Dec. 18, 1945. J. O. JACKSON 2,391,244

HEAT EXCHANGER

Filed March 21, 1942 3 Sheets-Sheet 1

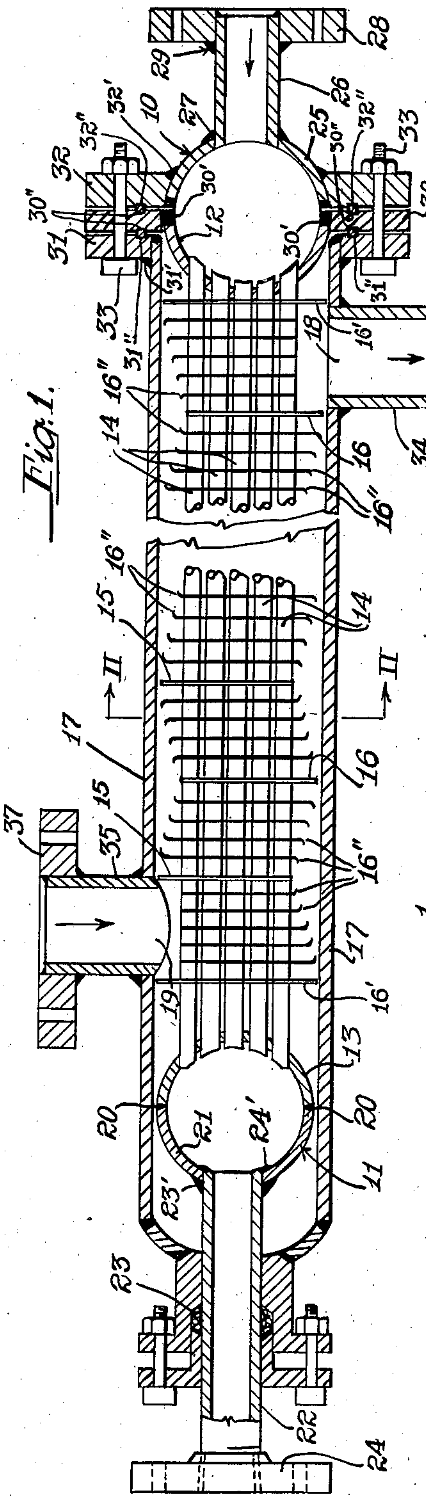

Fig. 1.

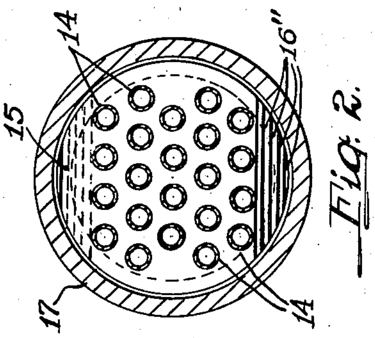

Fig. 2.

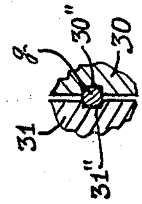

Fig. 1a.

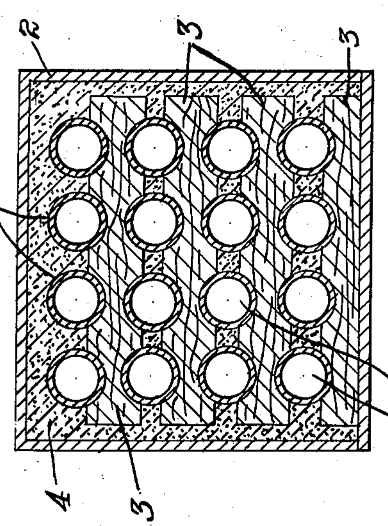

Fig. 3.

