United States Patent

[11] 3,561,524

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Continuation-in-part of application Ser. No. 711,646, Mar. 8, 1968, now abandoned.

[54] **MARINE KEEL COOLER**
21 Claims, 13 Drawing Figs.

[52] **U.S. Cl.** **165/76,** 115/0.5; 285/158; 165/44
[51] **Int. Cl.** **F28b 7/00**
[50] **Field of Search** ..... 115/.5; 165/76, 80—83, 166

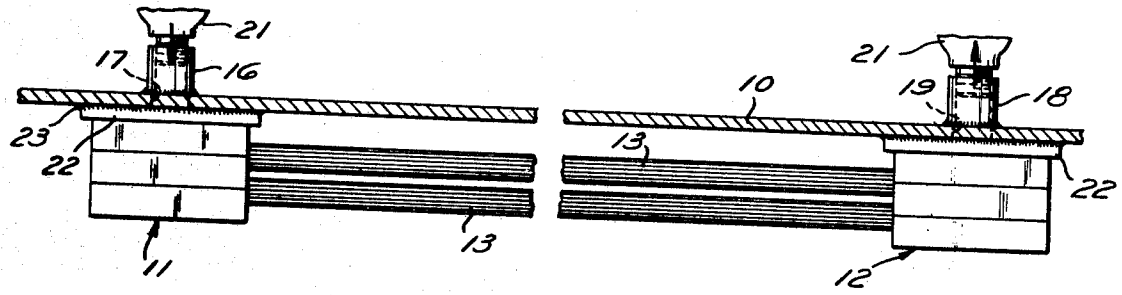
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Primary Examiner—Martin P. Schwadron
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ABSTRACT: A marine keel cooler is disclosed which includes two header assemblies each adapted to be mounted on the exterior of a vessel's hull. Each header assembly includes a stud plate and at least two separable members formed of an elastomeric material. The members are formed with semicylindrical recesses which cooperate with adjacent recesses to form openings which receive and grip the ends of the heat exchanger tubes. Relatively soft heat resistant seals are positioned over the ends of the tubes within the openings and are tightly gripped when the parts of the header assembly are bolted together. When fluted tubes are used, the parts are proportioned so that the tube is radially contracted to a uniform or standard size during the clamping by the headers. The header assemblies are arranged so that separators may be selectively positioned therein. Such separators permit a given header assembly to be used in single pass, multiple pass, and compound heat exchanger installations. When tubes having deep grooves are provided, i.e., tubes having an outside diameter to groove depth of about four to one or less, the cooler may be mounted in a location where forced flow thereover can be provided solely by the slip stream of the propulsion screw.



