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(54) **Heat transfer tube for LNG vaporizer, its production method, and LNG vaporizer using such heat transfer tubes**

(57) A heat transfer tube for an LNG vaporizer in which damage in the surface of the Al alloy substrate by corrosion is effectively prevented even when it is used in the lower portion of the panel or in the lower header where the surface is vigorously cooled and formation of the oxide coating is less likely to take place.

This heat transfer tube is used in an LNG vaporizer equipped with an Al alloy panel unit including a panel composed of a plurality of heat transfer tubes arranged in a row in the form of a curtain, and a lower header and an upper header respectively connected to the panel at its lower end portion and its upper end port ion; wherein the LNG is vaporized by heat exchange between seawater flowing down along the surface of the panel from the upper end portion of the panel unit and the LNG flowing through theheattransfertubes. In this LNG vaporizer, the outer surface of the heat transfer tube at least in the lower end portion of the panel and the outer surface of the lower head are subjected to surface roughening by blasting, and then, a coating of an Al-Mg alloy containing Mg at a content in the range of 1 to 80% by mass, and having a thickness of 100 to 1000 μm was formed by thermal spraying to realize protection by sacrificial corrosion. Formation as the corrosion protective of an A1 alloy coating containing Zn and/or Mn at a content in the range of 0.3 to 3.0% by mass with the proviso that the content of (Zn + Mn) is in the range of 0.3 to 3.0% by mass and containing Mg at a content in the range of 0. 3 to 5% by mass is also effective.

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Description

FIELD OF THE INVENTION

[0001] This invention relates to a heat transfer tube for an LNG (liquid natural gas) vaporizer which has an excellent corrosion resistance, and an LNG vaporizer produced by using such heat transfer tubes.

BACKGROUND OF THE INVENTION

[0002] Liquid natural gas (hereinafter referred to as LNG) is generally transported and stored in liquid form at a low temperature and a high pressure, and vaporized before its use.
For such vaporization, an open rack vaporizer (hereinafter referred to as ORV) is often used since the ORV can vaporize a large amount of LNG. FIG. 1 shows a typical ORV, and as shown in this FIGURE, an ORV is a heat exchanger in which LNG is heated for vaporization by heat exchange with seawater (see, for example, Patent Document 1). The seawater enters at a seawater header 6, flows through a sprinkling nozzle 7 to be stored in a trough 8. The seawater flowing over the edge of the trough 8 flows down along the outer surface of panel 3 composed of heat transfer tubes 3a arranged in a row in curtain form wetting the outer surface of the heat transfer tubes 3a. In the meanwhile, LNG enters an LNG manifold 1, and flows through a lower header 2 connected to the lower end of the panel 3, where the LNG is heated by heat exchange with the seawater. The LNG is then vaporized in each heat transfer tube 3a of the panel 3, and the vaporized natural gas (NG) flows upward through the heat transfer tube 3a to headers 4 and 4, and then, to NG manifold 5.

[0003] The material used for the heat transfer tubes 3a constituting the panel 3 should have satisfactory heat conductivity as well as high workability that allows the material to be worked into the complicated profile required for the panel 3, and an aluminum alloy is typically used for the heat transfer tubes. However, an aluminum alloy is susceptible to corrosion when it is immersed in seawater, and once the corrosion starts, pitting corrosion is likely to take place wherein the corrosion is concentrated to the corroded part resulting in a hole. Accordingly, extensive studies on corrosion protective treatment have been made on the aluminum alloy for use in applications in which the alloy is immersed in seawater, and currently, the most popular anti-corrosive treatment is the one using sacrificial corrosion protection. Patent Document 1 as mentioned above discloses a corrosion protection wherein a metal such as zinc (Zn) which is more susceptible to corrosion than the aluminum alloy used for the panel 3 (heat transfer tubes 3a) having the LNG flowing therethrough, namely, a bulk of a metal or an alloy which has a high ionization tendency is electrically connected to the lower header 2 which is immersed in the pond of the seawater flown down along the outer surface of the panel 3 wetting the outer surface for use as a sacrificial anode so that this sacrificial anode undergoes electrochemical dissolution and consumption and the surface of the lower header 2 and the panel 3 acting as a counter electrode is prevented from undergoing corrosion. However, in the LNG vaporizer, the seawater flowing over the edge of the trough 8 directly hits the surface of the heat transfer tubes 3a constituting the panel 3, and therefore, corrosion by the so called "erosion corrosion" inevitably proceeds even if such sacrificial anode were provided. Therefore, an alloy having an ionization tendency higher than the aluminum alloy of the heat transfer tube 3a (hereinafter referred to as "coating alloy") is preferably coated on the surface of the heat transfer tubes 3a so that the seawater is prevented from directly contacting with the surface, and so that the corrosion of the heat transfer tube surface is prevented by its corrosion protective effect even if local peeling of the coating alloy should occur. Exemplary alloys that have been known to have such protective effects of sacrificial corrosion include Al - Zn alloy, and those commonly used include Al-2% Zn alloy and Al - 15% Zn alloy. Accordingly, effective prevention of the corrosion is realized by thermally spraying such coating alloy to form a coating on the surface of the heat transfer tube.

[0004] In order to further improve the corrosion resistance of the coating formed on the surface of the heat transfer tube, Patent Document 2, for example, discloses a tube for use in an aluminum tube for a heat exchanger having an improved corrosion resistance wherein a heat transfer tube (tube produced by extrusion) of aluminum or an aluminum alloy has formed on its surface a first layer including a Zn layer which electrochemically acts as a sacrificial layer, and Al or an Al alloy of Al - Ca or Al - Zn - Ca metal thermally sprayed on the first layer to thereby prevent evaporation of the zinc during blazing in the production of the heat exchanger. Patent Document 3 discloses an Al alloy heat transfer tube having an improved corrosion resistance wherein the heat transfer tube has formed on its surface an Al - Zn alloy layer, and further on this layer, an Al - Zn alloy layer containing at least one element selected from In, Sn, Hg, and Cd. On the other hand, Patent Document 4 discloses a finned tube (a fin type heat transfer tube) for an ORV type vaporizer including an Al alloy tube having a thick sacrificial anode coating formed by cladding an Al - Zn alloy material.