INVENTOR

James O. Jackson

By Green & McCallister

His Attorneys

Dec. 18, 1945. J. O. JACKSON 2,391,244

HEAT EXCHANGER

Filed March 21, 1942 3 Sheets-Sheet 2

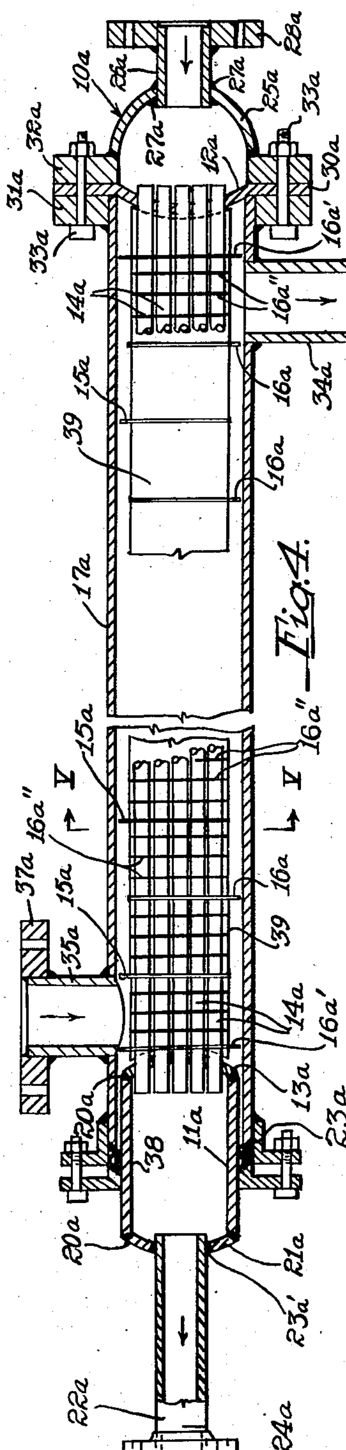
Fig. 4.

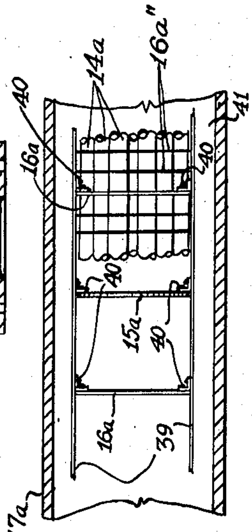
Fig. 7.

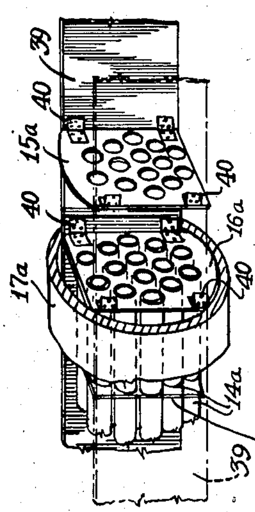
Fig. 6.

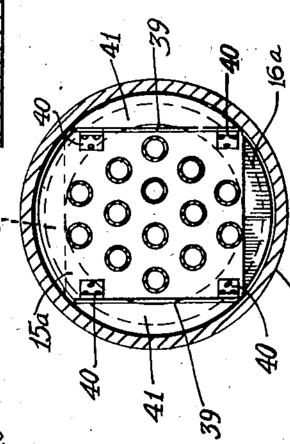
Fig. 5.