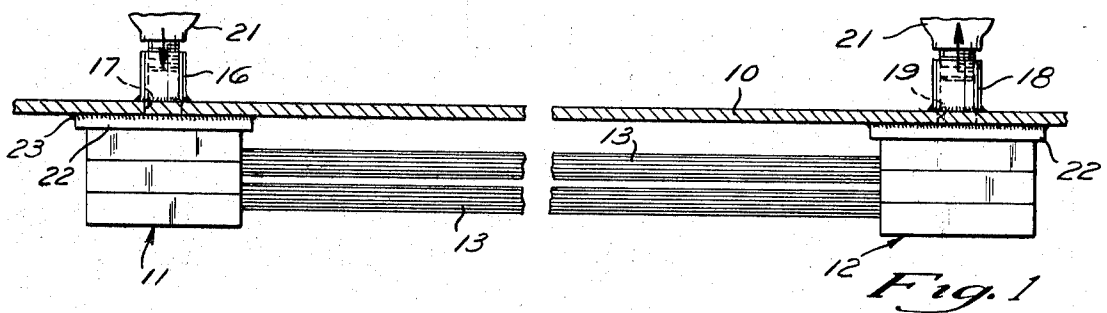


Fig. 1

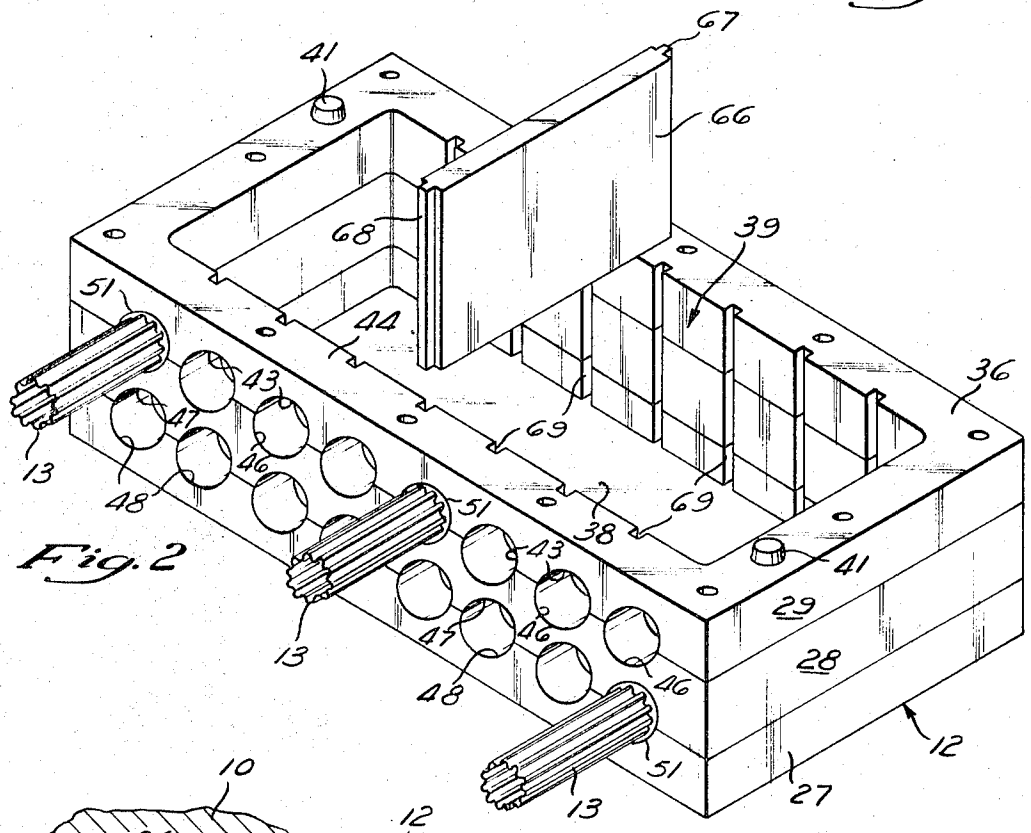


Fig. 2

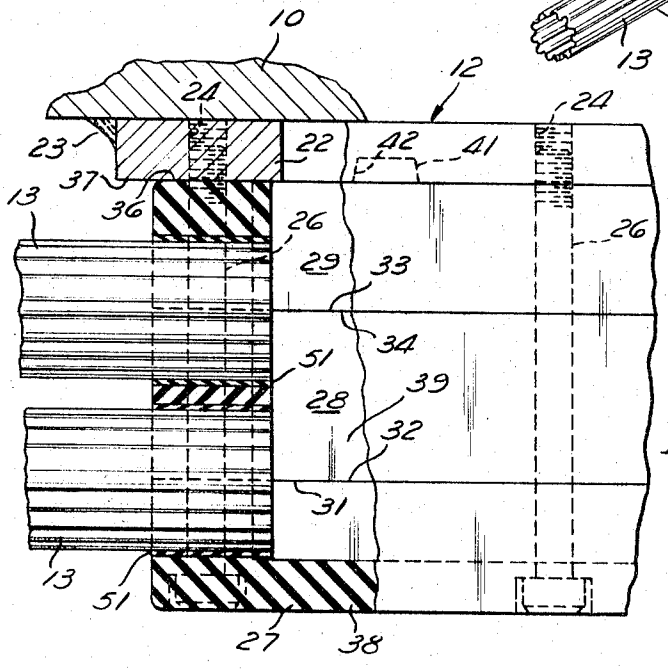


Fig. 3

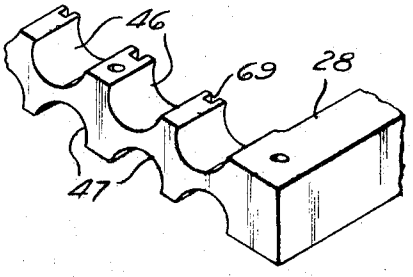


Fig. 4

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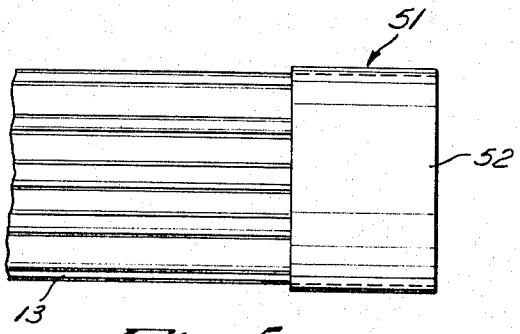