[0005] [Patent Document 1] Japanese Patent Application Laid-Open No. H9-178391

[0006] [Patent Document 2] Japanese Patent Application Laid-Open No. H1-114698

[0007] [Patent Document 3] Japanese Patent Publication No. H7-1157

[0008] [Patent Document 4] Japanese Patent Application Laid-Open No. H5-164496

SUMMARY OF THE INVENTION

[0009] However, lower part of the panel 3 of the ORV and the lower header 2 are the parts cooled to a temperature below freezing point by the LNG, namely, by the natural gas in liquid state flowing therethrough. When the surface of the heat transfer tube and the overflow of the seawater flowing thereon become in contact with each other in such low temperature part of the ORV, the oxide coating is not readily formed on the aluminum alloy surface of the heat transfer tube substrate, and the electrode potential of the heat transfer tube substrate including the aluminum alloy will be lower than the electrode potential of the Al - Zn ally coating described in Patent Documents 1 to 4. In such case, there is a risk that the protection by sacrificial corrosion of the Al - Zn alloy coating will not be realized, and the heat transfer tube substrate will be left unprotected. In a certain circumstance, for example, when the seawater is at a high temperature, or when the panel 3 is excessively cooled by the LNG flowing therethrough, there is a risk that the high potential of the Al - Zn alloy coating affects the heat transfer tube substrate and the heat transfer tube substrate undergoes galvanic corrosion.

[0010] The coating formed on the surface of the heat transfer tube is required to have durability in addition to the corrosion resistance. Even if the coating had excellent sacrificial corrosion protection for Al alloy heat transfer tube substrate, the heat transfer tube substrate will be ultimately damaged if the corrosion proceeds at a high speed and the coating has inferior durability. In addition, in the case of the LNG vaporizer, the seawater flowing over the edge of the trough 8 hits the surface of the heat transfer tubes 3a constituting the panel 3 as described above, and countermeasure for erosion corrosion is also required.

SUMMARY OF THE INVENTION

[0011] The present invention has been completed in view of such situation, and an object of the present invention is to provide a heat transfer tube for an LNG vaporizer in which damage in the surface of the Al alloy substrate by corrosion is effectively prevented even when it is used in the lower portion of the panel or in the lower header where the surface is vigorously cooled and formation of the oxide coating is less likely to take place. Another object of the present invention is to provide a method for producing such heat transfer tube and an LNG vaporizer using such a heat transfer tube.

[0012] In order to achieve such objects, the present invention has employed the constitution as described below.

DISCLOSURE OF THE INVENTION

[0013] In a first aspect of the invention, accordingly, the heat transfer tube for an LNG vaporizer is a heat transfer tube wherein the LNG is passed through its interior and seawater is supplied to its exterior surface for vaporization of the LNG by heat exchange between the LNG and the seawater, and which comprises an A1 alloy having a corrosion protective coating on its exterior surface. The corrosion protective coating comprises an Al alloy coating containing Mg.

[0014] In a second aspect of the invention, the heat transfer tube for an LNG vaporizer is a heat transfer tube wherein the corrosion protective coating contains Mg at an amount higher than that of the Al alloy constituting the heat transfer tube.

[0015] As described above, under the conditions in which the oxide coating is not readily formed on the surface of the aluminum alloy substrate of the heat transfer tube, natural electrode potential of Zn will be higher than that of the substrate alloy, and the Al - Zn sprayed coating will be a higher potential compared to the substrate alloy of the heat transfer tube or the lower header detracting from the effects of protection by sacrificial corrosion. Accordingly, in order to enable the protection by sacrificial corrosion to be realized even under such conditions in which the oxide coating is not readily formed on the surface of the aluminum alloy substrate of the heat transfer tube, a coating of a metal having a potential thermodynamically lower than that of the Al should be formed, for example, by thermal spraying. Such metal is most preferably Mg, and suitable sacrificial corrosion protective coatings include coatings of an Mg - containing alloy which are "meaner" than the Al alloy substrate material of the heat transfer tube or the lower header. Exemplary metals having a potential thermodynamically lower than that of the Al include, in addition to Mg, Hf (hafnium), Ti (titanium), and Be (beryllium). Among these, oxide coatings of Ti and Be are stronger than the oxide coating of Al, and even if these metals were thermodynamically "meaner" than Al, the oxides of these metals are substantially more "noble" than Al when the environment of the LNG vaporizer operation is taken into consideration. In addition, a metal containing Hf or Ti suffer from extremely poor drawability, and production of such metal into the spraying target to be used in the flame spraying employed in the formation of the coating is difficult.

Therefore, Hf and Ti can not be used for the coating formed for the purpose of protection by sacrificial corrosion. In the meanwhile, Be is also unsuitable for use as a sacrificial corrosion protection coating since Be is toxic and in view of the risk involved in the formation of the coating and the marine pollution during the operation of the ORV. Be is also a very expensive material.

[0016] Accordingly, an Al alloy coating containing Mg is most suitable for use as a coating which is provided to protect the Al alloy heat transfer tube by sacrificial corrosion, and such corrosion protective coating is effective if the coating

contains Mg at an amount higher than that of the Al alloy.

[0017] In the third aspect of the invention, the heat transfer tube for an LNG vaporizer has such Al alloy corrosion protective coating with a thickness of 100 to 1000 μm.

[0018] When such Al alloy coating is used in an ORV, an adequate control of the thickness of the coating is important in order to improve the resistance to blister peeling. When the thickness is less than 100 μm, corrosion resistance of the thermally sprayed coating will be insufficient, and the aluminum alloy substrate of the heat transfer tube or the lower header is readily exposed to the seawater. The minimum thickness typically at least 100 μm, preferably at least 150 μm, and more preferably at least 200 μm. While a thicker coating is preferable in view of preventing the corrosion at an early stage, peeling is promoted by the residual stress from the formation of the coating by the thermal spraying when the thickness is in excess of 1000 mm. Accordingly, the coating is typically formed to a thickness of up to 1000 μm, preferably up to 800 μm, and more preferably up to 600 μm.

[0019] In the fourth aspect of the invention, the heat transfer tube for an LNG vaporizer is the one wherein the Al alloy corrosion protective coating has a Mg content in the range of 1 to 80% by mass.

[0020] When the A1 alloy coating has a Mg content of less than 1% , the protection by sacrificial corrosion will be insufficient, and in order to realize effective protection by the sacrificial corrosion, the Mg content is preferably at least 1.5% by mass, and more preferably at least 2% by mass, and such Mg content will realize effective protection by the sacrificial corrosion. In the meanwhile, while the protection by the sacrificial corrosion of the Al - Mg alloy coating becomes stronger with the increase in the Mg content, the speed of the coating consumption will be too high under some environments, for example, under some temperature conditions. Therefore, the Mg content is preferably up to 80% by mass, more preferably up to 50% by mass, and most preferably up to 20% by mass. When the Mg content is in the range of 2 to 20% by mass, good adhesion of the coating, protection by the sacrificial corrosion, and durability of the coating are simultaneously realized.

[0021] In the fifth aspect of the invention, in the heat transfer tube for an LNG vaporize, the Al alloy corrosion protective coating is formed by thermal spraying, and boundary between the coating and the heat transfer tube has a center line mean roughness (Ra 75) in the range of 10 to 100 μm.

