APPLICATION OF SPIRAL PLATE HEAT EXCHANGERS

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ABSTRACT

Recent applications of the Spiral Plate Heat Exchanger have expanded its use from special services to areas of more general heat transfer operations. When it was developed commercially, it was used almost exclusively for heat recovery in the cellulose industry. The long, single passage of the spiral made it particularly applicable for use in services where distribution was a problem, where liquid with solids in suspension was to be handled, and where close temperature control was required. Since the spiral could handle these operations, it followed that it could advantageously be used in more standard applications.

This paper outlines the design features of the Spiral Plate Heat Exchanger and gives specific applications for its use. Design information covering both heat transfer and pressure drop for liquids is included. Limitations of use are also listed.

GENERAL DESCRIPTION

The Spiral Plate Heat Exchanger as it is used in the U.S.A. today was developed in Sweden in the early 1930s. It was developed to provide a heat exchanger for the recovery of low grade heat in the cellulose industry. It has gone through design refinements and innovations so that it is now used in all types of heat-transferring operations.

The Spiral Plate Heat Exchanger is an assembly of two relatively long strips of plate wrapped to form a pair of concentric spiral passages. Normal design calls for one passage to be closed on one side and the other passage on the opposite side. Passage closing can be altered to suit the requirement of the duty to be performed. The outer ends of the strips terminate at headers on the periphery. These headers are for the respective peripheral nozzles. Fig. 1 shows the basic flow arrangement of the Spiral Plate Heat Exchanger.

Covers are fitted to each side of the spiral assembly to complete the unit. Taking the basic spiral element, and by fitting it with different type covers, all types of heat transfer duties can be performed.

The strips for the spiral are from 4" to 72" wide. The spacing of either passage is from 3/16" to 1". Spacing of the passages does not have to be equal. The maximum diameter to which the spiral can be rolled is approximately 56", so that the maximum surface that can be contained in a single unit is approximately 1,800 sq.ft. There is no set limit as to minimum surface, but economically 5 sq.ft. is considered minimum.

Basically, the Spiral Plate Heat Exchanger can be fabricated of any material that can be cold worked and welded. These materials would include carbon steel, stainless steels, Hastelloy B and C, nickel and nickel alloys, copper alloys, aluminum alloys, and titanium.

The Spiral Plate Heat Exchanger can also be designed so that its surfaces can be protected, either anodically or by coatings. Spirals have been furnished with a baked phenolic resin coating, particularly for protection against corrosion from cooling water (1). They have also been furnished with electrodes wound into the element so that the surface can be anodically protected against corrosion.

The Spiral Plate Heat Exchanger is normally designed for full differential pressure for each of the two passages. Since each turn of the spiral must carry its pressure, the thickness of the strip at each turn must be such as to withstand the design pressure. The thickness of the material in the strip is, according to the pressure, from 0.078" to 0.3125". Because the turns of the spiral are of relatively large diameter, the design pressure is limited. Maximum is considered to be 150 psi, although for smaller diameter units a higher design pressure can be obtained. Design temperature limitations are governed by the limitations of the materials used in fabrication.