INVENTOR

James O. Jackson

By Green & McCallister

His Attorneys

Dec. 18, 1945. J. O. JACKSON 2,391,244

HEAT EXCHANGER

Filed March 21, 1942 3 Sheets-Sheet 3

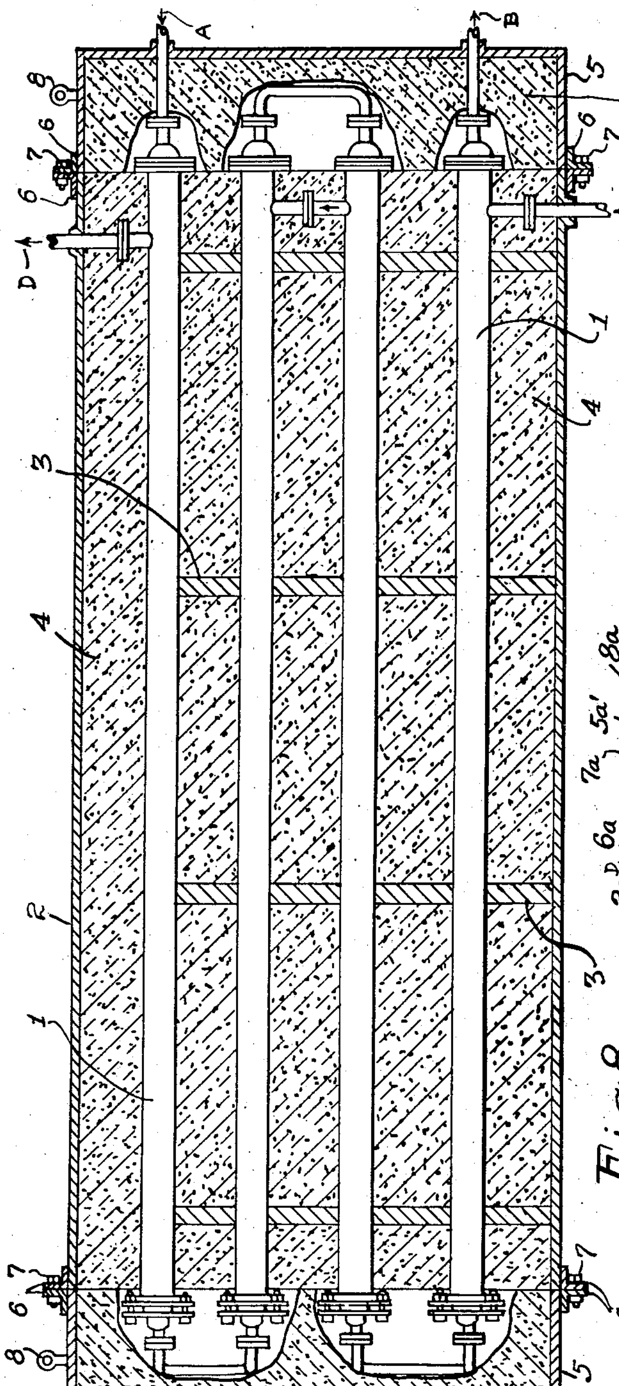

Fig. 8

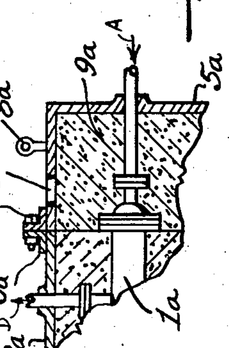

Fig. 9

INVENTOR
James O. Jackson
By Green & McCallister
His Attorneys

Patented Dec. 18, 1945 2,391,244

UNITED STATES PATENT OFFICE

2,391,244

HEAT EXCHANGER

James O. Jackson, Crafton, Pa., assignor to Pittsburgh-Des Moines Company, a corporation of Pennsylvania

Application March 21, 1942, Serial No. 435,750

5 Claims. (Cl. 257—236)

This invention relates to the art of heat transfer, and more particularly to an improved heat exchanger adapted for use in the liquefaction of natural gas, methane and other liquefiable gases.

Existing heat exchangers, although extensively employed and generally satisfactory, have certain inherent limitations, particularly when such are employed in carrying out procedures or operations involving high pressures and/or low temperatures. The conventional type of heat exchanger has a flat or straight tube sheet and a flat or dome-shaped closure at each end. In a heat exchanger of this character, the introduction of a gaseous medium at high pressure, e. g., at 2500 lbs. per square inch absolute, causes the straight tube sheet to flex or to assume a bowed or curved condition with the central portion entirely out of the plane of the peripheral portion. The amount which any particular tube sheet bends depends, of course, on the pressure and on the thickness and nature of the material of that tube sheet, but such action unavoidably occurs and when it occurs it brings about undesirable and harmful stresses on the system of tubes extending between such tube sheets and secured to them. The result is that the tubes in the center of the tube system are placed under compression and the tubes around the outer portion of the tube system are placed under tension, and the damage to the tubes is proportional to the extent of such stressing. In some instances, this even causes a buckling of the central tubes and rupturing of the outer tubes. Another difficulty is that conventional heat exchangers do not stand up under low temperature conditions because the metal or alloy of which they are made becomes embrittled, thus causing failure. Most heat exchangers are difficult to disassemble and repair and, in general, there are a number of disadvantages which are well recognized by engineers.

It is, accordingly, one object of my present invention to produce a heat exchanger which, regardless of pressure conditions, does not adversely axially stress the tube system.

Another object of my invention resides in producing a heat exchanger in which the headers thereof are so designed as to make them adequately strong to withstand any desired pressure without placing the central tubes of the tube system in compression and the outer tubes of the tube system in tension to any undesirable or dangerous degree.

A further object of my invention resides in producing a heat exchanger, the interior parts of which are readily removable as a unit and yet which are so constructed and designed as to avoid the imposition of harmful axial stresses on the tube system even at pressures as high as 2500 lbs. per square inch absolute.

A still further object of the invention is to provide a built-up welded structure which can be made from standard materials and thus which is relatively inexpensive.

A still further object of the invention is to produce a heat exchanger in which the tube shell may be composed of a special metal or alloy resistant to embrittlement and which even at temperatures as low as —260° F. has adequate ductility.

Other and further objects and advantages will be pointed out hereinafter or will be appreciated by those versed in the heat exchanger art.