[0022] When the roughness of the boundary between the thermally sprayed coating and the heat transfer tube or the lower header, namely, the Al alloy substrate is increased, speed of the expansion of the area of the preferential dissolution caused by the oxygen concentration cell formed between the internal defects of the thermally sprayed coating and the thermally sprayed coating to the surrounding area of the defects is suppressed, and this results in the improved resistance to blister peeling of the thermally sprayed coating. This method is quite effective in improving the adhesion of the thermally sprayed coating of A1 - Mg alloy whose improvement in the adhesion is difficult compared to other thermally sprayed coatings such as those including an Al - Zn alloy. An intensive study was conducted on this improvement in the adhesion, and the inventors found that resistance to peeling of the thermally sprayed coating from the Al alloy substrate under the circumstance that the moving seawater comes into contact with the thermally sprayed coating at a low temperature range will be improved when the boundary between the thermally sprayed coating and the Al alloy substrate has a center line mean roughness (Ra 75) of at least 10 μm, and excellent adhesion properties are thereby realized. In view of improving the adhesion, the center line mean roughness Ra 75of the boundary is preferably at least 12 μm, and more preferably at least 14 μm. On the other hand, when the boundary between the sprayed coating and the Al alloy substrate is excessively rough, spaces not filled by the thermally sprayed coating are likely to be left at the boundary, and the seawater entering such space will promote preferential corrosion at the boundary. Therefore, the roughness at the boundary is preferably not more than 100 μm, more preferably not more than 80 μm, and most preferably 60 μm in terms of the center line mean roughness Ra 75.

[0023] In a sixth aspect of the invention, in the heat transfer tube for an LNG vaporizer, the roughness of the boundary as described above has been formed by spraying a blast agent containing blast particles of #16 or higher to the exterior surface of the heat transfer tube on which the sprayed coating is to be formed.

[0024] Such blast surface roughening using a blast agent containing blast particles of #16 or higher enables adjustment of the roughness of the boundary to the range of 10 to 100 μm.

[0025] In a seventh aspect of the invention, in the heat transfer tube for an LNG vaporizer, the Al alloy coating has a percentage of pore area of not more than 15% in the region from the uppermost surface to the depth of 100 μm in the cross section including the central axis of the heat transfer tube.

[0026] When the percentage of the pore area in the surface layer part of the Al alloy coating is suppressed to not more than 15%, and preferably not more than 10%, the area percentage of blister peeling will be markedly reduced, and a satisfactory protection by sacrificial corrosion is thereby realized.

[0027] It is in view of the situation as described above that the present invention has adopted the constitution as described below.

[0028] In an eighth aspect of the invention, in the heat transfer tube for an LNG vaporizer according to claim 8, the corrosion protective coating comprises an Al alloy coating containing Zn and/or Mn and Mg wherein content of (Zn + Mn), Zn, or Mn is in the range of 0.3 to 3.0% by mass and content of Mg is 0.3 to 5.0% by mass.

[0029] To provide resistance to erosion, addition of an element which forms a solid solution in the Al to strengthen the matrix to the Al alloy substrate of the heat transfer tube is effective, and it is necessary that the electrode potential of the Al alloy coating does not becomemore "noble" than the electrode potential of the Al alloy substrate of the heat transfer tube when such element precipitates as a compound. Exemplary elements used for such strengthening include Zn, Nb, Mn, Zr, and Ti. Among these, Nb, Zr, and Ti are inadequate for use in such purpose because these elements form oxide coatings harder than the Al and these elements are expensive and difficult to alloy with the Al. Therefore, preferable element (s) added for the erosion protection is Zn and/or Mn. While it is preferable that Zn and/or Mn forms a solid solution in the Al alloy matrix, Zn and/or Mn and the Mg may form a compound such as Zn - Mg, Mn - Mg, or Zn - Mn - Mg depending on the amount added, and even if such compounds were formed, the electrode potential "meaner" than the Al alloy substrate will still be retained.

[0030] When the content of Zn + Mn or the content of Zn or Mn is less than 0.3%, strengthening by formation of the solid solution will be insufficient detracting from the required erosion protection. The content in excess of 3.0% by mass is unfavorable since the effect of strengthening the Al alloy matrix will be saturated at such content, and the Zn and/or Mn segregated in the Al alloy coating may adversely affect the anti-erosive properties. When the Mg content is less than 0.3%, substantially all of the Mg will form solid solution in the Al matrix irrespective the coating conditionsemployed, failing to realize the effect of reducing the electrode potential of the Al alloy coating to a level sufficiently lower than that of the Al alloy matrix of the heat transfer tube. An Mg content in excess of 5% by mass is also unfavorable since the electrode potential of the Al alloy coating will be "mean" to an unnecessary degree resulting in the increased amount of Mg dissolution and excessively high speed of the corrosion under some the conditions of use.

[0031] In a ninth aspect of the invention, the LNG vaporizer is an LNG vaporizer equipped with a panel unit including a panel composed of the plural heat transfer tubes having a thermally sprayed coating formed thereon arranged in a row in curtain form, and an upper header for discharging the LNG and a lower header for supplying the LNG respectively connected to the panel at its upper end portion and its lower end portion; wherein the LNG is vaporized by heat exchange between seawater flowing down along the surface of the panel from the upper end portion of the panel unit and the LNG flowing through the heat transfer tubes from the side of the lower header to the side of the upper header.

[0032] In a tenth aspect of the invention, in the LNG vaporizer, the thermally sprayed coating of the heat transfer tubes is formed at least on the exterior surface of the lower portion of the panel and the lower header.

[0033] As described above, LNG is in liquid form in the lower header and the lower portion of the panel in the LNG vaporizer of this type, and therefore, such part of the vaporizer are cooled to a temperature below freezing point. When the exterior surfaces of such portion of the LNG vaporizer become in contact with the overflow seawater flowing down along such surfaces, oxide coating is less likely to be formed on the aluminum alloy surface of the heat transfer tube substrate. Under such circumstance, favorable corrosion protection is realized when the surface of the lower portion of the panel and the lower header in the low temperature region are covered with the thermally sprayed coating as described above.

[0034] In an eleventh aspect of the invention, in the method for producing a heat transfer tube for an LNG vaporizer which is used by passing the LNG in its interior and applying seawater to its exterior surface for vaporization of the LNG by heat exchange between the LNG and the seawater, and which has a corrosion protective coating formed on its exterior surface, the corrosion protective coating is formed by thermally spraying an Al alloy containing Mg and subjecting the surface of the thermal spray coating to mechanical processing.

[0035] In a twelfth aspect of the invention, in the method for producing a heat transfer tube for an LNG vaporizer, the corrosion protective coating is formed by thermally spraying an A1 alloy containing Zn and/or Mn and Mg and subjecting the surface of the spray coating to a mechanical processing.

[0036] When the surface of the thermally sprayed coating is subjected to mechanical processing such as grinding or shot peening, pore defects in the sprayed coating are reduced and damages such as blistering or peeling during the use are suppressed to realize favorable protection by sacrificial corrosion.