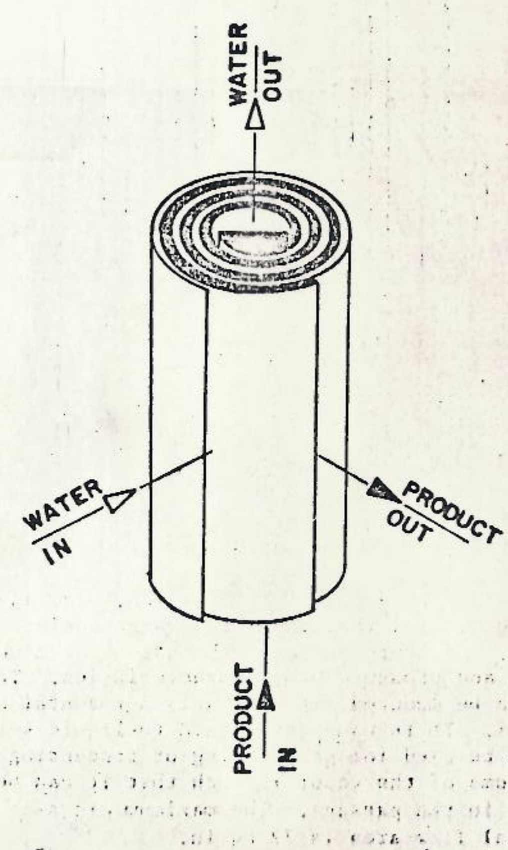

Fig. 1. Basic Flow Arrangement

BASIC TYPES AND OPERATION

The basic spiral element can be fitted with covers so that both media are in (a) spiral flow; (b) one fluid in spiral flow and the other in cross flow across the spiral; (c) or one fluid in spiral flow and the other in a combination of cross and spiral flow.

To have spiral flow for both media, the spiral element is fitted with flat covers on each side. Fig. 2 is a cross section drawing of this type of Spiral Plate Heat Exchanger. With this arrangement, the fluids normally travel through the long rectangular passages countercurrently to each other. The hotter fluid usually enters its passage at the center of the unit and flows outward to the periphery, and the colder fluid enters its passage at the periphery and flows inward to the center. Insulation is not normally required since the colder fluid is in the outside turn of the spiral.

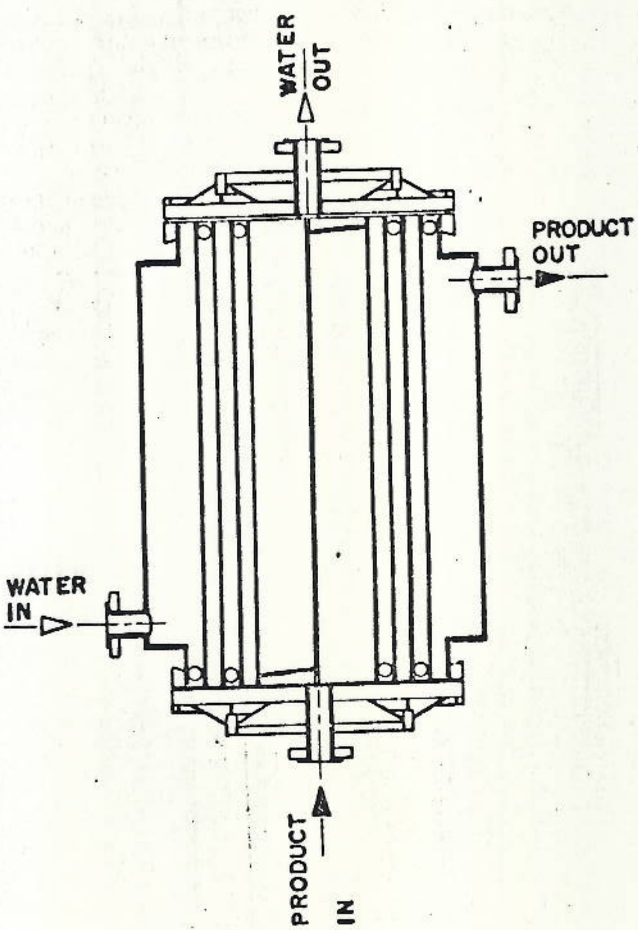

Fig. 2. Cross Section of Spiral Flow Both Sides

In this type of Spiral Plate Heat Exchanger both fluids flow in identical passage conformations, and therefore have the same heat transferring and pressure drop characteristics. This type can be mounted with its axis horizontal or vertical. It is used for liquid-to-liquid service and can be used for gas cooling or condensing if the volume of the vapor is such that it can be handled in the passage. The maximum cross-sectional flow area is 72 sq.in.