Fig. 5

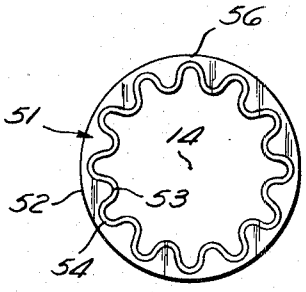


Fig. 6

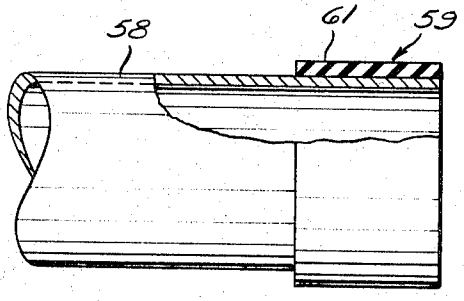


Fig. 7

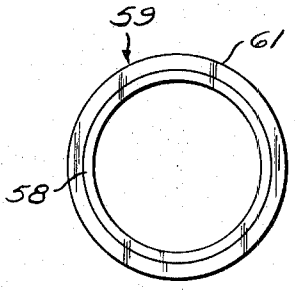


Fig. 8

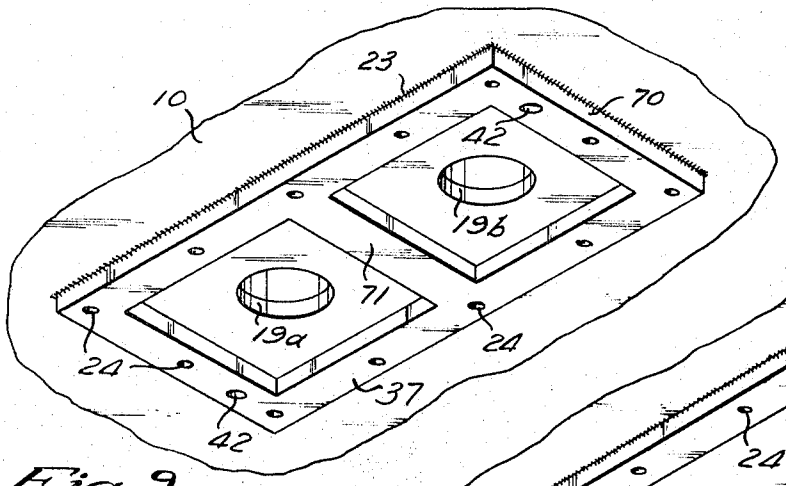


Fig. 9

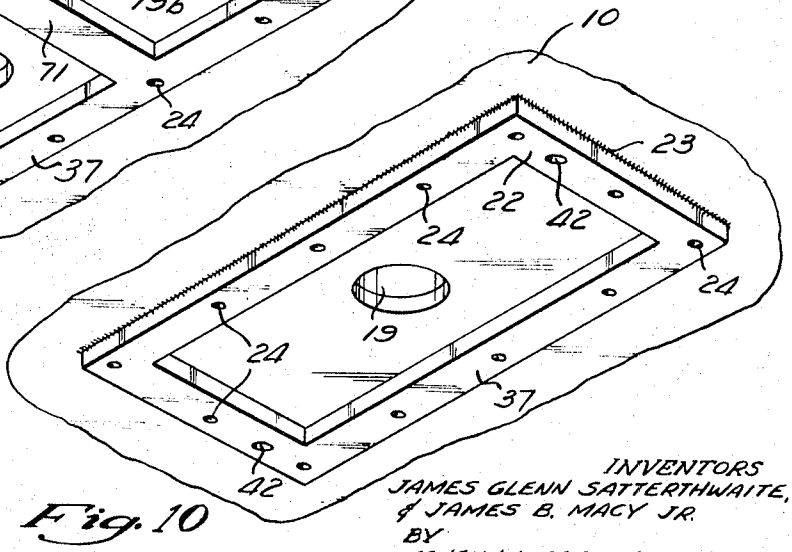


Fig. 10

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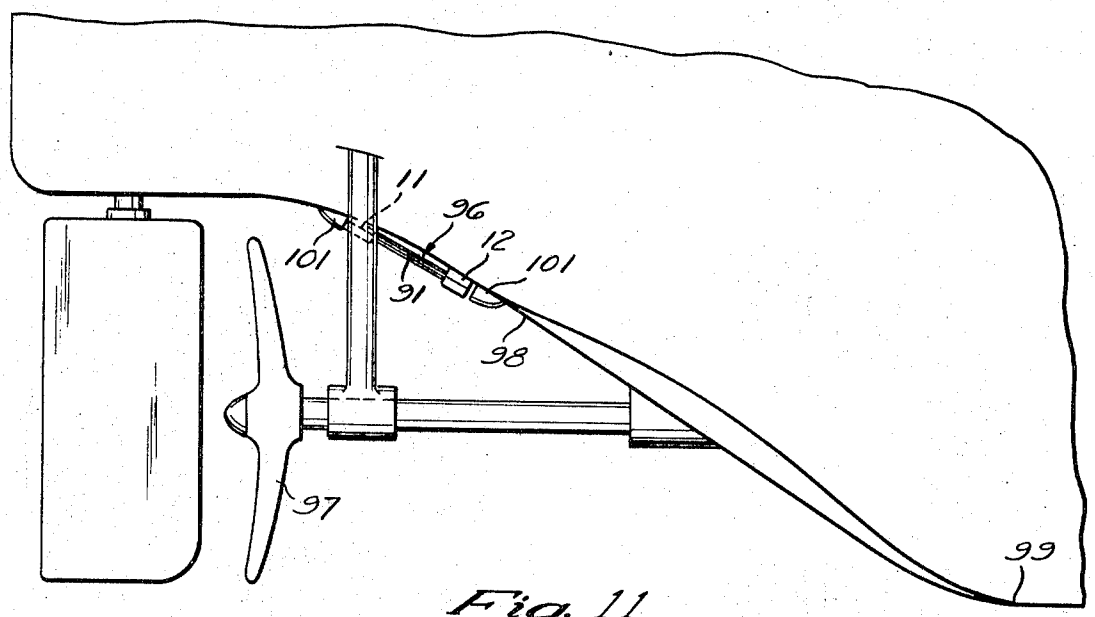


Fig. 11

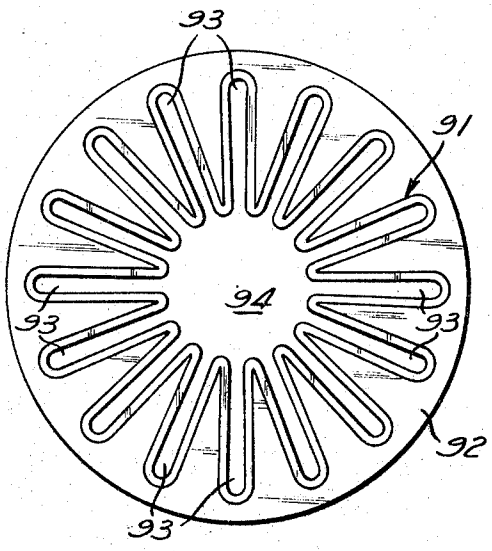


Fig. 12

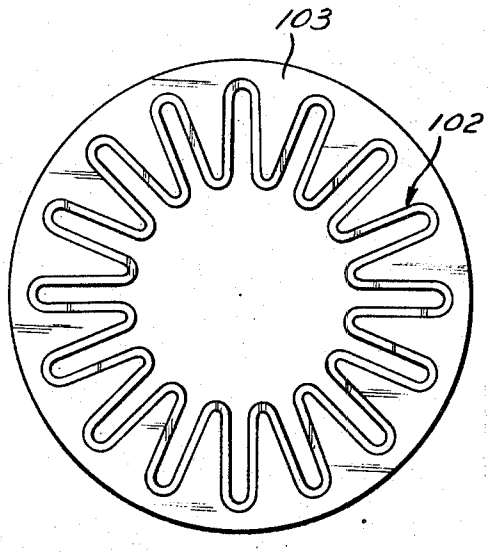


Fig. 13

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MARINE KEEL COOLER

This application is a continuation-in-part of our copending application, Ser. No. 711,646, filed Mar. 8, 1968 now abandoned.

BACKGROUND OF THE INVENTION

This invention relates generally to heat exchangers and more particularly to a novel and improved heat exchanger structure particularly suited for use as a marine keel cooler.

PRIOR ART

Various types of keel coolers are used to dissipate heat into the water surrounding a vessel. Generally, such keel coolers include a pair of headers externally mounted on the hull and connected to the internal system by a "through hull connection." Various types of tubes are connected between the headers to provide the principal heat exchanger surface. Usually the coolant for the equipment being cooled, such as the ship's engine or accessory equipment, is pumped through the header and tubes where it is cooled before it is recirculated back to the equipment being cooled. Examples of such keel cooler-type heat exchangers are illustrated in the U.S. Pat. Nos. 2,258,526 and 3,177,936.

Although such keel coolers usually function properly, they present several problems. For example, such prior keel coolers generally require a through hull connection (a pipe or tube extending through the hull) to connect the header to the internal system. Such through hull connections provide a possible hull leak, particularly when the heat exchanger is damaged.

Prior keel coolers also involve considerable expense during installation and during repair. For example, it is usually necessary to separately assemble the tubes and headers and then assemble the entire keel cooler unit on the ship's hull. Repair, for example, to replace a tube, therefore, generally requires the removal of the entire unit from the hull.

Further, when tubes of irregular shape are used because of their higher heat transfer capacity (such as the tube illustrated in the U.S. Pat. No. 3,177,936), special fittings are usually required to mount the tubes on the headers. This prevents stocking of bulk tubing in the field and increases cost, since all tubes must first be cut to length and equipped with special end fittings at the factory, prior to shipment and installation.