[0037] In a thirteenth aspect of the invention, in the method for producing a heat transfer tube for an LNG vaporizer, a sealing treatment of the sprayed coating is carried out as a pretreatment and/or a post-treatment of the mechanical processing.

[0038] When a sealing treatment is carried out in addition to the mechanical processing, pores in the thermally sprayed coating is further reduced, and the damages such as blistering or peeling are further suppressed.

[0039] In this invention, an Al alloy coating containing Mg which is a metal thermodynamically meaner than Al is formed on the outer surface of the alloy heat transfer tubes including an Al alloy at least in the lower end portion of the panel and the outer surface of the lower header which comes into contact with the seawater in the low temperature region of the LNG vaporizer. Therefore, even in the environment in which an oxide coating is less likely to be formed on the surface of the aluminum alloy of the heat transfer tube and the lower header, a satisfactory sacrificial corrosion protection is realized since the alloy coating containing Mg has an electrode potential meaner than the A1 alloy substrate of the heat transfer tube and the lower header. An even better sacrificial corrosion protection is realized when the Al alloy coating formed contains Mg at a higher content than the Al alloy as described above. In addition, when the roughness of the

boundary was controlled to the predetermined range of center line mean roughness (Ra 75) by blasting with a blast agent having a suitable particle size, peeling resistance of the Al alloy coating in the environment where overflow of the seawater contacts the Al alloy coating was improved to the level acceptable in practical use. Since an Al alloy coating containing Mg which is a metal thermodynamically meaner than Al having Zn and/or Mn added as a solid solution strengthening element of the heat transfer tube substrate is formed on the surface of the heat transfer tube for an LNG vaporizer in order to improve erosion resistant properties, favorable protection by sacrificial corrosion realizing excellent erosion resistant properties as well as high durability is achieved on the outer surface of the heat transfer tubes in the lower end portion of the panel and the outer surface of the lower header of the LNG vaporizer used in the environment in which the oxide coating is less likely to be formed due to the contact of the seawater in the low temperature region, and therefore, more susceptible to the damage by corrosion. Furthermore, a dramatic improvement in peeling resistance is achieved when the coating is mechanically processed or impregnated with a sealant after the formation of the alloy coating, and such improvement contributes to the prevention of the damage of the heat transfer tubes by corrosion, and hence, in the increase in the operation efficiency and service life of the LNG vaporizer.

BRIEF DESCRIPTION OF THE DRAWING

[0040]

FIG. 1 is a perspective view of the LNG vaporizer.

DETAILED DESCRIPTION OF THE INVENTION

[0041] Next, embodiments of the present invention are described by referring to FIG. 1.

[0042] FIG. 1 shows an LNG vaporizer wherein the heat transfer tubes according to an embodiment of the present invention are incorporated. The LNG vaporizer comprises a plurality of panel units U made from an Al alloy (for example, an Al - Mn based alloy such as A3203, an Al - Mg based alloy such as A5083, or an Al - Mg - Si based alloy such as A6063), and these panel units U are arranged in parallel. Each panel unit U comprises a panel 3 composed of plural heat transfer tubes 3a arranged in a row in the form of a curtain, and a lower header 2 for supplying the LNG and an upper header 4 for discharging the vaporized natural gas (NG) respectively connected to the upper end portion and lower end portion of the panel 3. The lower header 2 and the upper header 4 are respectively connected to a lower LNG manifold 1 and an upper NG manifold 5. Above the space defined between the adjacent panels 3 of the unit U is provided a trough 8 which makes the downward flow of the seawater used as a heat source for vaporizing the LNG. The LNG is supplied from the LNG manifold 1 to the lower header 2, and then, passes through the heat transfer tubes 3a of each panel 3. The LNG is vaporized during this upward flowing of the LNG in the heat transfer tube by the heat exchange with the seawater. The vaporized LNG is fed to the gas line (not shown) through the upper header 4 and the NG manifold 5.

[0043] On the exterior surface of the heat transfer tube 3a and the lower header 2 is formed a coating of an Al - Mg alloy, and more specifically, a coating of an Al alloy containing 1 to 80% by mass of Mg, and preferably 3 to 30% by mass of Mg. This coating is formed by thermal spraying to a thickness of 100 to 1000 μm, and preferably, to a thickness of 200 to 600μ m. In order to improve adhesion of the thermally sprayed Al - Mg alloy coating to the heat transfer tube 3a and the lower header 2, namely, to the underlying Al alloy substrate, the surface is treated with a blast agent for surface roughening as a pretreatment of the thermal spraying to thereby adjust roughness of the boundary between the thermally sprayed coating and the Al alloy substrate. The blast treatment is carried out using a blast agent containing fine blast particles of at least #16 until the exterior surface of the Al alloy substrate has a center line mean roughness Ra 75 of 10 to 100 μm, and preferably 14 to 60 μm. After the formation of the thermally sprayed coating, the coating is preferably subjected to a sealing treatment in which a compound such as epoxy polymer resin having excellent permeability to the Al - Mg alloy coating is coated at least once on the surface of the sprayed coating. The covering of the entire surface of the heat transfer tube 3a with the Al - Mg alloy coating is not necessarily required, and the heat transfer tube should be covered to at least about 1 m from the lower end of the panel 3.

[0044] The acceptable range of roughness, namely, the Ra 75 in the range of 10 to 100 μm at the broadest of the boundary between the Al alloy substrate of the heat transfer tube and the lower header and the thermally sprayed coating is useless if realized locally, and such acceptable range of roughness should be realized for the entire surface covered with the thermally sprayed coating. Accordingly, in this embodiment, at least 10 locations are randomly chosen from the area of the Al alloy substrate to be coated by the thermally sprayed coating before the application of the coating, and center line mean roughness Ra 75 is measured by the measurement method defined in the annexed paper of JIS B 0031 and JIS B 0061. It is after confirming that arithmetic mean of the all Ra 75 values measured is within the defined range that the coating is formed by thermal spraying. The roughness of the boundary between the Al alloy substrate and the sprayed coating can also be measured after the formation of the thermally sprayed coating. In this case, at least 10 locations are randomly chosen from the area coated by the thermally sprayed coating for the Al alloy substrate

randomly sampled from the lot of the same blast treatment and the same thermal spray coating, and the cross section of the surface coated with the thermally sprayed coating is observed by SEM, and Ra 75 can be calculated by image processing. It is also necessary in this case that the arithmetic mean of the all Ra 75 values measured is within the defined range. The roughness of the boundary can also be provided by a mechanical processing instead of the blast treatment.