When the Spiral Plate Heat Exchanger is designed for spiral flow for one passage and cross flow for the other, the element is fitted with conical covers, dished heads or extensions with flat covers so that one fluid flows across the element. Fig. 3 shows this type. With this design, the passage for cross flow is open on both sides and the passage for spiral flow is welded both sides. This type is suitable for use when there is a large difference in the volume of the two fluids to be handled. It can be used for liquid-to-liquid service, gas cooling, or as a condenser or a reboiler. In condensing and reboiling service, it is mounted vertically. It can be mounted horizontally for other services. This type can be fabricated so that there will be two or more passes on the cross flow side.

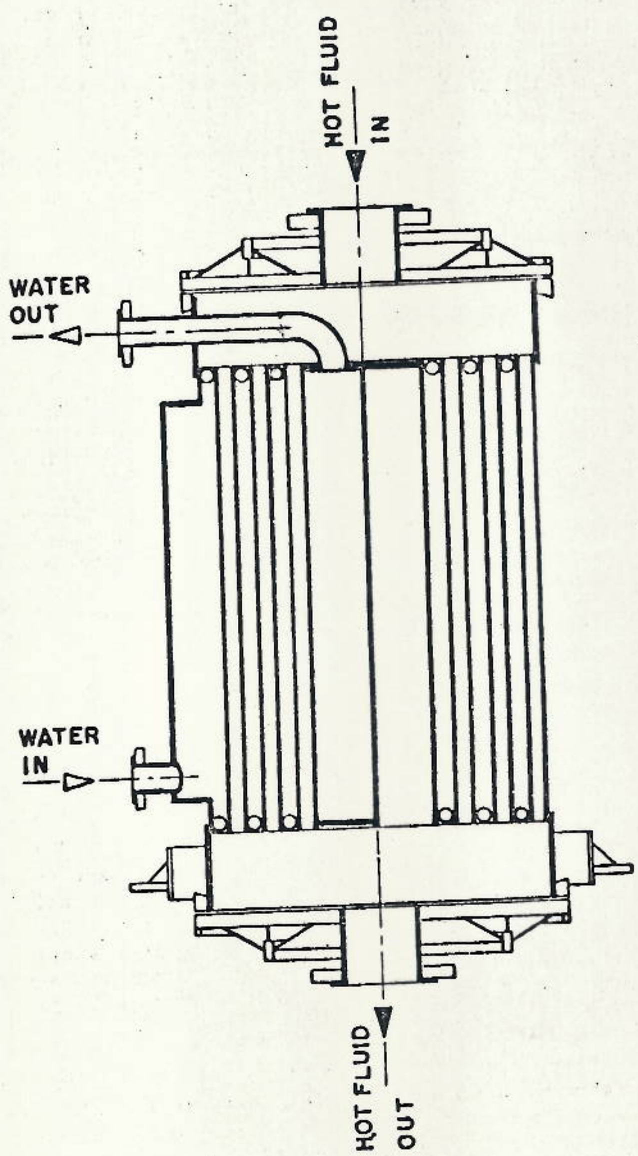

Fig. 3. Cross Section of Spiral Flow-Cross Flow

For combination flow, which would most often be required for condensing, the Spiral Plate Heat Exchanger is mounted vertically and the top is fitted with a conical cover with a wide flange. For condensing, the conical cover distributes the vapor into its passage for first condensing it in cross flow, and then, after the volume has been reduced, to do the final condensing and subcooling in spiral flow, the passage being closed by the wide flange of the cover. The cooling medium in the other passage is in spiral flow and its cover at the bottom is flat. The design for this type is shown in Fig. 4.