The depths of the grooves formed in the tubes of the type illustrated in the U.S. Pat. No. 3,177,936 has also in the past been limited. Such limitation of groove depth occurs for two reasons. First, the use of an end fitting of the type illustrated in this patent blanks off the groove areas and restricts flow into and out of the tube and tends to produce a condition in which the fluid flow is accelerated through the center of the tube and not through the fluted, or grooved portions. Secondly, deep narrow grooves tend to produce an insulating, or "dead" water layer around the exterior of the tube which retards heat transfer effectiveness. Consequently, in the past, convoluted tubes of the type illustrated in this patent have been limited to ratios of outside diameter to groove depth of about 8 to 1. Coolers using convoluted tubes with outside diameter to groove depth ratios of about 8 to 1 and greater, must have substantial length to provide the required cooling capacity and subsequently, must be located on the vessels hull remote from the main propulsion screw where long flat surfaces are available in order that the tubes may remain straight. In all such installations, positive movement between the vessels hull and the surrounding water is required before flow over the exterior of the tube occurs.

Still further, in most prior keel coolers, it has been impossible to increase the heat exchange capacity or arrangement after the unit is installed on a vessel, without requiring extensive alterations.

SUMMARY OF INVENTION

The present invention has several aspects. In accordance with one aspect of this invention a heat exchanger is provided

in which a simple low-cost structure effectively eliminates or minimizes most of the aforesaid problems and difficulties. The heat exchanger utilizes headers consisting of individual sections which separate along the centerline of the heat exchanger tubes. Preferably, the header parts are molded of an elastomeric or rubberlike material which, when the header parts are clamped together, provides a sealed joint between the header parts themselves and between the header parts and the tubes. The elastomeric headers may be reinforced with steel or other metal strengthening members around which the rubber is molded.

The headers are removably mounted on stud plates welded to the ship's hull. These plates and the hull itself cooperate with the header parts to define the header chamber. It is, therefore, not necessary to utilize a through hull connection between the header and the internal system.

In accordance with another aspect of this invention, convoluted tubes having axially extending grooves of the general type illustrated in the U.S. Pat. No. 3,177,936 extend between spaced headers to provide the heat exchanger surface. A molded elastomeric seal is positioned over the end of the tube so that the clamping of the header parts provides a fluid-tight sealing connection and mechanical mounting for the tubes. Therefore, separately assembled end fittings are not required thus permitting the tubes to be cut to length on site and easily installed in the headers while the headers are loosely mounted in place on the ship's hull.

Because the clamping and sealing of the tube occurs along the external surface, the flow of the fluid enters directly into the grooved portions without restriction to provide better heat transfer. Consequently, the depth of the grooves can be greatly increased with proportionate increases in heat exchange efficiency and capacity with respect to surface exposure and the fluid flow through the tubes. The occurrence of insulating dead water in the external grooves is prevented by forcing the fluid coolant over the external surfaces of the tube. In accordance with one embodiment in which the heat exchanger is used as a marine skin cooler, the heat exchanger is located immediately adjacent to the ship's propeller and directly in its slip stream. Consequently, cooling water is forced over the exchanger tubes at any time the propulsion system is delivering power, even though the ship may not be moving through the water. Because of the greatly increased and high efficiency of heat transfer of a deep grooved tube in accordance with this invention, the length of tubing required for a given amount of heat exchange capacity is greatly reduced when compared to conventional structures. This makes it possible to locate the heat exchanger along the curved and angled surfaces of the hull directly in the slipstream of the main propulsion screws, where forced flow occurs whenever heat dissipation is required.

Because the heat exchanger can be assembled in place on the hull, the cost of installation and handling is greatly reduced and it is a simple matter to remove and replace individual tubes when maintenance is required. In fact, the disassembly and reassembly of the heat exchanger is sufficiently simple to permit economical disassembly of the heat exchanger tubes to provide access to the hull for cleaning or painting of the hull surface itself.

The illustrated heat exchanger incorporating this invention is also arranged so that the heat exchanger capacity can be increased by adding additional tubes even after the heat exchanger is installed on the vessel. This is important in many installations since there is a tendency to install larger engines during the life of a given vessel and such larger engines usually require greater heat exchanger capacity. Still further, it is possible with a heat exchanger incorporating this invention to rearrange the heat exchanger, even after installation, so that a single heat exchanger assembly can be divided into separate heat exchanger subassemblies to provide cooling for additional equipment installed on the vessel after the vessel is built and in service. Still further, when the headers are formed of elastomeric material, the problem of electrolytic corrosion is

eliminated since the metal tubes of the heat exchanger are electrically insulated from the hull and from the internal system connected to the heat exchanger.

OBJECTS OF INVENTION

It is an important object of this invention to provide a novel and improved heat exchanger particularly suited for use as a marine keel cooler.

It is another important object of this invention to provide a novel and improved heat exchanger according to the preceding object which includes headers formed of elastomeric material or the like.

It is another important object of this invention to provide a novel and improved heat exchanger according to either of the preceding objects wherein through hull connections are not required between the headers and the connected internal system.

It is still another object of this invention to provide a heat exchanger according to any of the preceding objects wherein the headers are formed of parts which are separable along the centerline of the heat exchanger tubes to facilitate installation and removal of such tubes.

It is still another object of this invention to provide a novel and improved heat exchanger according to the last preceding object wherein clamping of the header parts automatically grips the heat exchanger tubes and also provides a fluid seal between the tubes and the headers.

It is still another object of this invention to provide a novel and improved heat exchanger according to the last preceding object wherein tubes of irregular cross section are provided with formed gaskets at the header to grip and seal the ends of the tubes.

It is still another object of this invention to provide a novel and improved heat exchanger according to the last preceding object wherein tubes are formed with deep grooves to substantially increase the heat exchange area and efficiency and wherein means are provided to insure proper flow along both the inner and outer surfaces of the grooves.