In the accompanying drawings:

Fig. 1 is a vertical sectional view taken through a preferred form of heat exchanger responding to my present invention;

Fig. 1*a* is an enlarged fragmentary view of certain details of Fig. 1;

Fig. 2 is a cross-sectional view taken through Fig. 1 along the line II—II thereof;

Fig. 3 is a diagrammatical cross-sectional view taken through a group of heat exchanger units enclosed in a box and insulated to form a compact thermally efficient liquefaction or other system;

Fig. 4 is a view similar to Fig. 1 of a modified form of heat exchanger;

Fig. 5 is a cross-section through the heat exchanger of Fig. 4 taken on line IV—IV thereof;

Fig. 6 is a fragmentary perspective view, partly in section, showing the manner of assembling and connecting certain of the parts of the modified heat exchanger;

Fig. 7 is a plan view of the right-hand end of the heat exchanger of Fig. 4 but with the heat exchanger shell in horizontal section in order to show further the mode of assembling and connecting certain of the parts;

Fig. 8 is a longitudinal vertical sectional view of the box of Fig. 3 at right angles thereto and showing therein in elevation an exemplary group of heat exchanger units such as might be employed in a liquefaction system; and

Fig. 9 is a fragmentary view similar to Fig. 8 of a somewhat modified form of box.

Referring now to the drawings, it will be observed that the preferred heat exchanger of Figs.

1 and 2 is provided with a spherical header 10 and 11 at the entrance and exit ends, respectively. Each such header is not only admirably adapted to withstand high pressures but such spherical form has the further advantage of having a minimum surface for a given volumetric capacity. The spherical shape, besides being inherently the strongest structural shape, in addition provides a hemispherical or concavo-convex portion 12 and 13 each of which serves as a curved tube sheet. Such tube-sheet portions are provided with openings of the desired size and spacing for the reception of the ends of the system or bundle of tubes which extends therebetween and which is made up of a number of copper tubes 14 which are preferably but not necessarily so arranged as to be equi-distant from one another throughout their length. The ends of such tubes are brazed, welded, galvanized, tinned, soldered or otherwise suitably secured in place in the said curved tube sheets 12 and 13.

At longitudinally spaced intervals, baffles 15 and 16 are provided which are substantially disc-shaped and provided with openings through which the tubes 14 pass. The tubes and baffles are suitably secured to each other as by brazing, welding, galvanizing, tinning or soldering. It will be noted that alternate baffles, those numbered 15, extend upwardly into close juxtaposition with the heat exchanger shell 17 and that the lower end of each such baffle 15 is appreciably spaced from the bottom of such shell to form a plano-convex passageway. The other set of alternate baffles, those numbered 16, is of such nature that they are in close juxtaposition with the bottom of heat exchanger shell 17 and are appreciably spaced from the top thereof to form a plano-convex passageway. A pair of end baffles 16′ is provided, as shown, the diameter of which is only slightly less than the internal diameter of shell 17 and which effectively limit the longitudinal penetration of the cooling medium within shell 17.

These baffles divide that portion of the shell between ports 18 and 19 into a series of connecting compartments through which the fluid medium entering inlet port 19 travels to outlet port 18; the fluid medium passing successively through the compartments with a reversal in direction of flow through adjacent compartments of the series.

Located between each pair of spaced baffles 15, 16 and 16′ are disposed a plurality of secondary or intermediate baffles 16″ which take the form of plate fins which are arranged in groups or sets, as shown. Each of these plate fins 16″ is provided with apertures suitably arranged so as to enable the heat exchanger tubes 14 to pass therethrough. The plate fins are secured to tubes 14 in the manner of baffles 15, 16 and 16′. The plate fins are provided at their top and bottom portions with curved guides or deflectors constituting curved turning vane extremities, it being noted that these are oppositely curved with respect to each such baffle. The structure of baffles 16″ is such that the exchange efficiency is greatly improved, the effective exchange area is further increased, "channeling" of the cooling medium is prevented and a uniform distribution of the cooling medium is effected. In addition, power requirements are decreased (by as much as 4/5) and frictional losses are reduced. The precise number of secondary baffles employed between succeeding spaced main baffles may be varied depending upon circumstances without departing from the principles of the invention and in each such group of intermediate baffles (except the terminal group at each end) the individual baffles are arranged either as a descending or as an ascending series. Referring to Fig. 1, for example, it will be apparent that the intermediate baffles 16″ between the main baffles 15 and 16 (the first set to the right of inlet 35) are successively lower toward the entrance (right hand) end of the heat exchanger, that between the next main baffles 16 and 15 each intermediate baffle in the group of four baffles is disposed successively higher and that the main baffles alternately have their top and bottom portions flush with the tubes 14 so as not to interfere with the action of the deflector portions of the intermediate baffles and so as to prevent the setting-up of undesirable eddy or other currents.