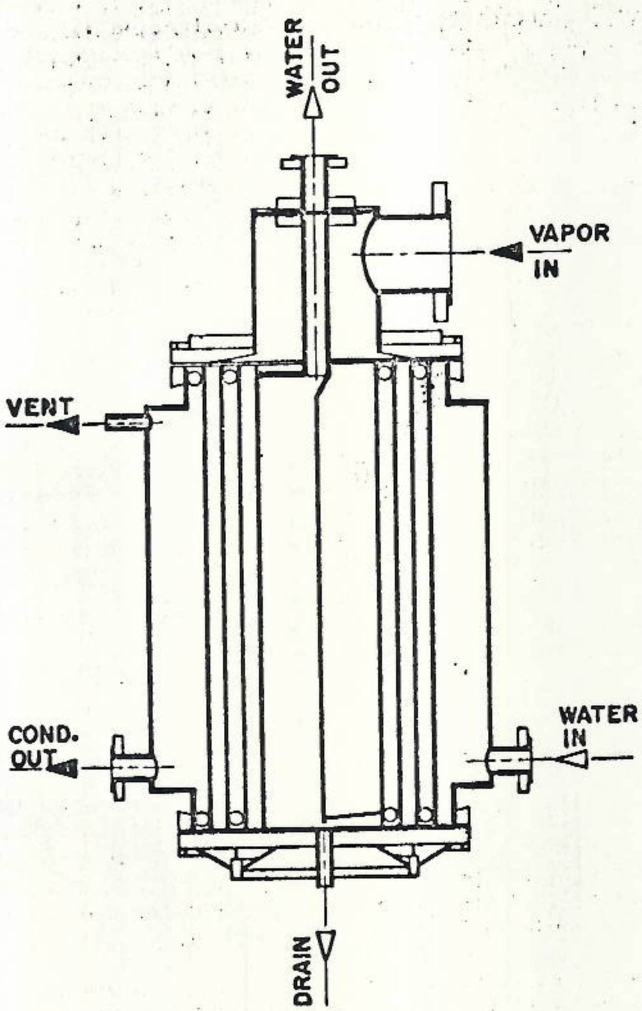

Fig. 4. Cross Section of Spiral Flow-Combination Cross and Spiral Flow

An innovation of this type is the column-mounted spiral plate condenser, where a bottom extension is fitted with a flange to mate with the column flange, and the vapor is directed up through a large central tube. The vapor then flows back across the spiral element in cross flow. It can be arranged for final condensing and subcooling in spiral flow. Fig. 5 shows the basic design for this type condenser.

APPLICATION AND THERMAL DESIGN INFORMATION

Since the different types of flow arrangements of the Spiral Plate Heat Exchanger indicate the types of service, applications have been suggested. However, to give more explicit applications with design information, the types will be treated individually.

Spiral Flow Both Passages

This type of Spiral Plate Heat Exchanger is used for most liquid-to-liquid services. As stated above, both liquids have the same heat transfer and pressure drop characteristics since both passages are of the same conformation. For a given exchanger, the cross section of one passage can be more than four times the other since spacing can be from 3/16" to 1" wide.

Of liquid-to-liquid services the Spiral Plate Heat Exchanger has several distinct applications because of its design. One is for cooling or heating highly viscous liquids, because with its single passage there is no distribution problem (2). This would be as in a double pipe exchanger. Another application has been for the requirement of close temperature control. Because of the spiral's long passage (up to 200 ft. long), close approaches and close control can be effected. Again because of the spiral's single passage, it has been used extensively for handling sludges and liquids with fibers or solids in suspension, including slurries. In handling these types of liquids, the Spiral Plate Heat Exchanger is normally mounted horizontally. However, with this mounting, the unit cannot be drained. If solids should settle out, they would fall to the volute of the spiral and then be picked up by the increased velocity and thus higher turbulence caused by obstruction in the single passage. It has been found that slurries can be handled in spirals with velocities as low as 2 ft. per sec. or Reynolds numbers as low as 1250. For the same reasons that the spiral can handle slurries, it can handle fouling cooling water. Also, because of the single passage of the spiral, it can handle scaling liquids, particularly if the scale can be removed by flushing or chemical