[0045] On the exterior surface of the heat transfer tube 3a and the lower header 2, it is effective to form a coating of an Al - Zn - Mn - Mg alloy having a Mg content of 0.3 to 5% by mass, and preferably 2 to 4% by mass, and a (Zn + Mn) content of 0.3 to 3% by mass. This coating may be formed by thermal spraying to a thickness of 100 to 1000 μm. In order to improve adhesion of the thermally sprayed Al - Zn - Mn - Mg alloy coating to the heat transfer tube 3a and the lower header 2, namely, to the underlying Al alloy substrate, the surface may be treated with a blast of fine particles for surface roughening as a pretreatment of the thermal spraying to thereby adjust roughness of the boundary between the thermally sprayed coating and the Al alloy substrate. The roughness of the boundary can also be provided by a mechanical processing instead of the blast treatment. The Al alloy coating may also be a Al - Zn - Mg alloy coating or a Al - Mn - Mg alloy coating, and in such a case, content of the Zn or Mg is in the range of 0.3 to 3% by mass. The covering of the entire surface of the heat transfer tube 3a with such Al alloy coating is not necessarily required, and the heat transfer tube 3a should be covered to at least about 1 m from the lower end of the panel 3. After the formation of the thermally sprayed coating, the coating is preferably subjected to a sealing treatment in which a compound such as epoxy polymer resin having excellent permeability to the Al - Zn - Mn - Mg alloy coating is coated at least once on the surface of the sprayed coating. In addition, a mechanical processing such as grinding or shot peening is preferably carried out before or/and after such sealing treatment in order to remove the pore defects in the surface layer of the thermally sprayed coating.

Example 1

[0046] In order to simulate the environment near the panel 3 and the lower header 2 of the LNG vaporizer (ORV) (see FIG. 1), a disk of pure aluminum having a diameter of 16 mm and a thickness of 4 mm was prepared, and a coating of the composition shown in Table 1 was thermally sprayed to a thickness of 300 μm on one surface of the disk defined by the straight line passing through the center of the disk. No further treatment was conducted after the thermal spraying, and the test specimen was thereby provided. Peltier element was brought in close contact with the rear surface of the test specimen on the side that have not been subjected to the thermal spraying to thereby cool the rear surface of the test specimen to 20°C below the freezing point. The surface of the side formed with the thermally sprayed coating at 20°C below the freezing point was exposed to a commercially available artificial seawater (Marine Art Hi manufactured by Tomita Pharmaceutical Co. , Ltd.) at 30°C for 20 hours, and extent of the recess formed by the corrosion was measured for both the disk substrate and the thermally sprayed coating. The results of the measurement are shown in Table 1. As demonstrated in Table 1, extent of the recess in the thermally sprayed coating was as low as 1 to 2 μm in the case of conventional thermally sprayed Al - Zn based coating (Nos. 15 and 16), while extent of the recess in the disk substrate was as high as approximately 12 μm, indicating that protective effect by the sacrificial corrosion was not fully exerted in the seawater exposure conditions as described above. In contrast, in the case of the thermally sprayed Al - Mg based coating, extent of the recess in the thermally sprayed coating was higher and extent of the recess in the disk substrate was lower compared to the case of the Al - Zn based sprayed coating. In particular, when the Mg content was 1% or higher, extent of the recess in the thermally sprayed coating was as high as 5 μm or higher indicating the realization of the protective effect by the sacrificial corrosion, and extent of the recess in the disk substrate decreased to the level of 8 μm or lower. In particular, in view of reducing the extent of recess of the pure aluminum disk substrate, Mg content is preferably 1% by mass or higher, preferably 3% by mass or higher, and most preferably 5% by mass or higher. When the Mg content is 5% by mass or higher, the extent of recess of the thermally sprayed Al - Mg coating increases while the extent of recess of the disk substrate does not substantially change. When the Mg content increases to over 80% by mass and reaches 90% by mass, consumption of the thermally sprayed coating becomes significant, and therefore, the Mg content preferably does not exceed 80% by mass. In view of preventing excessive consumption of the thermally sprayed coating, the Mg content is more preferably up to 50% by mass, and most preferably up to 30% by mass. In Table 1, G1, G2, and G3 indicate the level of the sacrificial corrosion protection, and the level of the sacrificial corrosion protection increases in the order of G1 < G2 < G3.

Table 1

No.	Composition of thermally sprayed coating	Recess in Al alloy substrate (μm)	Recess in thermally sprayed coating (μm)	Note
1	Al - 1% Mg	5.2	8.3	Example(G1)
2	Al - 2% Mg	5.1	8.1	Example(G1)

(continued)

No.	Composition of thermally sprayed coating	Recess in Al alloy substrate (μm)	Recess in thermally sprayed coating (μm)	Note
3	Al - 3% Mg	3.7	10.1	Example(G2)
4	Al - 4% Mg	3.4	9.9	Example(G2)
5	Al - 5% Mg	1.1	11.2	Example(G3)
6	Al - 10% Mg	0.9	12.1	Example(G3)
7	Al - 30% Mg	1.2	12.5	Example(G3)
8	Al - 40% Mg	0.8	15.2	Example(G2)
9	Al - 50% Mg	1.2	16.5	Example(G2)
10	Al-60% Mg	0.9	19.2	Example(G1)
11	Al-70% Mg	0.8	20.5	Example(G1)
12	Al - 80% Mg	0.9	19.8	Example(G1)
13	Al-90% Mg	1	30.5	Comparative Example
14	Al- 0.5% Mg	8.5	5.2	Comparative Example
15	Al - 2% Zn	12.5	1.2	Comparative Example
16	Al- 15% Zn	11.4	2.1	Comparative Example

Example 2

[0047] One side of an aluminum alloy (A5083) plate of 200 mm x 200 mm having a thickness of 5 mm was mechanically processed to various degree of surface roughness, and this plate was used for the aluminum substrate. Immediately after the mechanical processing, the aluminum substrate was evaluated for its center line mean roughness Ra 75 using a surface roughness meter. 10 aluminum substrates (n = 10) which had been mechanically processed with the same target surface roughness were prepared for each set of test conditions, and average of Ra 75 for these 10 aluminum substrates is shown in Table 2 as the roughness (Ra 75) of the boundary between the aluminum substrate and the thermally sprayed coating. In order to realize satisfactory adhesion with the aluminum substrate, a coating of Al - 5% by mass Mg was formed to a thickness of 300 μm on the mechanically processed aluminum substrate immediately after the machine processing by flame spraying using a wire of Al - 5% by mass. On a part of the mechanically processed aluminum substrate, a coating of Al - 90% Mg was formed to a thickness of 300 μm by flame spraying using a wire of Al - 90% by mass Mg. No further treatment was conducted after the thermal spraying, and the test specimen was thereby provided. The composition and the thickness of the thermally sprayed coating are shown in Table 2 for each set of conditions.