Those groups of intermediate baffles 16″ which are substantially in alignment with the inlet opening 19 and the outlet opening 18 are provided with the deflector portions aforesaid only as to that portion of each of the intermediate baffles which is remote from each such opening as will be appreciated from Fig. 1. In the former case, the baffles 15 and 16′ effectively direct the incoming cooling fluid medium in the desired direction and prevent undesirable spreading or wasting of the cooling medium by retarding its penetration to that portion of shell 17 which lies rearwardly of the contiguous end baffle 16′. The arrangement at outlet opening 18 is the same in principle but opposite structurally so as to direct the cooling medium to the outlet fitting 34.

Particular attention is directed to the fact that as the cooling medium travels from inlet fitting 35 to outlet fitting 34 its direction of movement is predominantly normal to the direction or axis of the tubes 14. As cooling medium enters shell 17 via inlet fitting 35 it passes directly downwardly between the various baffles above described, is turned through approximately 90° by the bottom deflector portions of such baffles, is received by and again turned through 90° by the bottom deflector portions of the next group of intermediate baffles and is thereupon directed upwardly and the stream of cooling fluid is subjected to a number of additional reversals in direction of flow as will be readily understood from Fig. 1 until it is eventually directed out of shell 17 via outlet fitting 34. The effectiveness as well as the thermal efficiency of the arrangement described is far beyond that which can be secured by means of prior heat exchangers. In its travel longitudinally of shell 17 the cooling fluid is caused to follow an up-and-down tortuous path, the major proportion of which is vertical, either upward or downward, and thus differs markedly from heat exchangers in which the direction of flow of the cooling fluid is chiefly longitudinal or parallel to the axis of the shell and its interior tubes. Since the medium to be cooled is introduced into tubes 14 via head tube 26 and leaves by way of tail tube 22 the advantages of the countercurrent principle of heat exchange are also secured.

The tube sheet 13 of spherical header 11 is welded, as at 20, to an opposed hemispherical member or portion 21—the header being preferably composed of two substantially equal halves—which is provided with an opening for the reception of the tail tube 22, one end of which is securely welded as shown at 23′ and 24′ within such opening. The tail tube 22 extends axially through a stuffing box 23 which is on the discharge end of the heat exchanger shell 17. The construction of the stuffing box is conventional and requires no specific description. The tail tube is provided at its rearward end with a tail tube flange 24 which is threaded for engagement with the exterior threads provided on the end of the tail tube and which is removed prior to disassembly of the exchanger.

The spherical header 10 is also preferably made up of two halves, namely, the hemispherical portion 12 which serves as a tube sheet and an opposed hemispherical portion 25 having an opening for the reception of one end of the head tube 26, one end of which is welded or otherwise suitably secured in place therein, as at 27, and the other end of which is provided with a flange 28 welded at 29 to the tube 26 and adapted for connection to another heat exchanger or to other equipment. The tube sheet portion 12 of such spherical header 10 is provided with an apertured flange member extension 30 welded thereto at 30′ which is located between an apertured flange 31 welded at 31′ to and extending at right angles from the heat exchanger tube 17 and an apertured flange 32 secured by welding 32′ or otherwise to the hemispherical portion 25 of the header. Members 30, 31 and 32 are bolted together, as shown at 33, and have opposed, annular, flat-bottomed pairs of grooves 30″, 31″ and 32″ between which are the wire (preferably copper) gaskets *g*, as will be understood best from Fig. 1*a*. The heat exchanger shell 17 is provided with an outlet nozzle or fitting 34 and an inlet nozzle or fitting 35, which consist of short tubular members disposed in openings 18 and 19 provided for that purpose in the shell 17 and welded to the shell and a flange member 36 and 37, respectively, positioned around and welded to the distal end of each such tube member and adapted for connection with similar members of other heat exchanger units or to other equipment.

