta$ is barrel wall thickness, $\gamma$ is the fouling resistance at the outside refrigerant side of the material cylinder, $\gamma$ is generally small and negligible, $\lambda_0$ is the thermal conductivity of oils, $Cp_0$ is the specific heat content of oil, $\rho$ is the density of oils, $N$ is spindle speed, $\lambda_6$ is the total heat transfer coefficient[6].

**3.3 Convection heat transfer in heat exchanger**

Because of the heat exchanger are oil, coolant and hot water are three kinds of fluid and pipe surface heat transfer tube heat exchanger, the rotation of the spindle agitates cream, the coolant entrance and exit pressure, so as to introduce the turbulent heat transfer, turbulence model, this paper adopts two equation model,

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)= \frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{5}$$

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_i}(\rho \varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] +C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \tag{6}$$

Where $\rho$ is the fluid density, $k$ is kinetic energy of turbulent fluctuation, $t$ is time, $u_i, u_j$ are speed, $i, j$ are tensor Subscripts, $\mu, \mu_t$ are dynamic viscosity, Subscripts said the physical quantity caused by turbulence, $G$ is the turbulent kinetic energy production rate, $\varepsilon$ is the dissipation rate of turbulent pulse energy[7].

It provides the basis for further research and verifies the feasibility and improvement of the design, The production line of margarine production equipment with scraping surface heat exchanger as the core equipment was developed, The crystalline form of $\beta$ and $\beta'$ in the finished product reached 35.60%(show in fig.3), Product surface smooth and delicate, good performance, high efficiency and stable operation of the production line.

Note:4.6Å is the β crystalline characteristic peaks,4.2Å 、 3.8Å are the $\beta'$ crystalline characteristic peaks, Scanning angle from 3°to 40°, Scanning speed 4°/min , Voltage 40kV Electric current 40mA. The corresponding X - ray diffraction parameters, test parameters, show in table 1.

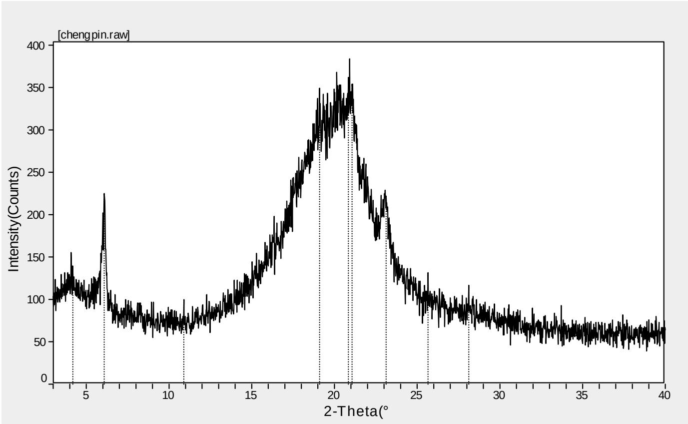


Figure 3. X ray diffraction pattern of products

Table 1: X-ray diffraction test parameters

PEAK: 21-pts/Parabolic Filter, Threshold=3.0, Cutoff=0.1%, BG=3/1.0, Peak-Top=Summit

| 2-Theta | d(A) | BG | Height | I% | Area | I% | FWHM |
|---|---|---|---|---|---|---|---|
| 4.190 | 21.0721 | 101 | 38 | 29.2 | 939 | 27.2 | 0.420 |
| 6.085 | 14.5127 | 95 | 130 | 100.0 | 1813 | 52.4 | 0.237 |
| 10.895 | 8.1142 | 67 | 32 | 24.6 | 245 | 7.1 | 0.130 |
| 19.104 | 4.6418 | 287 | 63 | 48.5 | 897 | 25.9 | 0.242 |
| 20.841 | 4.2586 | 272 | 91 | 70.0 | 3458 | 100.0 | 0.646 |
| 21.066 | 4.2138 | 285 | 70 | 53.8 | 1445 | 41.8 | 0.351 |
| 23.120 | 3.8438 | 160 | 62 | 47.7 | 1448 | 41.9 | 0.397 |
| 25.650 | 3.4701 | 94 | 37 | 28.5 | 228 | 6.6 | 0.105 |
| 28.117 | 3.1710 | 82 | 34 | 26.2 | 175 | 5.1 | 0.087 |

## 4. Summary

The structural analysis of scraped surface heat exchanger is carried out, the internal heat transfer is analyzed, a mathematical model of heat transfer is established, and there is a better understanding of heat transfer and convection heat transfer in scraped surface heat exchanger.

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