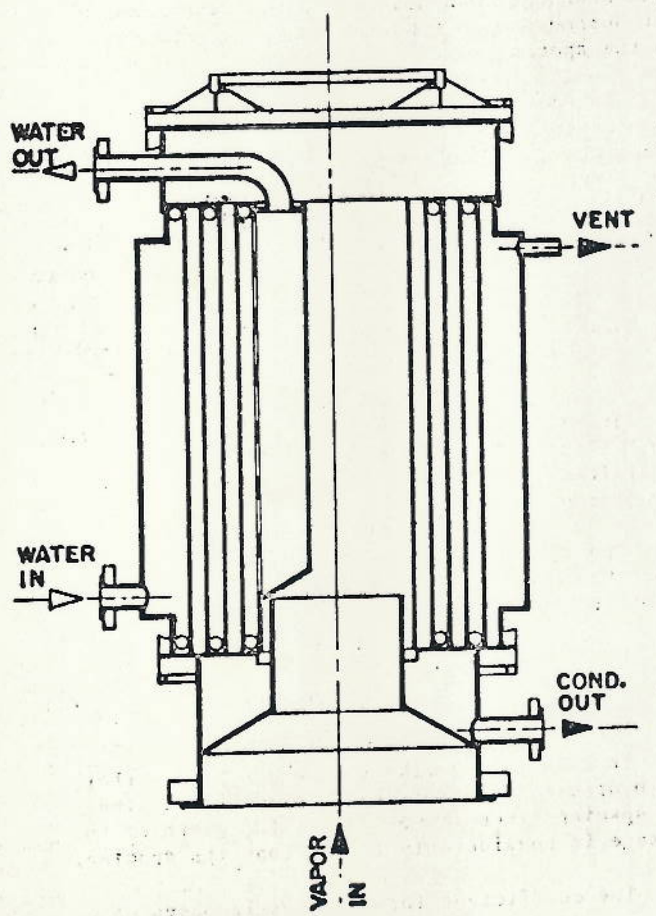

Fig. 5. Cross Section of Overhead Condenser

cleaning. Since the spiral can also be fabricated with identical passages, it has been used in services where switching of the passages allows the one media to remove the scale deposited by the other, as in sulfite liquor heating and phosphoric acid cooling. In addition to these special types of applications, the Spiral Plate Heat Exchanger is adaptable to most liquid-to-liquid services where pressures do not exceed 150 psi.

The majority of Spiral Plate Heat Exchanger installations are for liquid-to-liquid service, and it is in this area only that extensive research has been done. Coons, et al. (3) in work done at the University of Alabama, reported on film coefficients for both turbulent and laminar flow. They stated that the heat transfer coefficients obtained in the small Spiral Plate Heat Exchanger they tested conformed to those in tubes, and that conventional equations for tubes could be used. They also determined that turbulent flow occurred at Reynolds numbers between 1400 and 1800 in an apparatus approaching a commercially designed Spiral Plate Heat Exchanger.

Later work was done in Stockholm, Sweden, on a number of spiral exchangers and liquids, and equations developed for both heat transfer and pressure drop for Spiral Plate Heat Exchangers as commercially marketed. Sander (4) reported that in effect there is no true laminar flow in the Spiral Plate Heat Exchanger because the spacer studs used in construction of the exchanger create a disturbed flow. However, he also reported that fully developed turbulent flow in the Spiral Plate Heat Exchanger was not at a given Reynolds number, but depended upon L/S (length of passage divided by the spacing).

In Sander's evaluation of test data, he attempted to develop empirical equations for heat transfer which would cover the complete range of flows from so-called laminar flow through the transition region to turbulent. In doing so, the empirical equation for heat transfer for liquids in transition and turbulent flow was determined to be

$$Nu = Pr^{0.25}\left(\frac{\mu}{\mu_w}\right)^{0.17}\left(0.0315\ Re^{0.8} - 6.65 \times 10^{-7}\left(\frac{L}{S}\right)^{1.8}\right) \qquad (1)$$

In practice at Reynolds numbers above 30,000, the L/S is neglected since its influence is negligible. This equation in general is used for Reynolds numbers above 1000.