In any heat exchanger unit which is subjected to low temperatures, and this is usually the case with the third and subsequent units in a liquefaction system, the shell 17 is composed of a material which resists embrittlement and has adequate ductility at the lowest temperature involved. While such shell can be made of copper or aluminum or of an austenitic steel like 18–8, I prefer to employ nickel steel containing approximately 3½% of nickel, but any amount of nickel between about 3% and about 4% is fully satisfactory and is intended to be included within the scope of the term "approximately 3½% of nickel." In my opinion, any metal or alloy which has a Charpy impact value of at least 10 ft. lbs. at any given temperature is completely satisfactory for use at such temperature and will have the necessary ductility and other properties. The addition of nickel to steel lowers the temperature at which an impact test value of 10 ft. lbs. (Charpy) is obtained and the addition of about 3½% of nickel produces a steel which has a Charpy impact value of about 18–20 ft. lbs. at −260° F. Any addition of nickel is, however, advantageous depending upon the temperature and other conditions involved in a given installation and thus I have determined that I may employ nickel in any amount from a fraction of 1%—i. e., the minimum amount at which the Charpy impact value is at least 10 ft. lbs. for a given temperature—up to about 10%.

In the modified form of heat exchanger illustrated in Fig. 4 et seq., the construction is generally similar to that of Fig. 1 with certain noted exceptions. This inlet header 10*a* at the entrance end of the heat exchanger is of modified spherical shape, being made up of a substantially hemispherical portion 25*a* provided with a central opening in which is secured as by welding 27*a* one end of a head tube 26*a*, the distal end of which is provided with a flange member 28*a* welded in position and adapted for connection to the discharge end of another unit or to other equipment. The other portion of the head 10*a* is a concavo-convex tube sheet 12*a* of relatively large radius in which one end of each of tubes 14*a* is fixed and provided with a flange extension 30*a* which is bolted at 33*a* or otherwise suitably secured to and between a flange 32*a* welded to the edge of hemispherical member 25*a* and a flange 31*a* welded on the outside of the heat exchanger tube 17*a*. Copper wire gaskets may be provided as shown in Figs. 1 and 1*a*.

The header 11*a* at the other end of the heat exchanger is likewise not a true sphere, as compared with the construction of Fig. 1. In Fig. 4, I build up the header 11*a* from a short cylinder or tube 38 of less diameter than shell 17*a* one end of which is provided with a concavo-convex tube sheet portion 13*a* suitably welded at 20*a* to the contiguous end of the cylinder and the other end of which is provided with a concavo-convex member 21*a* similar in shape to the tube sheet portion 13*a* and welded at 20*a* to the other end of the cylinder 38 but provided with a central opening in which is secured, by welding 23*a*′ or the like, one end of a tail tube 22*a*, the distal end of which is provided with a welded-on tail tube flange 24*a* which is small enough to pass through shell 17*a* during disassembling of the heat exchanger.

Another distinction between the structure of Fig. 4 and that shown in Fig. 1 resides in the employment of the side vanes 39 which are thin strips of suitable metal or alloy such as copper and are usually made of the same material as the tubes 14*a* but I wish it distinctly understood that such vanes may also be, and in many cases are, employed in the Fig. 1 form of the invention. As will be especially noted from Figs. 4–7, vanes 39 reduce the effective fluid-carrying capacity of the tubular shell 17*a* to a predetermined value so that there can be readily obtained the desired or requisite ratio between the net fluid-carrying capacity of the shell and that of the tubes. In this way it is possible to employ a standard pipe size for the shell 17*a* and to adjust or alter its fluid-carrying capacity by means of the said vanes. This is both desirable and highly advantageous.

In the structure of Fig. 4 et seq., the baffles 15*a* are disposed in the same manner as the baffles 15 in Fig. 1, but the baffles 15*a* have straight sides, as will be apparent from Fig. 5, instead of being substantially disc-shaped as shown in Fig. 2. The nature of baffles 16*a* will be equally apparent. The vanes 39 are preferably continuous and suitable connections are made between such vanes and the baffles, such as by the use of the angle brackets shown at 40, but it is to be understood that other modes of connection or any suitable connecting instrumentality may equally well be employed. In this form of the invention, it will be noted that plano-convex passageways 41 are left between the vanes and the sides of the shell 17*a*. These are inactive spaces and since the vanes 39 extend substantially from tube sheet to tube sheet, and since the outlet 34*a* for the cooling medium is connected into shell 17*a* rearwardly of the forward ends of the vanes, it will be apparent that such cooling medium does not enter the said spaces 41 and, therefore, that the desired proportion is maintained between the reduced cross-sectional area of the shell and the cross-sectional area of the tubes of the tube system.