Table 2

NO.	Composition of thermally sprayed coating	Thickness of thermally sprayed coating (μm)	Boundary roughness (Ra 75, μm)	Area of blister peeling (%)	Note
1	Al - 5% Mg	300	5.2	64.2	Example
2	Al - 5% Mg	300	10.8	22.4	Example
3	Al - 5% Mg	300	11.3	21	Example
4	Al - 5% Mg	300	12.5	13.4	Example
5	Al - 5% Mg	300	13.2	11.5	Example
6	Al - 5% Mg	300	14.5	2.8	Example
7	Al - 5% Mg	300	16.8	2.3	Example
8	Al - 5% Mg	300	20.5	2.1	Example

(continued)

NO.	Composition of thermally sprayed coating	Thickness of thermally sprayed coating (μm)	Boundary roughness (Ra 75, μm)	Area of blister peeling (%)	Note
9	Al - 5% Mg	300	38.5	2.5	Example
10	Al - 5% Mg	300	42.4	3.2	Example
11	Al - 5% Mg	300	58.5	8.5	Example
12	Al - 5% Mg	300	65.2	12.9	Example
13	Al - 5% Mg	300	79.2	17.5	Example
14	Al - 5% Mg	300	86.2	21.2	Example
15	Al - 5% Mg	300	98.5	25.3	Example
16	Al - 5% Mg	300	115.2	65.2	Comparative Example
17	Al - 5% Mg	175	20	5.5	Example
18	Al - 5% Mg	120	19.8	14.2	Example
19	Al - 5% Mg	50	20.4	50.2	Comparative Example
20	Al - 90% Mg	300	20.1	59.3	Comparative Example
21	Al - 90% Mg	300	75.2	98.3	Comparative Example

[0048] Blister peeling test was conducted for the aluminum substrates of No. 1 to 21 having the thermally sprayed coating formed thereon as shown in Table 2. 10 test specimens of the aluminum substrate were used for each type. First, the test piece was immersed for 3 months in an artificial seawater (Marine Art Hi manufactured by Tomita Pharmaceutical Co. , Ltd.) at 20°C and pH 8.2 flowing at a flow rate 3 m/s to measure and calculate area percentage of blister peeling on the thermally sprayed coating after the immersion by means of image analysis. The average of the 10 test specimens is indicated in Table 2 as the area percentage of blister peeling of the aluminum substrates of No. 1 to 21 having the thermally sprayed coating formed thereon. The relationship between the roughness (Ra 75) of the boundary between the thermally sprayed coating and the aluminum substrate and the area percentage of blister peeling was noteworthy in Table 2, and when the roughness (Ra 75) of the boundary increased to the level of about 10 μm or higher (test piece Nos. 2 and 3), the area percentage of blister peeling rapidly decreased to the level of approximately 20% to demonstrate improvement in the peeling resistance in the environment of moving seawater. The area percentage of blister peeling further reduced to about its half when the roughness (Ra 75) of the boundary was about 12 μm or higher (test piece Nos. 4 and 5), and even further reduced to the level of approximately 2 to 3% when the roughness (Ra 75) of the boundary was about 14 μm or higher (test piece No. 6). Accordingly, in order to improve the peeling resistance of the thermally sprayed coating in the environment of moving seawater, it would be effective to control the roughness (Ra 75) of boundary to the level of 10 μm or more, preferably to 12 μm or more, and more preferably to 14 μm or more.

[0049] In the meanwhile, when the roughness (Ra 75) of the boundary reached about 60 μm (test piece No. 11), the area percentage of blister peeling started to increase again, and in the case of test piece No. 16 with the boundary roughness exceeding 100 μm, the area percentage of blister peeling rapidly increased to the level equivalent with test piece No. 1 wherein the boundary roughness was less than 10 μm. As described above, when the roughness (Ra 75) of the boundary is excessively high, space not filled by the coating is apt to be formed between the thermally sprayed coating and the aluminum substrate, and the seawater entering such space will promote preferential corrosion at the boundary. As a consequence, area percentage of the peeling will be increased to detract from the peeling resistance of the thermally sprayed coating. Accordingly, it would be effective to control the roughness (Ra 75) of the boundary to the range of up to 100 μm, preferably up to 80 μm, and more preferably up to 60 μm.

[0050] It is to be noted that, when the content of Mg is as high as 90% by mass which is outside the scope of the present invention (test piece Nos. 20, 21), the area percentage of blister peeling is quite high even if the roughness (Ra 75) of the boundary were within the scope of the present invention (i.e. 10 to 100 μm). In addition, even if the Mg content and the roughness (Ra 75) of the boundary were both within the scope of the present invention, the area percentage of

blister peeling will also be high if the thermally sprayed coating were thinner (i.e. 50 μm) than the thickness of the present invention. When the Mg content is at the level as high as 90% by mass, consumption of the thermally sprayed coating will be accelerated, and the seawater will penetrate into the boundary between the aluminum substrate and the alloy coating at an earlier timing and aluminum rust will occur at a faster rate at the boundary between the substrate and the coating. This results blister or bulging of the alloy coating, and hence, peeling, and significant increase in the area of blister peeling is thereby invited. The situation is similar when the thermally sprayed coating is as thin as 50 μm, and penetration of the seawater into the boundary between the aluminum substrate and the alloy coating invites blister and peeling of the alloy coating and increase in the area of blister peeling.

Example 3

[0051] An aluminum alloy (A5083) plate of 200 mm x 200 mm having a thickness of 5 mm was used for the aluminum substrate. On one side of such aluminum substrate was thermally sprayed an Al-5% by mass Mg alloy to form a coating of the Al-5% by mass Mg alloy. Test specimen Nos. 1 to 7 were prepared as shown in Table 3 by subjecting the aluminum substrate to different post treatments after forming the thermally sprayed coating. 11 test specimens were prepared for each type of post treatment.

Table 3

No.	Thickness of thermally sprayed coating (μm)	Mechanical processing after thermal spraying	Treatment after thermal spraying	Pore area (%)	Area percentage of blister peeling (%)	Note
1	300	No	No treatment	17.1	44.2	Comparative Example
2	300	No	Sealer impregnation	18.2	20.4	Comparative Example
3	450	Yes	Grinding	10.4	4	Example
4	400	Yes	Shot peening	6.6	2.4	Example
5	400	Yes	Sealer impregnation → Shot peening	1.7	0.5	Example
6	400	Yes	Shot peening → Sealer impregnation	1.6	0.8	Example
7	400	Yes	Sealer impregnation → Shot peening → Sealer impregnation	1.6	0.3	Example

[0052] The thermal spraying of test specimen Nos. 1 to 7 was conducted so that the coating thickness after the post treatment (the treatment after the thermal spraying) was 300 μm as shown in Table 3. More specifically, the target thickness of the thermally sprayed coating was 300 μm in test specimen Nos. 1 and 2 which were not treated by mechanical processing after the thermal spraying; 470 μm in test specimen No. 3 which was treated by grinding (for 10 seconds) after the thermal spraying; and 400 μm in test specimen Nos. 4 to 7 which were treated by shot peening (for 60 seconds). While the coating thickness in the test specimen Nos. 1 and 2 which was not subjected to mechanical processing after the thermal spraying and the test specimen Nos. 3 to 7 which were treated by mechanical processing and other treatment after the thermal spraying were variable among the 11 (N = 11) specimens of the same treatment, coating thickness of the test specimen Nos. 1 to 7 were all within the range of 250 to 350 μm.