Further objects and advantages will appear from the following description and drawings wherein:

FIG. 1 is a side elevation of a heat exchanger incorporating this invention mounted on the exterior side of a hull of a vessel;

FIG 2 is an enlarged perspective view illustrating the structure of one of the headers illustrated in FIG. 1 with three tubes in position and further illustrating a separator which may be used to divide the header;

FIG. 3 is an enlarged fragmentary section through one pair of tubes illustrating the mounting thereof;

FIG. 4 is a fragmentary perspective view illustrating the structure of the middle element of the heat exchanger;

FIGS. 5 and 6 are side and end views, respectively, of a fluted tube illustrating a formed gasket mounted thereon;

FIGS. 7 and 8 are side end views of the end of a circular cross section tube with a gasket mounted thereon;

FIG. 9 is a perspective view of a stud plate adapted to use with a separator installed in the header;

FIG. 10 is a view similar to FIG. 9 illustrating a stud plate of the type used when a separator is not provided to divide the header;

FIG. 11 is a fragmentary view illustrating a heat exchanger in accordance with this invention mounted adjacent to the main propulsion screw of a ship where forced flow over the heat exchanger is provided by the screw;

FIG. 12 is an enlarged end view similar to FIG. 6 illustrating a tube structure provided with a deep groove for increased heat exchange capacity; and

FIG. 13 is a view similar to FIG. 12 illustrating a tube formed with an intermediate groove depth.

FIG. 1 illustrates a preferred embodiment of a keel cooler incorporating this invention mounted on the exterior surface of the hull 10 of the vessel. It should be understood that the term "keel cooler" is broadly used herein and is intended to include heat exchangers mounted on a hull in any under water location and is not limited to heat exchangers mounted adjacent to the keel itself. The keel cooler includes two header assemblies 11 and 12 located at spaced points on the hull 10. A plurality of heat exchanger tubes 13 extends between the two headers 11 and 12 so that fluid entering the header assembly 11 can pass through the tubes 13 to the header assembly 12 and be cooled by the surrounding water. The tubes 13 illustrated in FIGS. 1 through 3, 5, and 6 are fluted tubes of the type disclosed in the U.S. Pat. No. 3,177,936. These tubes are formed with axially extending convolutions or fluting and the tube is symmetrical about its central axis 14 as best illustrated in FIG. 6.

Welded to the interior of the hull 10 adjacent to the header assembly 11 is a threaded nipple 16 which communicates through an opening 17 in the hull 10 to the chamber defined by the header assembly 11. Similarly, a second nipple 18 is welded to the hull 10 adjacent to the header assembly 12 and communicates with the header chamber through an opening 19 formed in the hull 10. Usually a valve body 21 is threaded into each of the nipples 16 and 18 to close off the nipples when desired. Such a valve may be closed to prevent leakage of the surrounding water into the vessel in the event the keel cooler is damaged.

In the typical installation the cooling water from the vessel's power plant is pumped through the nipple 16, the header assembly 11, along with tubes 13, and through the header assembly 12 for recirculation back to the power plant through the nipple 18. It should be understood, however, that the keel cooler incorporating this invention may be used to provide cooling of any type of equipment within the vessel which requires the rejection or absorption of heat energy.

Referring now to FIGS. 2 and 3 each of the header assemblies 11 and 12 embody a similar structure so a detailed description of the structure of the header assembly 12 should be understood to be equally applicable to the structure of the header assembly 11. The header assembly 12 includes a stud plate 22 which is rectangular in shape and which is welded at 23 to the hull 10. The shape of the stud plate 22 is best illustrated in FIG. 10. The weld 23 extends along the entire periphery of the stud plate 22 and provides a fluid-tight joint therebetween.

Spaced around the stud plate 22 are a plurality of tapped holes 24 each of which is adapted to receive a clamp bolt 26. The bolts 26 extend through an outer cover member 27, an intermediate member 28 and an inner member 29, and operate to clamp each of the members 27 through 29 against the stud plate 22. The bolts 26 are preferably socket head-type bolts and the outer member 27 is preferably recessed so that the heads of the bolts are flush with the end surface of the header.

The three members 27, 28, and 29 are preferably molded of an elastomeric material with the outer member 27 formed of a relatively hard material having a durometer in the order of 90 D and the inner members 28 and 29 formed of material having a durometer in the order of 85 C. With such an arrangement the outer member is quite rigid and is substantially dimensionally stable so that the clamping forces of the bolts 26 are substantially uniformly distributed along the joint between it and the intermediate member 28. With such a substantially rigid outer member 27 it is not necessary to provide an excessive number of clamping bolts in order to provide the uniform clamping force. The inner members 28 and 29 being somewhat softer, can deform to a sufficient degree so that a seal is provided between its outer surface and the inner surface of the outer member 27. Similarly a fluid-tight joint is provided between the interengaging surfaces 33 and 34 of the two members 28 and 29, respectively. This slight deformation of the inner member 29 also assures a fluid-tight joint between its inner surface 36 and the outer surface 37 of the stud plate 22.

The outer member 27 is formed with an end wall 38 extending thereacross which cooperates with the rectangular mem-

bers 28 and 29, and with the stud plate 22 and hull 10 to define a header chamber 39 which is generally rectangular in shape as best illustrated in FIG. 2. Proper positioning of the inner member 29 in respect to the stud plate 22 is assured by locating projections 41 which fit into locating recesses 42 formed in the stud plate 22. Proper alignment between the members 27 through 29 does not require such locating projections and recesses since the bolts 26 can easily be inserted in their aligned openings.

The inner member 29 is formed with a plurality of semicylindrical tube gripping recesses 43 along one side 44. In the embodiment illustrated in FIG. 2 there are eight similar recesses 43 formed in the inner member 29. The intermediate member 28 is formed with eight similar semicylindrical tube gripping recesses 46 which are located in registry with the recesses 43 and cooperate therewith, when the members 28 and 29 are clamped together, to form eight cylindrical openings each adapted to receive the end of a tube 13. A second group of eight similar semicylindrical recesses 47 and 48 are formed in the two members 28 and 27, respectively, which cooperate to form a second group of cylindrical openings when these two members are clamped together. Each of these openings is also adapted to receive and grip the end of a tube 13. Therefore, in the illustrated structure, there are 16 heat exchanger tubes 13 arranged in two groups of eight.