Intermediate or secondary baffles 16a'' are provided between the main or primary baffles and are similar to baffles 16'', above described, except that they are not provided with the curved or deflecting end portions characteristic of baffles 16''. The baffle structure of Fig. 1 may, however, be employed equally well here and the arrangement and functioning of baffles 16a'' will be understood from what has preceded. The path of the cooling medium is likewise predominantly normal to the axis of the tubes 14a and such cooling medium follows an up-and-down tortuous path between the inlet 35a and the outlet 34a. The general direction of travel of the cooling medium is also counter-current to the medium to be cooled which enters via head tube 26a and leaves via tail tube 22a.

The remaining parts of the heat exchanger of Fig. 4 are generally similar to those of Fig. 1 as will be appreciated from the numerals employed. In Fig. 4, however, it should be particularly noted that the stuffing box 23a is of an alternate type as compared with that of Fig. 1 and whereas in the latter construction the stuffing box 23 is relatively small and cooperates with tail tube 22 in the former the stuffing box is substantially of the same diameter and size as the tube shell 17a itself. Thus, stuffing box 23a cooperates directly with the tubular portion 38 of the spherical type header 11a. Contraction and expansion can take place readily through this enlarged stuffing box 23a and therefore avoids the necessity of a screwed connection between flange 24a and tube 22a and permits welding or otherwise permanently securing the two parts together. Moreover, the headers of Fig. 4, although not true spheres, partake of spherical nature and the advantages of the spherical form. The significance of such will be appreciated by those skilled in this art.

In Figs. 3 and 8 I have illustrated, somewhat diagrammatically, a set of heat exchanger units 1, which may be of any suitable or desired construction such as either that of Fig. 1 or Fig. 4 and as shown a set or system of heat exchangers has been grouped together within an enclosing metal box 2. Within the box the units are maintained equi-distant from one another or in any desired relative positioning by means of transverse spacers 3, which, while preferably made of wood, may be composed of any suitable material which is a poor conductor of heat. Spacers 3 are located along the length of the box and units at intervals, as will be noted from Fig. 8, and these intervals are suitably selected so as to maintain the units in properly positioned and supported condition, but preferably in such manner as to avoid the imparting of bending or other undesirable stresses to the said units. The unoccupied spaces within the box are filled with a suitable heat-insulating material 4 which may, for example, be granulated cork but which may be of any other thermally effective material.

From Fig. 8 it will be observed that the box 2 is made in three parts, namely, a body portion and a pair of end closures 5. Such closures are detachably bolted or secured to the body portion of the box as by means of the angle brackets 6 bolted together at 7. Each end closure is also provided with an "eye" 8 by means of which it may be removed by a hook or the like operated by a crane or winch (not shown). Each end closure member 5 is filled with a granular heat-insulating medium such as cork which has been mixed with a suitable binder and molded-in in such form or configuration as to cooperate properly with the projecting ends, couplings, etc., of the various heat exchanger units. In other words, the molded insulating material designated as 9 has recesses to receive the portions of the heat exchanger units which extend beyond the body portion of the box 2. In Fig. 9 the arrangement is modified to the extent that each end closure 5a is provided with an opening 5a' by means of which granular cork or other suitable heat-insulating material may be introduced into the said end closures after the same have been assembled with the body portion of the box. In this form of the invention enough granular insulating material is introduced to fill the end closures and this automatically positions itself around the heat exchanger parts which project thereinto. In such case also no binder is employed so that when the end closures are removed the granular insulating material runs out but it can be readily collected and reused.

It will be appreciated that by removing either of the end closures 5 access can be readily obtained to the ends and/or connections of the various heat exchanger units. Various connections can also be made and likewise the connections can be changed in any desired manner. In addition, when the appropriate end closure 5 has been removed, that spherical or spherical type header which is detachably connected to the entrance end of a given heat exchanger can be disconnected and the bundle of tubes with its baffles and associated parts can be readily withdrawn from the shell of the header as an integral unit for any desired or required purpose.