[0053] From the 11 specimens of each of the test specimen Nos. 1 to 7, 1 specimen was used for measuring area percentage of pores of thermally sprayed coating in the region from the uppermost surface to the depth of 100 μm of thermally sprayed coating. 10 locations were evenly selected from the entire area of 200 mm x 200 mm of each test

specimen, and a sample was sliced from each location. The cross section of the thermally sprayed coating was examined by SEM as in the case of Examples 1 and 2, and area percentage of pores observed in the region from the uppermost surface to the depth of 100 μm of thermally sprayed coating was determined by image analysis. The average of the thus determined area percentage of pores from the 10 location for test specimen Nos. 1 to 7 are shown in Table 3 as the area percentage of pores of the thermally sprayed coating from the uppermost surface to the depth of 100 μm.

[0054] The remaining 10 specimens of the test specimen Nos. 1 to 7 were used for blister peeling test. The test specimen was immersed for 3 months in an artificial seawater at 20°C and pH 8.2 flowing at a flow rate 3 m/s to measure. The test specimen after the immersion/exposure test was bent so that the side of the thermally sprayed coating is in the inside to thereby apply compression stress to the thermally sprayed coating and occurrence of the blister peeling was examined by SEM to measure and calculate area percentage of the blister peeling on the surface of the thermally sprayed coating by means of image analysis. The average of the 10 test specimens of test specimen Nos. 1 to 7 is indicated in Table 3 as the area percentage of blister peeling.

[0055] The results in Table 3 indicate that the area percentage of pores of the thermally sprayed coating was as high as approximately 17 to 18% in test specimen No . 1 which was subjected to neither of the mechanical processing after the thermal spraying nor the post-treatment and in test specimen No. 2 which was impregnated with the sealer without the mechanical processing after the thermal spraying, and in accordance with such high area percentage of pores, the area of blister peeling was also high. The area percentage of pores decreased to approximately 6 to 10% in test specimen Nos. 3 and 4 which were treated only by mechanical processing of either grinding or shot peening, and the area percentage of blister peeling also greatly reduced to 2 to 4%. In test specimen Nos. 5 to 7 which were treated by the combination of the impregnation with a sealer and the mechanical processing of the shot peening, the area percentage of pores markedly reduced to approximately 1.6%, and the area percentage of blister peeling also decreased to the level of 1% or less. It was therefore indicated that a treatment by the combination of the impregnation with a sealer and the mechanical processing after the thermal spraying was extremely effective in reducing the area percentage of pores and the area percentage of blister peeling.

Example 4

[0056] In order to simulate the environment near the panel 3 and the lower header 2 of the LNG vaporizer (ORV) (see FIG. 1), a disk of aluminum alloy A5083 having a diameter of 16 mm and a thickness of 4 mm was prepared, and a coating of the composition shown in Table 4 was thermally sprayed to a thickness of 300 μm on one surface of the disk defined by the straight line passing through the center of the disk. No further treatment was conducted after the thermal spraying, and the test specimen was thereby provided. Peltier element was brought in close contact with the rear surface of the test specimen on the side not subj ected to the thermally spraying to thereby cool the rear surface of the test specimen to 20°C below the freezing point. The surface of the side formed with the thermally sprayed coating at 20°C below the freezing point was exposed to a commercially available artificial seawater (Marine Art Hi manufactured by Tomita Pharmaceutical Co., Ltd.) at 30°C for 20 hours at a flow rate of 1 m/s, and extent of the recess formed by the corrosion was measured for both the disk substrate and the thermally sprayed coating. The results of the measurement are shown in Table 4.

[0057] As demonstrated in Table 4, extent of the recess in the thermally sprayed coating was as low as 1 to 2 μm in the case of conventional thermally sprayed Al - Zn based coating (Nos. 1 and 2), while extent of the recess in the in the disk substrate was as high as approximately 8 μm, indicating that the protective effect by the sacrificial corrosion was not fully exerted in the seawater exposure conditions as described above. In the test specimens of Nos. 3, 4, and 5 in which content of the alloying elements Zn, Mn, and Mg are outside the scope of the present invention, the extent of the recess of the thermally sprayed coating was slightly lower than that of the Al alloy substrate (disk substrate), and the protective effect by the sacrificial corrosion was not fully exerted. In contrast, in the cases of the thermally sprayed coating having the alloying composition of the present invention, the extent of the recess of the thermally sprayed coating was approximately 5 to 10 μm, which was larger than the extent of the recess (up to 4.5 μm) of the Al alloy substrate, and the protective effect by the sacrificial corrosion was not exerted. In addition, the extent of the recess of the thermally sprayed coating was relatively low, indicating that the durability of the thermally sprayed coating was maintained at a satisfactory level. In particular, in the cases of test specimen Nos. 10 to 13 in which the Mg content was up to 24% by mass and the content of (Zn + Mn) was 1.5 to 2.5% by mass, the extent of the recess of the Al alloy substrate was as low as 1. 5 μm or less and the corrosion protective effect was excellent. In the cases of test specimen Nos. 16 to 19 in which the content of the alloying element Zn, Mn, or (Zn + Mn), or Mg was outside the scope of the present invention, despite the apparent satisfactory sacrificial corrosion protection, such composition was unsuitable as described above due to the segregation caused by the increased content of the alloying element in the thermally sprayed coating, or the excessively increased corrosion speed.

Table 4

No.	Composition of thermally sprayed coating	Recess in Al alloy substrate (μm)	Recess in thermally sprayed coating (μm)	Note
1	Al - 2% Zn	8.1	1.1	Comparative Example
2	Al -15% Zn	7.8	1.7	Comparative Example
3	Al - 0.2% Zn - 0.2% Mg	6	5	Comparative Example
4	Al - 0.2% Mn- 0.2% Mg	6	5.2	Comparative Example
5	Al - 0.2% Mg	6.3	5.6	Comparative Example
6	Al - 0.3% Zn - 0.3% Mg	4.3	6.2	Example
7	Al - 0.3% Mn - 0.3% Mg	4.2	6.5	Example
8	Al - 0.2% Zn - 0.1 % Mn - 0.3% Mg	4.4	6.9	Example
9	Al -1% Mn - 1%Mg	3.2	7.2	Example
10	Al - 1.5% Zn - 0.5% Mn - 3% Mg	0.9	9	Example
11	Al - 1.5% Zn - 1 % Mn - 4% Mg	0.8	9.1	Example
12	Al - 1.5% Zn -1% Mn - 2% Mg	1.5	7.9	Example
13	Al - 1.5% Zn - 3% Mg	1.3	8.6	Example
14	Al - 1% Zn - 2% Mn - 2% Mg	1.6	8.4	Example
15	Al - 0.5% Zn -1% Mn - 5% Mg	1	9.3	Example
16	Al - 4% Zn - 3% Mg	1	10.5	Comparative Example
17	Al - 5% Mn - 3% Mg	2.3	11.6	Comparative Example
18	Al - 2% Zn - 2% Mn - 3% Mg	2.1	9.8	Comparative Example
19	Al - 3% Zn - 7% Mg	1	12.1	Comparative Example

