Chapter II

LITERATURE SURVEYS

2.1 Double Pipe Heat Exchanger

The simplest kind of heat exchanger consists of two concentric tubes through which the hot and cold fluids flow in the same or in opposite directions. This device, called a double pipe heat exchanger, can be made either from a pair of single lengths of pipe with appropriate fittings at the ends or from a number of lengths arranged in a vertical raw with the sections connected at alternate ends as shown in Figure 2.1

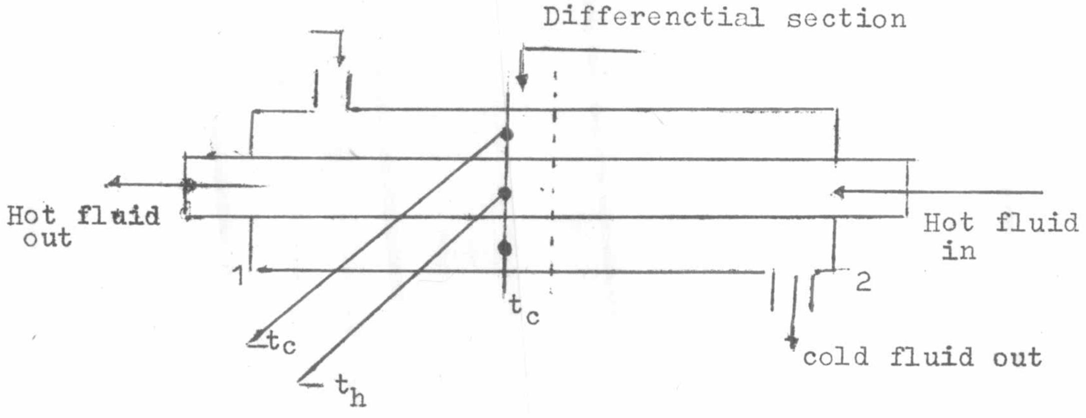

Fig 2-1 Double-pipe heat exchanger

2.2 Heat Transfer in a Vibrational Flow

In recent years many workers have studied heat transfer to both Newtonian and non Newtonian fluids in laminar flow and turbulent flow in pipes. The investigators considered the possibility of improving the heat transfer by vibrating the flow. Heat transfer coefficients were formed to be increased when a tube was subjected to a rotary vibration. Fluid would have formed a thin film adhering to the tube wall. The bulk of the film rotated at practically the same frequency as the vibration. This film had effects on heat transfer.

Bergles and Morton (1965) studied the heat transfer of surface vibration included stagnant fluid and forced fluid flow, for tubes vibrating either horizontally or vertically, wires vibrating vertically or transversely, vertical plates vibrating transversely, a channel vibrating transversely and annuli with a heated inner surface subjected to a plane vibration. Mostly, the fluids considered were air or water, in one case it was kerosine. They reported that the effects of vibrational flows varied from a lowering of heat transfer coefficients up to a 600% increase for air in forced or natural convection and a 400% increase for water and kerosine.

Ogel and Engle (1965) vibrated a double pipe heat exchanger with an amplitude range of 1.07 to 5.27 mm, 300 to 2700 cycles per minute frequency, tube Reynolds number 400 to 20450, and shell Reynolds number 629 and 9650. At laminar flow the heat transfer coefficients were formed to increase up to 66%, and the improvement became greater at high vibrational intensities. However, it was found to levelled off at about 86% or less for very high vibrational intensities.

Additional information has been reported on wall vibration. Watson (1965) studied the effect of vibration on heat transfer from cylinders vibrated sinusoidally within a vertical plane in free convection. He worked within a range of amplitude of 0 to 38 mm. and frequency between 960 and 4800 cycles per minute, at surface temperatures 100 to 200°F above room temperature. His results agreed closely with those previously presented for cylinders.

Chaffee (1966) continued Watson's study on free convection (1965). It was shown that only vibrational intensity had effect on the heat transfer rate for fluid flow in transition region.