Each of the heat exchanger tubes is provided with a relatively soft heat resistant elastomeric seal gasket 51 positioned over its end as illustrated in FIGS. 5 and 6. The outer surface 52 of the seal 51 is cylindrical and the inner surface thereof 53 is shaped to conform to the outer surface 54 of the tube 13. The seal may be molded separately and slipped over the end of the tube 13 or may be formed with an axial cut 56 to facilitate the position of the seal around the tube. The various elements are proportioned so that the outer surface 52 is cylindrical and has a diameter slightly larger than the diameter of the openings formed by the recesses 43, 46, 47, and 48. Consequently, clamping of the members 27, 28, and 29, after the ends of the tubes are positioned in the recesses, causes releasable compressive stress to be uniformly applied to the seals 51 to form a fluid-tight joint between the tubes 13 and the associated members of the header assembly.

Because the elastomeric gasket 51 grips and seals with the exterior surface of the tube, there is no restriction resisting passage of the fluid into and out of the tube from the header. In the past, when using fluted tubing, it has been customary to provide an adapter of the type illustrated in the U.S. Pat. No. 3,177,936. Such an adapter provides an entrance passage of circular section having a diameter less than the I.D. of the fluted tube while completely blanking off the fluted passages. Consequently, such adapters reduce the area at the inlet and outlet of the tube and seriously restrict both the flow and access of the fluid to the extended fluted surfaces. Further, these adapters tend to produce accelerated flow along the center of the tube so that the fluid passes through the tube without making good heat exchange contact with the fluted surface. In fact, in this patent a spiral baffling arrangement is provided to deflect the flow through the tube outward into the grooved areas for greater heat exchange efficiency even though the grooves are very shallow.

In the structure of the present invention, however, the full cross-sectional area within the tube is directly open to the headers so no restriction is provided to resist flow in and out of the tube. Further, since the fluid entering the tube flows directly into the grooved portions, the flow occurs along the extended surfaces of the tube and greater heat exchange efficiency is achieved.

It should be noted that fluted tubing of the type illustrated is difficult to manufacture to extremely close tolerances and that the size of the tubing when unstressed varies a substantial amount. It is, therefore, preferable to size the various elements so that the clamping of the members around the ends of the tube cause the tube to be radially contracted to a size slightly smaller than the smallest tube size normally manufactured. With this arrangement tight gripping is provided for all the various sizes encountered within the normal tolerances of manufacture of a given tubing size.

Referring to FIGS. 7 and 8, standard cylindrical tubing 58 may also be mounted in the headers where the greater heat exchange surface of a fluted tube is not required. In this embodiment a seal 59 is again positioned over the end of the tube before it is clamped in position in the header assembly. Since circular tubing is manufactured to relatively close tolerances, sufficient elasticity is provided in the seal 59 to insure proper sealing and mounting of tubes in the header assemblies without appreciable deformation of the tube itself. The various elements are again proportioned so that the outer surface 61 of the seal 59 is slightly larger than the opening provided by the associated recesses so that the seal is subjected to releasable compressive stress to insure proper gripping and sealing.

It should be noted that the recesses 48 in the end member 27 are positioned in alignment with the recesses 43 in the inner member 29. Therefore, the outer member 27 can be assembled against the inner member 29 without the intermediate member 28 when a heat exchanger having only eight tubes is required. Similarly additional intermediate members 28 can be inserted when more than two groups of tubes are required to provide sufficient heat exchange capacity. Therefore, with a structure in accordance with this invention a heat exchanger having eight tubes, for example, may be installed on a vessel when the vessel is constructed, and by adding additional intermediate members the heat exchanger capacity can be easily changed without large labor or material expense.

Although only three tubes are illustrated in FIG. 2, to simplify the understanding of this invention, it should be understood that normally 16 tubes would be mounted in such a header assembly. However, if only 13 tubes were required, for example, suitable plugs are inserted in the other three openings. Preferably such plugs include a solid piece of cylindrical metal provided with a seal similar to the seal 59.

Because special fittings are not required on the ends of the tubes 13, they may be cut to length on site and it is a simple matter to position a seal therearound and install such tubes and a header. This provides flexibility and materially decreases the labor and expense involved in the installation of the heat exchanger. Further, in the event that one of the tubes must be replaced, because of damage or the like, it is a simple matter to loosen the screws 26 to release the clamping engagement with the seals 51 and thereafter removal is achieved by axial movement of the tube to free first one end and then the other end. Reinsertion of the replacement tube may be accomplished in the opposite manner. For this reason it is preferable to arrange the seals so that the outer surfaces 52 have a diameter at least as great or greater than the largest diameter of the adjacent portion of the tube.

In the heat exchanger illustrated in FIG. 1 a single pass is provided with the fluid to be cooled flowing into the header assembly 11 and out of the header assembly 12. In some installations, however, it may be desirable to provide two or more passes. In such installations a separator 66 is used. The separator is preferably formed of a relatively hard elastomeric material which is provided with projections 67 and 68 adapted to fit into a pair of vertically extending grooves 69 formed in the members 27 through 29. The separator 66 is preferably formed with a vertical height, when unstressed, which is slightly greater than the vertical height of the header chamber 39. It is also preferably sized to slide with a relatively snug fit into the grooves 69. When a separator is used, the stud plate is provided with a center wall 71 positioned to engage the top surface of the separator. The stud plate 70 illustrated in FIG. 9 is provided with a center wall substantially midway between its ends and is used when a separator 66 is inserted in the central notches 69. As the bolts 26 are tightened, the separator 66 engages the surface of the center wall 71 on one side and the end wall 38 on the other side and is deformed from an unstressed condition. This causes the separator to deform laterally form-

ing a tight seal between the separator and the inner surfaces of the members **27** through **29**.

In a two pass heat exchanger a single separator **66** is normally mounted in the center of one header assembly to divide it into two similar chambers, each connected through an opening **19***a* and **19***b* to the connected internal system. The other header is not provided with a separator in such an installation so that cooling fluid passes through one group of tubes in one direction and back to the divided header through the other tubes. In such an installation the undivided header assembly is not provided with internal connections.

A compound heat exchanger can be provided by using separators in each header to completely separate one group of tubes from the other group of tubes. In such an installation a connection is provided between each separate header chamber and the associated system. A single heat exchanger assembly can then be used to cool two separate systems. It should also be noted that a groove **69** is provided between each group of tube gripping surfaces so that the separator can be selectively positioned to separate any desired number of tubes from the other tubes. Of course the stud plate should be provided with an appropriately located cross wall **71** for the particular installation.

With a heat exchanger incorporating this invention, considerable savings in cost of manufacture, installation, and maintenance are provided. By the proper use of intermediate members and separators, it is possible to use standard header assembly parts for a large variety of heat exchanger arrangements.