The arrangement is further such that a continuous path is or can be provided for the cooling or heat exchanging medium and not only is there provided generally countercurrent flow of cooling or heat exchanging medium with relation to the medium to be cooled for each individual heat exchanger unit but the group of units as a whole or any sub-group within the enclosing box likewise has the cooling or heat exchanging medium flowing in countercurrent relationship with the medium to be cooled. While as above stated the heat exchanger units 1 can be inter-connected in various ways, as shown in Fig. 8 the medium to be cooled enters at the arrow A, travels from right to left of that particular heat exchanger unit and then may pass directly to the next lower unit 1 in which it travels from left to right and so on until it is discharged at the arrow B in the condition desired, for example, as a liquified gas, or, since it will be understood that a plurality of vertical rows of units 1 are or may be employed, the medium to be cooled may alternatively pass horizontally or laterally to another row or rows eventually returning to the appropriate unit visible in Fig. 8. Similarly, the cooling or heat exchanging medium enters the system at the arrow C, travels from right to left of the lowermost unit 1 and, as in the case of the medium to be cooled, eventually works its way up to the topmost unit 1 where it is discharged at the arrow D. It is not essential that a direct path be provided from C to D, nor does the arrangement illustrated fully show such but it is to be understood that, in the manner explained in connection with the medium to be cooled, the cooling or heat exchanging medium may travel laterally or horizontally to another row or rows depending upon the particular installation and the results to be achieved.

The arrangement of heat exchanger units within the box is thus not only susceptible to many variations but a group of heat exchanger units assembled in a box provides a flexible and a versatile arrangement for carrying out any desired heat exchange operations. The individual heat exchanger units in the box can be connected in series, in parallel or in any other desired way, can be segregated into high or low pressure subgroups, into high or low temperature sub-groups or in any other desired manner depending upon the particular nature of the operations to be carried out. While the arrangement illustrated and described is particularly well-adapted for those heat exchange operations which take place during liquefaction it is to be understood that the present arrangement is not restricted or limited thereto and that the particular illustration and description is intended to be purely exemplary.

It will be appreciated from the structures above described and from the underlying conception upon which the present invention is based that curved tube sheets are not subject to the defects and disadvantages pointed out above in connection with flat or straight tube sheets. The fact that the curved tube sheet is a part of a header which is either spherical or of near spherical shape not only produces a much stronger construction and one in which the high pressure fluid is advantageously confined to relatively small headers and tubes but tube sheet movement is practically nil and any very slight amount of movement which might occur under high pressure is not of such character as to bring about undesirable bending stresses on the tube system. The construction is also unusually free from temperature stresses due to contraction and expansion. If any slight stresses are imparted to the tubes, such will be of negligible amount. Conditions thus do not arise which would cause buckling of the central tubes or rupturing of the peripheral tubes. Such an arrangement, particularly in conjunction with the ready removability of the internal parts of the heat exchanger as a unit, constitutes important parts of this invention. Removal of those internal parts as a unit is accomplished, as will be appreciated, by detaching (unscrewing) the tail tube flange (Fig. 1 only) and unbolting the flanges on the forward tube sheet, whereupon the unit may be slid out after loosening up on the stuffing boxes.

The foregoing is intended as illustrative and not as limitative and within the scope and principles hereof other and further additions, omissions, substitutions and modifications may be made. The invention is rather that defined by the subjoined claims. The expression "spherical type header" is employed in the claims in a generic manner to designate both headers in accordance with Fig. 1 which are true or substantially true spheres as well as spheroidal or near spherical headers such as those illustrated in Fig. 4 in which the headers partake of the nature of spherical headers and have similar advantages.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A heat exchanger comprising a tubular shell having longitudinally spaced inlet and outlet ports, a bundle of tubes extending longitudinally of the shell, a series of parallel baffles carried by said tube bundle, extending at right angles to the major axis of the shell and dividing the shell between said ports into a series of connecting compartments so constructed and arranged as to cause the fluid entering the inlet port to reverse its direction of travel through adjacent compartments of the series, and a series of plate fins carried by the tube bundle between said baffles, arranged in parallel relation thereto and each having oppositely curved fluid directing terminal portions; the construction and arrangement being such that fluid entering said inlet flows successively through said compartments, is separated by said plate fins into relatively thin parallel layers, and friction in the fluid entering and leaving the compartments is minimized by the oppositely curved fluid directing terminal portions of said plate fins.

2. A structure according to claim 1 in which the plate fins in each compartment have their curved terminal portions located within the space between the tube bundle and the shell and positioned at different distances from the major axis of the tube bundle.

3. A structure according to claim 1 in which the plate fins in line with the inlet and outlet ports have curved terminal portions only at their ends remote from such ports; said terminal portions curving toward the opposite port.

4. A structure according to claim 1, in which the terminal portions of corresponding plate fins in adjacent compartments are curved in opposite directions.

5. A structure according to claim 1, in which the distance between the major axis of the tube bundle and the curved terminal portions of the fins at the inlet end of each compartment increases from the inlet port side of the compartment to the opposite side thereof, and at the outlet end of each compartment increases from the outlet port side thereof to the opposite side.

JAMES O. JACKSON.