Haughey (1965) reviewed work on heat transfer under vibration. **They** found that the vibrational frequency increased the heat transfer coefficient from a critical frequency to an asymptotic value around 6600 to 8400 cycles per minute. Below the critical value vibration had no effect. Increasing amplitude at constant frequency increased the heat transfer coefficient. The maximum effect reported was a 20% increase in the water side heat transfer coefficient. As only one fluid was involved, there was no attempt at correlation using dimensionless numbers. The data were correlated by

$$h_v/h_o = 1.0 + .0018\, A_v f_v$$

where A_v is the amplitude of vibration

f_v is the frequency of vibration

Rotestein, Urbicain, Elustond and Capiati (1970) have studied the vibration of the countercurrent double pipe heat exchanger. The hot stream circulated through the annulus and the cold stream through the inner pipe. The outer tube was a plain carbon steel schedule 40 pipe 2 inches in diameter. The inner tube was a stainless steel pipe, of 2.8 cm. internal diameter. Total heat exchanger length was 100 cm. Temperatures were measured with thermocouples. Liquids used were water, a glycol methanol mixture and momoethanolamine (MEA). Flow rates were measured with rotameters, ranging between 1000 and 5000 grams per minute. Frequency was varied between 800 and 1600 rpm. Amplitude was between 6.5 and 8.9 mm.

The individual heat transfer coefficient was calculated from the relationship.

$$h = \frac{m_c C_{pc} \left(t_{c_2} - t_{c_1} \right)}{S \Delta t_m}$$

where

$$t_m = \frac{\left(t_{w_1} - t_{c_1} \right) - \left(t_{w_2} - t_{c_2} \right)}{\ln \dfrac{t_{w_1} - t_{c_1}}{t_{w_2} - t_{c_2}}}$$

Their results showed that film thickness is a function of axial and vibrational Reynolds numbers. A design correlation adequate for this type of heat exchanger was proposed as

$$Nu = 1.175 \, Re_v^{0.52} \, Pr^{0.43}$$

The axial Reynolds number has no significant influence on the Nusselt number. Heat transfer was controlled by the liquid thermal conductivity rather than viscosity. They based on the penetration theory for a theoretical model.

2.3 Heat Transfer in Pulsating Flow in Pipes

The heating and cooling of liquids in steady laminar flow through straight pipes have been developed for many years in order to increase the amount of heat transfer. It was found experimentally that for Newtonian fluids the heat transfer in pulsating flow was the same as that in steady flow at the same flow rate, regardless of the amplitude and frequency of the pulsations. For non Newtonian liquids the results were different. Under the pulsation conditions used in the experimental work, heat transfer was greatly increased.

The early experimental investigations were carried out by Webb (1949) and by Morris (1950). Webb observed increases of up to about 10% in heat transfer coefficients with motor oils due to the addition of pulsations. Marchant (1943) reported an increase of about 40% in heat transfer for water in the laminar region, and Linke and Hufschmidt (1958) observed increases of up to 400% over the steady flow heat transfer coefficients for oils.

Romie obtained a correlation to the problem of heat transfer in laminar flow when the thermal boundary layer was thin and the momentum boundary layer was fully developed. The correlation was restricted to pulsations of small amplitude. It was found that pulsations can either increase or decrease the value of heat transfer coefficient depending upon the frequency of pulsation.

Edwards, Nellist and Wilkinson (1973) have studied the heat transfer coefficient in pulsating and in steady laminar flow. The pulsator was a simple piston/cylinder device with no values which had a variable stroke and frequency. Thus, the combination of steady flow pump and pulsator provided a variable steady flow or pulsating flows having controllable mean flow rate, amplitude and frequency. A thermocouple was used to measure the bulk mean inlet temperature and the wall temperature. The heat transfer section were well insulated to reduce heat losses. The fluid used were a lubricating oil and three polymer solutions.

The local heat transfer coefficients were calculated by the relationship.

$$h_Z = \rho \bar{q} C_p \frac{(T_{b,o} - T_{b,i})}{A (T_{wZ} - T_{bZ})}$$

Where A is the area of the heat transfer surface and $T_{w,Z}$ is the local wall temperature.

From experimental results and theoretical studies, they concluded that

1. For a non Newtonian fluid, pulsations did not enhance heat transfer above the values found in steady flow at the same flow rate

2. If the fluid were shear thinning, the heat transfer could be improved by pulsations. The experimental data yielded increases of up to about 12% in those cases.