The equation for pressure drop in a Spiral Plate Heat Exchanger has to take into consideration the spacer studs. This equation for liquids is

$$\Delta P = \frac{LV^2(s.g.)}{415}\left[\frac{A}{Re^{0.33}} + B + \frac{16.4}{L}\right] \qquad (2)$$

In all spiral work it should be noted that the hydraulic diameter is taken to be two times the spacing since in most units the width of the passage is considerably larger than its spacing.

The coefficient for slurries is based on equation (1) using the properties of the carrying liquid except for the viscosity which is taken as the apparent viscosity of the slurry. This is as recommended by Kern (5).

The development of equations for heat transfer for liquids in the Spiral Plate Heat Exchanger has always been based on the assumption that there was true countercurrent flow and no correction made to the LMDT. It may be argued that flow is not truly countercurrent since all through the unit each passage is adjoined by an ascending and a descending turn of the other passage. However, if correction is required, it is accounted for in the heat transfer coefficients established.

No laboratory work has been performed to determine the heat transfer coefficients for gases or for condensing. The Spiral Plate Heat Exchanger has not been used extensively for gases because of the limitation of the cross-sectional area to handle the flows. However, the spiral-flow-both-passages has been used for compressor inter- and aftercoolers. In these cases the coefficient for the air is calculated from the basic equation for inside tubes (6)

$$h = 0.0144\,\frac{c_p}{(2S)^{0.2}}\left(\frac{w}{WS}\right)^{0.8} \qquad (3)$$

For condensing in spiral flow, the film coefficient for the condensing vapor is calculated based on conventional equations for condensing on vertical surfaces. Converted to nomenclature for Spirals, the equation (7) is

$$h = 102\left[\frac{10^4\ k^3(s.g.)^2\lambda}{\mu\ W\Delta T_c}\right]^{0.25} \qquad (4)$$

When subcooling is required, a calculation of the depth of condensate in the channel is made in order to estimate the film coefficient for cooling of the condensate and noncondensables.

Normally calculations are broken down into a number of zones with the overall coefficient and LMTD calculated for each zone. In most cases flows are countercurrent, and for each zone there is no correction to the LMTD.

Limitation for the use of the spiral flow both passages Spiral Plate Heat Exchanger is mainly pressure since maximum design pressure is approximately 150 psi. Since a single unit is limited to a cross section for a passage of 72 sq.in. and to a heat transfer surface of 1,800 sq.ft., if greater cross section or surface is required, it is necessary to employ multiple units for a duty. In many cases, banks of multiple units have been found to be economically feasible.

While the Spiral Plate Heat Exchanger does not tend to foul at the same rate as conventional exchangers, it is suggested that if it is known a hard deposit would be set up that could only be removed by drilling, a spiral not be used in this service since the spiral passages cannot be drilled out as inside of tubes.

Spiral Flow One Passage-Cross Flow Other Passage

This type of Spiral Plate Heat Exchanger is most frequently used as a condenser, a gas cooler, or a reboiler, with the condensing vapor, gas, or boiling liquid in cross flow.

As a condenser, the vapor enters the top of the exchanger, flows across the spiral element, and the condensate and noncondensables exit through separate connections in the bottom head of the unit. The coolant flows in the spiral flow passage normally from the periphery to the center. Since the cross section for the vapor can be large, up to approximately 1,500 sq.in., and the length of the spiral sheet is short, maximum 6 ft., this type is used for vacuum service requiring low pressure drop.

Film coefficients for the condensing vapor are based on equation (4). Film coefficients for the coolant are in accordance with equation (1).

Since condensing is in cross flow, there can be little subcooling of the condensate. Subcooling of the noncondensables can be accomplished by fabricating the spiral element so that the noncondensables flow back up into the element and are subcooled in this second pass. This is accomplished by closing part of the final turns of the passage for the vapor at the top and inserting a bar the length of the width of the sheet at the end of the passage closing. Thus, the entering vapor is allowed to flow through only the center part of the element, with the outer section used for the subcooling. In this case the outlet for the noncondensables is on the periphery of the element.