The headers illustrated in the drawings have tube gripping openings only on one side. However, it should be understood that headers may be formed with tube gripping openings on one or more sides so that tubes can extend from the header in more than one direction. For example, a header with tube gripping openings on opposite sides may be mounted between two headers of the type illustrated in FIG. **2**. Separate tubes are then mounted to extend between the center header and each of the two end headers. With this arrangement a relatively long heat exchanger can be provided without requiring the use of excessively long tubes.

Since the tubes are mounted in elastomeric material which is electrically insulating in character, electrolytic corrosion is not encountered and it is not necessary to provide separate structure to prevent such corrosion. Still, further, the use of a stud plate welded directly to the hull, to mount the header assemblies, eliminates the need of through hull connections. Therefore, in the event that the heat exchanger is damaged during use, there is no tendency to damage the connecting piping within the hull. In fact, the hull in the area of the heat exchanger is reinforced by the stud plates so the likelihood of leakage damage is extremely remote. Since the tubes can be removed or replaced with ease and since the header assemblies are formed of a noncorrosive material, it is practical to disassemble the heat exchanger for such purposes as providing access to the portion of the hull underneath the tubes when the hull needs scraping and painting.

FIGS. **11** through **13** illustrate a further aspect of this invention. In the embodiments of FIGS. **11** through **13** the tube is formed with deep grooves and consequently, the tubes provide far greater heat exchange surface area for a given tube diameter. In the past, fluted tubes have been formed with a ratio of outside diameter to groove depth in the order of 8 to 1. For example, a tube having 1½inch outside diameter normally has been formed with a grooved depth in the order of three-sixteenths of an inch. Such a tube is substantially as illustrated in FIG. **6**. However, in accordance with this invention, tubes can be formed with outside diameter to groove depth ratios as low as three to one, as illustrated in FIG. **12**, and lower, depending only upon manufacturing limitations. In this tube the groove depth is one-half inch and the outside diameter of the tube is 1½inches. This can usually be accomplished without decreasing the number of flutes in the tube and the resulting tube has about 300 percent greater surface area for a given outside diameter than the prior art tubes.

The tube **91** illustrated in FIG. **12** is provided with a seal **92** formed of a relatively soft heat resistant elastomeric material so that it can be mounted in the header **12**. Here again, the seal is proportioned so that it has a cylindrical outer surface and is shaped to conform to the tube surface along its inner surface. Also, the seal is sized so that it is gripped tightly in the header and is releasably compressed to a sufficient degree to provide a positive seal with the tube and a positive mounting for the tube. Because the seal **92** engages the outer surface of the tube, the ends of the flutes **93** are open to the header and flow is not restricted into and out of the flutes or the center portion **94**.

Because of the substantial depth of the grooves in the tube **91**, heat exchangers employing such tubes, when immersed in liquid, should be arranged so that there is a forced flow of fluid over the outside of the tube in order to prevent insulating dead water in the grooves. Therefore, when a tube of this type is utilized as a skin or keel cooler on a ship, it is desirable to mount the heat exchanger so that flow over the heat exchanger is insured under all conditions of operation. It is therefore preferable to mount the heat exchanger in the slipstream of the main propulsion screw of the ship. When located in such a position, flow of cooling water over the heat exchanger tubes is insured whenever the propulsion system of the ship is developing power and requires substantial heat dissipation. Because the tubes have a very high heat exchange efficiency, that is, are capable of dissipating substantial amounts of heat for a given length of tubing, the length of such heat exchanger tubes required for a given engine is greatly reduced and it is practical to mount the heat exchanger even along the curved and angled surfaces of the hull adjacent to the propeller.

FIG. **11** illustrates such a mounting wherein a heat exchanger **96**, provided with tubes **91** extending between the headers **11** and **12**, is mounted adjacent to the main propulsion screw **97** of a ship and along a curved portion **98** of the ship's hull. Fairing blocks **101** may be mounted adjacent to the header **12**. In this location flow of cooling water over the heat exchanger tubes **91** is assured whenever the screw **97** is turning and adequate heat exchanger efficiency is therefore provided whenever heat dissipation is required. In the past, because of the greater length of tubing required, it has been customary to mount the heat exchangers along the flat bottom portion of the hull forward of the location **99**. However, in such installations, deep grooved tubes could not be used in many cases since forced flow of the water over the tubes was created only by movement of the hull through the water. In many marine installations substantial amounts of power may be delivered without appreciable hull movement. In operations of tow boats, tugs or the like, substantial amounts of power must often be delivered for extended periods of time even though the boat is not moving to any appreciable extent. Such a situation can occur when a tow boat is starting a long tow, or when a part of the tow is grounded on a bar in the river and prolonged maneuvering is required at full power without appreciable relative movement between the hull and the surrounding water.

It should be understood, because of its high capacity and very short length, the heat exchanger can be located in areas normally prohibitive to other type coolers. For example, it may, in some instances, be located sternward of the screw **97**.

FIG. **13** illustrates another deep grooved tube **102**. This tube **102** is provided with the same number of flutes as the tube illustrated in FIG. **12**, but is provided with a groove three-eighths inch deep. Such a tube does not provide as much heat exchange surface for a given outside diameter, but does provide about 200 percent greater surface area than the shallow fluted tube of the type illustrated in FIG. **6**. Here again, the tube is mounted in a seal **103** which engages its outer surface and does not restrict flow into the flutes of the tube. Such a tube should also be used in an installation wherein sufficient flow is present along the exterior surface of the tubes to prevent the build up of a dead water insulation zone in the exterior grooves of the tube.

In the tubes illustrated in FIG. 12, the ratio of tube outside diameter to groove depth is about 3 to 1. In the tube of FIG. 13, the ratio of tube outside diameter to groove depth is about 4 to 1. In both cases, the ratios are substantially less than the ratio of 8 to 1 heretofore considered to be the minimum usable ratio of outside diameter to groove depth for this type of tubing.

Although preferred embodiments of this invention are illustrated, it is to be understood that various modifications and rearrangements of parts may be resorted to without departing from the scope of the invention described and claimed herein.