3. Because of the wide range of variables which influenced heat transfer in pulsating flow more work would be required to pin point the effect of each major parameter upon the improvement of heat transfer.

4. The increase of heat transfer was found at high frequency, high stroke and low flow rate. These are conditions which necessitate a large power requirement.

2.4 Controlled Cycling

Controlled cycling has been applied to various types of mass transfer processes, heat transfer processes, and others. The useful-ness has been proved by experimental work in many fields, especially in the fields of distillation and liquid-liquid extraction. Lehrodt (1965) has summarized some of the experimental results concerning the following processes: extraction, distillation, absorption, screening, crystalization, heat transfer and electrolysis. He concluded that the magnitude of the improvement in the performance of process equipment due to controlled cycling was much more than a few per cent. One hundred percent increases in column efficiency were possible and order of magnitude increses in through put were observed.

The experimental work concerning the application of controlled cycling is mainly in the fields of extraction and distillation. The literature concerning these fields is discussed in detail here.

2.4.1 Controlled cycling in extraction

Controlled cycling was applied for the first time to a liquid-liquid extractors by Cannon (1956) the extractor was filled with light and heavy phase. When the two phases existed on every plate the controlled cycling was begun. Cannon divided the cycle of operation into four different parts:

1. A light phase flow period during which an amount of light phase was introduced through the bottom of the column. This displaced the less dense phase (which was just below each plate) upward through each sieve plate in a stream of high velocity droplets, and these struck screens which were located between plates to assist coalescence.

2. A coalescing period during which there was no flow at all and the phases separated at each plate.

3. A heavy-phase flow period during which an amount of heavy phase was introduced through the top of the column. This displaced the more dense phase (which was just above each plate) down ward through each plate in a stream of high velocity droplets which struck the screens again, but in the opposite direction to aid in rapid coalescence of the dispersed phase.

4. Another coalescing period to permit phase separation before the cycle was repeated.

In this type of column each phase was continuous for a part of the cycle and discontinuous for another part of the cycle. Each phase dispersed into streams of droplets be between plates and coalesced into a continuous phase between plates.

The results of experiments on extractors using the method of operation described above were reported by Szabo, Lloyd, Cannon, Speaker (1964), Feick and Mustaklem (1964). The experiments were done in both perforated plate (or sieve plate) column and a packed column. Conclusions of these experiments are as follows:

a) For the perforated or sieve plate column the magnitude of throughput did not affect the column efficiency, but for the packed column the column efficiency decreased with increasing throughout.

b) In comparison to the conventional column, the capacity of the perforated or sieve plate column was increased greatly and the column efficiency was somewhat improved. On the other hand, the capacity of the packed column was slightly increased and the efficiency was highly improved.

c) The efficiency of both column increased linearly with the ratio of raffinate flow to extract flow.

d) The phase input flow period and jet velocity through the plates had an effect on the column performance. The column efficiency increased with decrease of the phase input flow period or increase of the jet velocity.

e) When the number of plates was doubled while the spacing was held constant the column efficiency decreased.

Because of the additional degree of freedom provided by varying the cycle time, the contactor could be operated in controlled cycling for either high efficiency or high capacity.

2.4.2 Controlled cycling in distillation

Gaska and Cannon (1961) applied controlled cycling to sieve and screen plate columns. The columns and types of plates used in the experiments were varied in size. The cycle of operation consisted of two distinct parts: liquid flow period and vapour flow period. The process was controlled by a solenoid valve installed on the vapour outlet line of the reboiler. When the valve was opened vapour flowed up the column at a high velocity preventing liquid from flowing down. When the valve was closed, the liquid was not hindered by vapor flow, so it drained by gravity from one plate to another. Liquid down-comers were not necessary since both phases flowed through the same passages during their separate parts of the cycle. The rate of boilup in the reboiler was controlled automatically by the use of column pressure drop. A simple manometer circuit contained one fixed electrode immersed in the manometer liquid and one movable electrode that could be set for any desired column pressure drop. When the set pressure drop was reached a small electric current flowed through the manometer circuit to a simple electric relay which operated the electric valve in the steam line to the reboiler. Total reflux was used.