Claims

1. A heat transfer tube for an LNG vaporizer,
wherein the LNG is passed through its interior and seawater is supplied to its exterior surface for vaporization of the LNG by heat exchange between the LNG and the seawater,
wherein the heat transfer tube comprises an Al alloy and has a corrosion protective coating on its exterior surface, and the corrosion protective coating includes an Al alloy coating containing Mg.

2. The heat transfer tube for an LNG vaporizer according to claim 1,
wherein the corrosion protective coating contains Mg at an amount higher than that of the Al alloy having the corrosion protective coating on its exterior surface.

3. The heat transfer tube for an LNG vaporizer according to claim 1 or 2,
wherein the Al alloy corrosion protective coating has a thickness of 100 to 1000 μm.

4. The heat transfer tube for an LNG vaporizer according to any one of claims 1 to 3,
wherein the Al alloy corrosion protective coating has a Mg content in the range of 1 to 80% by mass.

5. The heat transfer tube for an LNG vaporizer according to any one of claims 1 to 4, wherein the Al alloy corrosion protective coating is formed by thermal spraying, and boundary between the coating and the heat transfer tube has a center line mean roughness (Ra 75) is in the range of 10 to 100 μm.

6. The heat transfer tube for an LNG vaporizer according to claim 5, wherein the roughness of the boundary has been formed by spraying a blast agent containing blast particles of #16 or higher to the exterior surface of the heat transfer tube on which the sprayed coating is to be formed.

7. The heat transfer tube for an LNG vaporizer according to claim 5 or 6, wherein the Al alloy coating has a percentage of pore area of not more than 15% in the region from the uppermost surface to the depth of 100 μm in the cross section including the central axis of the heat transfer tube.

8. The heat transfer tube for an LNG vaporizer according to claim 1, wherein the corrosion protective coating comprises an Al alloy coating containing Zn and/or Mn and Mg wherein content of (Zn + Mn), Zn, or Mn is in the range of 0.3 to 3.0% by mass and content of Mg is 0.3 to 5.0% by mass.

9. An LNG vaporizer comprising:

a panel unit including a panel composed of a plurality of heat transfer tubes having a thermally sprayed coating formed thereon of any one of claims 1 to 8 arranged in a row in curtain form; and
an upper header for discharging the LNG and a lower header for supplying the LNG respectively connected to the panel at its upper end portion and its lower end portion,

wherein the LNG is vaporized by heat exchange between seawater flowing down along the surface of the panel from the upper end portion of the panel unit and the LNG flowing through the heat transfer tubes from the side of the lower header to the side of the upper header.

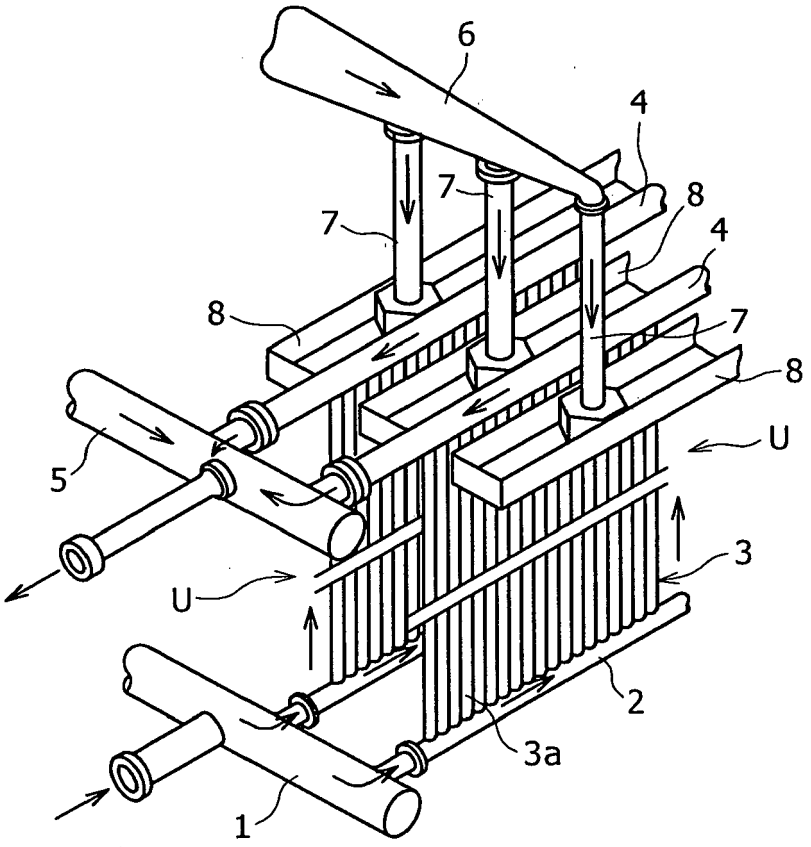
10. The LNG vaporizer according to claim 9, wherein the thermally sprayed coating of the heat transfer tubes is formed at least on the exterior surface of the lower portion of the panel and on the exterior surface of the lower header.

11. A method for producing a heat transfer tube for an LNG vaporizer which is used by passing the LNG in its interior and supplying seawater to its exterior surface for vaporization of the LNG by heat exchange between the LNG and the seawater, and which has a corrosion protective coating formed on its exterior surface, wherein the corrosion protective coating is formed by thermal spraying an Al alloy containing Mg and subjecting the surface of the thermal spray coating to a mechanical processing.

12. A method for producing a heat transfer tube for an LNG vaporizer, wherein the LNG is passed through its interior and seawater is supplied to its exterior surface for vaporization of the LNG by heat exchange between the LNG and the seawater, and which has a corrosion protective coating formed on its exterior surface,
wherein the corrosion protective coating is formed by thermal spraying an Al alloy containing Zn and/or Mn and Mg and subjecting the surface of the spray coating to a mechanical processing.

13. The method for producing a heat transfer tube for an LNG vaporizer according to claim 11 or 12, wherein a sealing treatment of the sprayed coating is carried out as a pretreatment and/or a post-treatment of the mechanical processing.

FIG. 1



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EUROPEAN SEARCH REPORT

Application Number
EP 06 29 1353

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CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

Application Number
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