This type of flow arrangement of the Spiral Plate Heat Exchanger is used for both thermosyphon and "kettle" reboilers. In thermosyphon design, the liquid to be boiled enters the bottom extension of the unit, flows across the spiral element, where it is boiled, and the liquid-vapor mixture exits through a connection on the top extension of the unit. The heating medium is in spiral flow in the closed passage, normally entering the center bottom, and flows outward to the periphery.

Spiral kettle-type reboilers have the spiral element fitted into a shell which has a trough inside the shell at the top of the spiral element. Liquid is caught in this trough, and leaves through a nozzle on the shell. The vapor generated flows out through the upper part of the shell to a connection at the top. Again the heating medium is in spiral flow, and enters and leaves through connections to the spiral element inserted through the shell.

In sizing spiral reboilers, conventional methods for tubular units are used for the boiling liquid. For the heating medium, which is in spiral flow, standard spiral flow equations are used.

The spiral flow one side-cross flow other side type of Spiral Plate Heat Exchanger has been used limitedly to handle liquid-to-liquid duties where one flow was large with little change in temperature and the other flow was small. Similarly it has been used to cool larger flows of gases than could be handled in spiral flow. Here the larger volume is in cross flow and the smaller in spiral flow.

With this type of flow arrangement in the Spiral Plate Heat Exchanger a correction has to be made on the LMTD. This is taken as conventional correction for mean temperature difference in cross flow exchangers with both fluids unmixed with single pass arrangement.

Limitations for the use of the spiral flow-cross flow Spiral Plate Heat Exchanger are again pressure and available cross-sectional area and size. Also, the spiral flow passage is welded on both sides so that it is not accessible for inspection or mechanical cleaning.

Spiral Flow One Passage-Combination Cross and Spiral Flow Other Passage

This type of Spiral Plate Heat Exchanger is used basically as a condenser, although it can be used as a vaporizer. Its advantage as a condenser is to have in effect an inbuilt aftercooler. In this type, the vapor enters through the top cover of the unit, and flows into the spiral element in cross flow. Final condensing and cooling is in spiral flow. It is used particularly where subcooling of both the condensate and noncondensables is required.

As in spiral-flow-both-passages, calculations are broken down into a number of zones. Ratings are made similar to for spiral-flow-both-passages condensing, but with proper calculations for velocities with the change in types of flow.

The use of this type of Spiral Plate Heat Exchanger is limited to handling vapor volumes of approximately 20,000 CFM in a single unit. It originally was used in the cellulose industry for condensing relief vapors both in sulfate and sulfite mills. It is used for heating with steam or Dowtherm, as well as condensers for organic and inorganic vapors.

Column-Mounted Overhead Condensers

This type of spiral condenser is known as the "G" type, and it can be furnished with any of the types of flows for the vapor side. It is the same as the other types of condensers except that it is mounted directly on top of a column or reaction vessel. It can be furnished with a mounting flange to mate with the column flange, or a nozzle to mate with the column nozzle. Since vapor volumes are normally too large for the standard 12" center for spirals, the spiral element is rolled on a large tube. The vapor flows up through this center tube. If all spiral flow is allowable, the vapor then flows into the spiral passage for condensing. If the volume of the vapor is larger than can be handled in spiral flow, the vapor flows back across the spiral element in cross flow. As in other types of spiral condensers, the element can be arranged for final condensing and subcooling in spiral flow. It can be arranged so that the condensate drops from the spiral element to prevent subcooling of the condensate, yet permit full subcooling of the noncondensables. This "G"-type condenser can also be designed to include a reflux chamber or surge tank for the condensate in the lower extension to which the mounting flange is attached. See Fig. 5.

This type of condenser has also been furnished as an upflow condenser. It has also been used as a freeze condenser, with the noncondensables flowing from the top of the unit.

As in other types of spiral condensers, the cooling medium normally enters the element at the periphery and flows in spiral flow to the center, where it exits through a nozzle at the top of the element.