We claim:

1. A heat exchanger comprising at least a pair of spaced headers, and a plurality of heat exchanger tubes extending between said headers, said headers each including first and second separable members, said members each being formed with tube gripping surfaces along the joint therebetween which cooperate with associated tube gripping surfaces on the other member to encircle the end of a tube, nd clamp means releasably operable to clamp said members together to form a fluid-tight joint between said members and to cause said tube gripping surfaces to grip the ends of said tubes forming a fluid seal therewith, said members cooperating to define at least part of a header chamber open to said tubes, release of said clamp means permitting relative axial movement between individual tubes and header for removal and replacement of individual tubes without moving said headers toward or away from each other.

2. A heat exchanger as set forth in claim 1 wherein said headers are adapted to be mounted on the exterior of the hull of a vessel, said headers having openings proportioned to fit against the exterior of the hull and be closed thereby, said members when mounted on said hull cooperating with a portion of said hull to define a header chamber.

3. A heat exchanger as set forth in claim 1 wherein said associated gripping surfaces are semicylindrical and cooperate to form cylindrical gripping openings when said members are clamped together.

4. A heat exchanger as set forth in claim 3 wherein a resilient seal is positioned on the ends of said tubes within said gripping openings, said clamp means causing said seals to be subjected to compressive stress to provide gripping and sealing between said tubes and header, release of said clamping means releasing said seals and permitting axial movement between said headers and tubes.

5. A heat exchanger as set forth in claim 4 wherein said tube is noncircular and the inner surface of said seal conforms to the exterior surface of said tube.

6. A heat exchanger as set forth in claim 5 wherein said tube is axially fluted and is substantially symmetrical with respect to its central axis, and the wall of said tube is radially contracted from its unstressed condition substantially to a standard size when said seal is clamped between said tube gripping surfaces.

7. A heat exchanger as set forth in claim 4 wherein the diameter of the exterior surface of said seal is greater than the maximum diameter of said tube adjacent said end whereby release of said clamping means permits axial movement of said tube with respect to said header members in both directions.

8. A keel cooler including a heat exchanger as set forth in claim 7 wherein said seal is formed of electrical insulating material and is adapted to electrically insulate said tube from the hull of a vessel.

9. A heat exchanger as set forth in claim 8 wherein a separator is adapted to be removably positioned in said header chamber to separate said chamber into at least two separate chambers, and each separate chamber is open to at least one pair of tube gripping surfaces.

10. A heat exchanger as set forth in claim 1 wherein said headers each include a third separable member which cooperates with said second member to provide additional opposed pairs of tube gripping surfaces, said additional opposed pairs of tube gripping surfaces being spaced from the joint between said first and second members.

11. A keel cooler comprising a header assembly defining at least part of a header chamber, said assembly including a substantially rigid first member adapted to be mounted on the hull of a vessel, a substantially rigid second member and an intermediate member formed of material which is softer than the material forming said first and second members, said intermediate member and at least one of said first and second members being formed with mutually engageable surfaces providing a fluid tight seal therebetween when clamped together and opposed tube gripping surfaces, a tube, a resilient seal around the end of said tube adapted to be positioned between said tube gripping surfaces, and releasable clamp means adapted to clamp said intermediate member between said first and second members and tightly clamp said seal causing said seal to provide a fluid-tight joint between said two members and said tube, release of said clamping means permitting axial movement of said tube with respect to said members.

12. A keel cooler as set forth in claim 11 wherein said first member is a metal stud plate, and said second member and said intermediate members are formed of elastomeric material, and said clamp means is a plurality of threaded fasteners connected to said stud plate.

13. A keel cooler as set forth in claim 11 wherein a second intermediate member is provided between the first intermediate member and said first member, said first and second intermediate members being formed with mutually engageable surfaces providing a fluid-tight seal therebetween when clamped together and opposed tube gripping surfaces adapted to grip the seal at an end of said tube.

14. A keel cooler comprising a hull of a vessel, a header assembly cooperating with the exterior surface of said hull to define a header chamber, said hull being formed with an opening therethrough providing flow passage into said header chamber, conduit means secured to the interior of said hull around said opening, said header assembly including at least two separable members formed with mutually engageable surfaces providing a fluid-tight seal therebetween when clamped together and opposed tube gripping surfaces, a tube, a resilient seal around the end of said tube adapted to be positioned between said tube gripping surfaces, and releasable clamp means releasably clamping said members together and tightly clamping said seal causing said seal to provide a fluid-tight joint between said members and said tube, release of said clamping means permitting axial movement of said tube with respect to said two members.

15. In combination a hull of a vessel, a stud plate welded to the exterior surface of said hull, a conduit mounted on the inside of said hull in alignment with said stud plate, a header assembly removably mounted on said stud plate cooperating with said hull and plate to define a header chamber, a plurality of heat exchanger tubes mounted on said header assembly, and an opening in said hull providing a flow passage between said conduit and chamber.

16. A combination as set forth in claim 15 wherein said header assembly includes at least two separable members formed of elastomeric material, one of said members being positioned between said stud plate and the other of said members, and said one member being formed of softer elastomeric material than the elastomeric material of said other member.

17. A heat exchanger comprising a pair of spaced headers, a tube extending between said headers formed with axial fluting substantially symmetrical with respect to the central axis thereof, an elastomeric seal at each end of said tube engaging the outer surface of said fluting, said seal when unstressed being formed with an inner surface substantially conforming to the outer surface of the adjacent end of said fluting, said headers being provided with means to releasably clamp said seals into tight engagement with said outer surface of said tube to mount said tube on said headers and to provide a fluid seal between said tube and the adjacent headers, said seals and said clamping means providing substantially no restriction of flow between said headers and said tubes.

18. A heat exchanger as set forth in claim 17 wherein means are provided to force fluid to flow over the exterior surfaces of said tube.

19. A heat exchanger as set forth in claim 18 wherein the ratio of the outside diameter of said tube to the depth of the grooves formed by said fluting is at least as small as about 4 to 1.

20. A heat exchanger as set forth in claim 19 wherein said seals are provided with cylindrical outer surfaces, and said headers are formed of separable members providing semicylindrical clamping surfaces proportioned to engage and grip the associated seals.

21. A heat exchanger as set forth in claim 19 wherein said heat exchanger is mounted on the hull of a ship having a propulsion screw and is located with respect to said screw so that operation of said screw forces sufficient coolant water over the exterior surfaces of said tube without movement of the ship through the water being required.