Using the principles and equipment described above, Gaska and Cannon found that the column capacity was increased by appoximately 50% over the capacity for conventional operation of the same column operated at the same pressure drop acress each plate, but the column efficiency was slightly lower and nearly constant with varying vapour velocity or column capacity. Increasing the liquid flow period for a fixed vapour-flow period decreased the column efficiency but markedly increased the capacity. When the number of plates was doubled while the height of the column was held constant, the plate efficiency and the capacity of the column decreased. It was also found that increasing the free area of the plate increased the capacity but decreased the efficiency of the column.

Controlled cycling in a packed-plate distillation column was done by McWhirter and Cannon. It was found that controlled cycling was more flexible than conventional operation. It was possible to operate a column for either maximum efficiency or maximum capacity by changing the ratio of liquid to vapour-flow periods. Increasing the ratio decreased the efficiency but increased the capacity of the column. However, when the ratio was greater than unity, the capacity of the column was nearly constant with change of the ratio. A given pressure drop per plate did not fix the boil-up rate as it did in columns operated in the conventional manner. The boil up rate at a certain pressure drop increased with increase in the ratio of liquid to vapour flow periods. As expected, increasing the packed depth of each plate decreased the capacity but increased the efficiency. McWhirter and Lloyd have done some experiments in a 5 stages, packed-plate distillation column operated in both the cyclic manner and the conventional manner. They compared the results of the two methods and found that the efficiency and capacity of the column were increased by controlled cycling as much as two times over the conventional operation. By an unsteady-state theoretical analysis they found that this improvement was entirely due to having a high average concentration driving force with controlled cycling. The analysis was done using the following assumption:

1. Column vapour held up negligible in comparison to liquid hold up
2. Constant molar vapour rates during vapor flow period
3. Constant and equal liquid hold up on all plates
4. Constant and equal Murphee efficiency on all plate
5. Binary mixture with constant relative velalility
6. Perfect mixing on all plates during vapour flow period.
7. Reflux to the column cycled in phase with the liquid flow period
8. Total condenser with liquid hold up equal to the amount of vapour introduced during the vapour flow period.
9. Constant and equal quantity of liquid flows from all plates during liquid-flow period
10. No mass transfer during the liquid-flow period
11. Plug flow of liquid from plate to plate during the liquid flow period.

The experimental results obtained by McWhirter and Lloyd show that, with constant vapor flow period, increasing the liquid flow period increased the capacity but decreased the column efficiency. If the liquid flow period were incresed while the vapour flow period were held constant, the liquid hold up on each plate and consequently the resistance to the vapour flow would be less. Then,for a given pressure drop acron the column the time-average vapour flow and therefore the capacity of the column would be increased. On the other hand, the mixing of liquid on one plate with other plates would be more extensive. This would distroy the concentration driving force and, of course decrease the column efficiency they also found that the pressure drop across each plate was much lower when the column was operated in the cyclic manner that when conventional operation was used. Thus the column with controlled cycling had a higher flooding rate or capacity. In addition to the improvement in capacity and efficiency, the column was simplified by eleminating the down-comers, and the degree of flexibility was extended to give a larger operating range.

Schrodt (1965) applied controlled cycling to distillation columns, and found that the increase in through-put over conventional operation for a five-stage batch vacuum still column was five times, and for a packed column was three times. By mathematical means he found that, for the ideal case of plug flow and complete dumping of liquid on each plate during the liquid flow period (i.e. having no liquid mixing between plates) the average mass transfer driving force was about twice as great as in conventional operation.

2.4.3 Controlled cycling of double pipe heat exchanger

The previous literature study led to an idea of improvement of heat transfer coefficient of a double pipe heat exchanger by controlled cycling. It was expected that the heat transfer coefficients of a controlled cycling heat exchanger would be higher than a conventional one. Conventionally, there are two approaches to increase heat transfer either having a very large heat transfer surface area, or having a large temperature difference. The former possibility of utilising large surface areas leads to a large capital cost of equipment whilst the latter suggestion of employing large temperature differences could produce an unacceptable thermal degradation of the material.

In this work the possibility was considered of increasing heat transfer coefficients by applying controlled cycling to the flow. It is necessary to establish the operating conditions for controlled cycling which could lead to increase heat transfer coefficients compared to the values obtained in steady flow at the same mean flow rate.