Since the spiral element is relatively compact, it can readily be installed on columns or reaction vessels (8). With column-mounted condensers, supports, large vapor piping, reflux tank, and frequently the reflux pump can be eliminated. Its disadvantage is that the cooling medium passage cannot be inspected or cleaned mechanically except in special designs.

It has the normal limitations of Spiral Plate Heat Exchanger of pressure, cross-sectional area and size. It has been used extensively in condensing acid gas, water with H_2S, hydrocarbons and other chemicals.

CONCLUSIONS

Film coefficients and pressure drop characteristics in a Spiral Plate Heat Exchanger are not exceptionally different from those for tubes. However, since it does have countercurrent flow and can be furnished with very long passages, it can handle a number of heat transfer units in a single exchanger. Because of its single passage it can handle viscous and fouling liquids more readily than other heat transfer equipment.

In recent years, more attention has been paid to fouling of heat transfer surfaces. Since fouling can differ so widely, there are no published factors for Spiral Plate Heat Exchangers. Gilmour (9) reported that for Spiral Plate Heat Exchangers in use, fouling was at the rate of one-tenth the rate found in shell-and-tube exchangers. This can be explained by the fact that any deposits formed decrease the cross section of the single passage of the spiral, thereby increasing the velocity and scrubbing effect at the area of fouling. The opposite is true in tubular equipment, where if deposits form in a tube, flow in that tube is restricted (flow is shunted to the other tubes), and the velocity reduced with a resultant increase in fouling tendencies. In one case, a user reported that a Spiral Plate Heat Exchanger replaced tubular equipment that had plugged. The spiral has performed successfully in this service, the only maintenance being chemical cleaning in place at six-month intervals (10).

Another advantage of the Spiral Plate Heat Exchanger is that normally it can be cleaned more readily than tubular equipment. Because of its single passages it responds readily to chemical cleaning. For mechanical cleaning which can be accomplished by high pressure water or steam, the relatively short depth of the spiral sheet makes it simple to clean after removing the covers.

When cleaning is known to be a problem, or when liquids with high fiber content are to be handled, the spiral is fabricated with no spacer studs in the passage. With this construction there is no obstruction to cleaning when the cover is removed. Elimination of the studs does, however, restrict size and design pressure for the unit.

The Spiral Plate Heat Exchanger's disadvantages, other than pressure and size, are concern for repair in the field. A leak cannot be plugged as in a tubular, but the possibility of leakage in a spiral is reduced because it is fabricated of sheet or plate material considerably thicker than normal tube walls. Also, it does not have the same entrance disturbances or expansion problems as in tubular exchangers. If a spiral should need repairing, most of the welding of the spiral assembly is exposed, or can be by removing the covers.

Pricewise there is no correlation of the selling price of a Spiral Plate Heat Exchanger to other heat transfer equipment. In steel units and units requiring alloy on one side only, spirals are competitive. If alloy material is required on both sides, the Spiral Plate Heat Exchanger is normally less expensive than tube-and-shell exchangers. The Spiral Plate Heat Exchanger cannot be furnished in bimetallic construction.

Although the Spiral Plate Heat Exchanger is not as well known or widely used as tubular equipment, its advantages in performance and maintenance, because of lower fouling and easy cleaning, as well as its compactness, are reasons for it to be given consideration for all heat transferring applications.

NOMENCLATURE

A = Constant

B = Stud density, no./sq.ft.

c_p = Specific heat, Btu/(lb.)(^{o}F)

h = Film coefficient, Btu/(hr.)(sq.ft.)(^{o}F)

k = Thermal conductivity, Btu/(hr.)(sq.ft.)(^{o}F per ft.)

L = Length, ft.

Pr = Prandtl number

Re = Reynolds number

S = Spacing, ft.

s.g. = Specific gravity

Δt_c = Temperature difference between condensing temperature and wall temperature, ^{o}F

V = Velocity, ft./sec.

W = Width, ft.

w = Flow rate, lb./hr.

μ = Viscosity, cp

μ_w = Wall viscosity, cp

λ = Latent heat, Btu/lb.

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