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(71) Applicant: **NOVA Chemicals (International) S.A.**,
Fribourg (CH)**Publication Classification**(72) Inventors: **Leslie Wilfred Benum**, Red Deer (CA);
Eric Clavelle, Calgary (CA); **Kamal K Botros**,
Calgary (CA); **Vasily Simanzhenkov**, Calgary (CA); **Hany Iskandar Farag**,
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Fribourg (CH)(57) **ABSTRACT**(21) Appl. No.: **16/076,003**(22) PCT Filed: **Jan. 18, 2017**(86) PCT No.: **PCT/IB2017/050264**

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If a cracked gas heat exchanger becomes damaged water may enter the transfer line causing it to rupture. This may be avoided using a heat exchanger having heat pipes to conduct heat from the cracked gas to a cooling device, typically a water cooler to generate steam. The latter (cooling device) is physical separated from the hot cracked gas stream. The heat pipes may be modified at the hot or cold end with fins, ribs, protuberances, pins and the like.

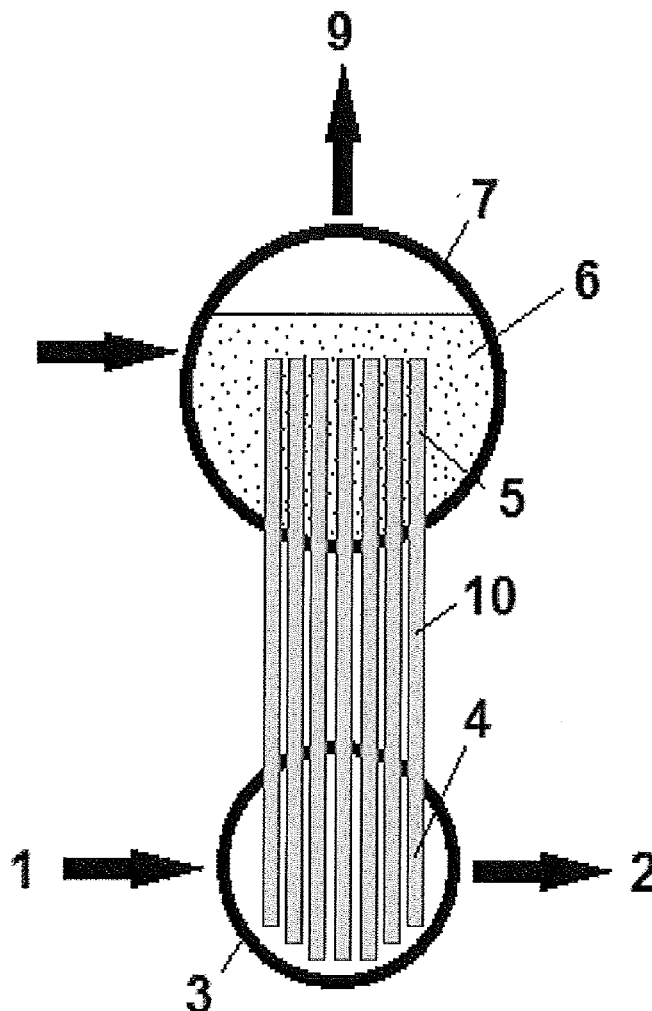


FIGURE 1

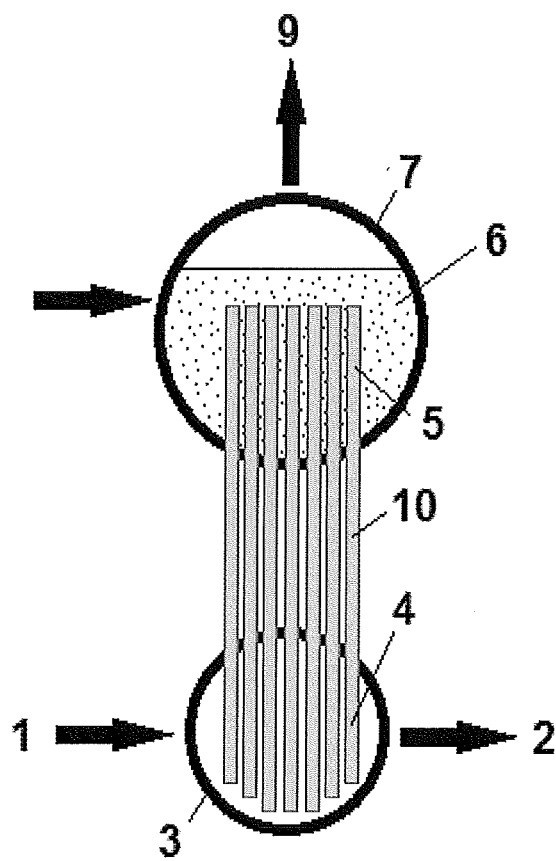


FIGURE 2A

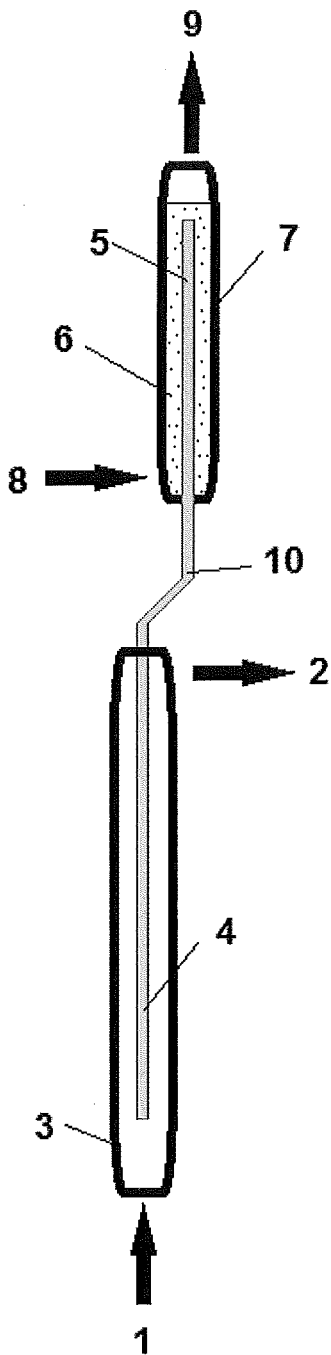


FIGURE 2B

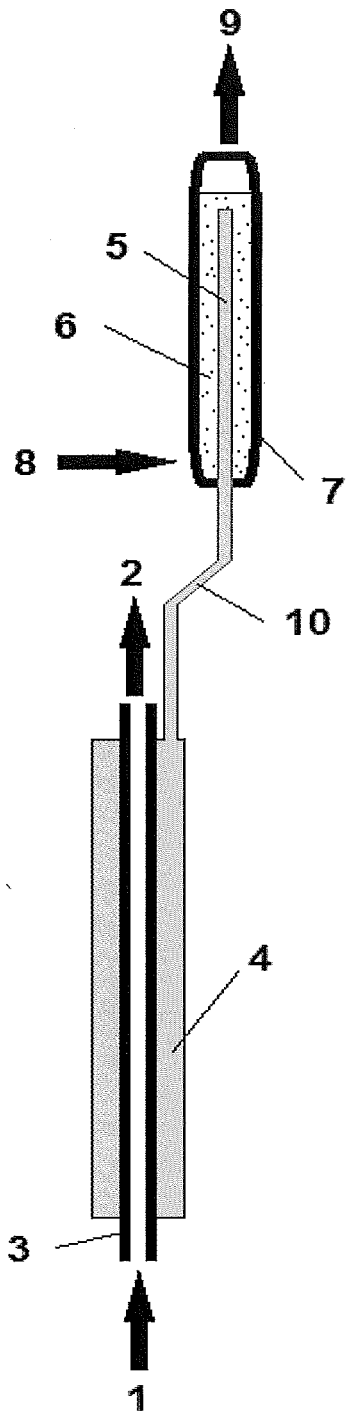
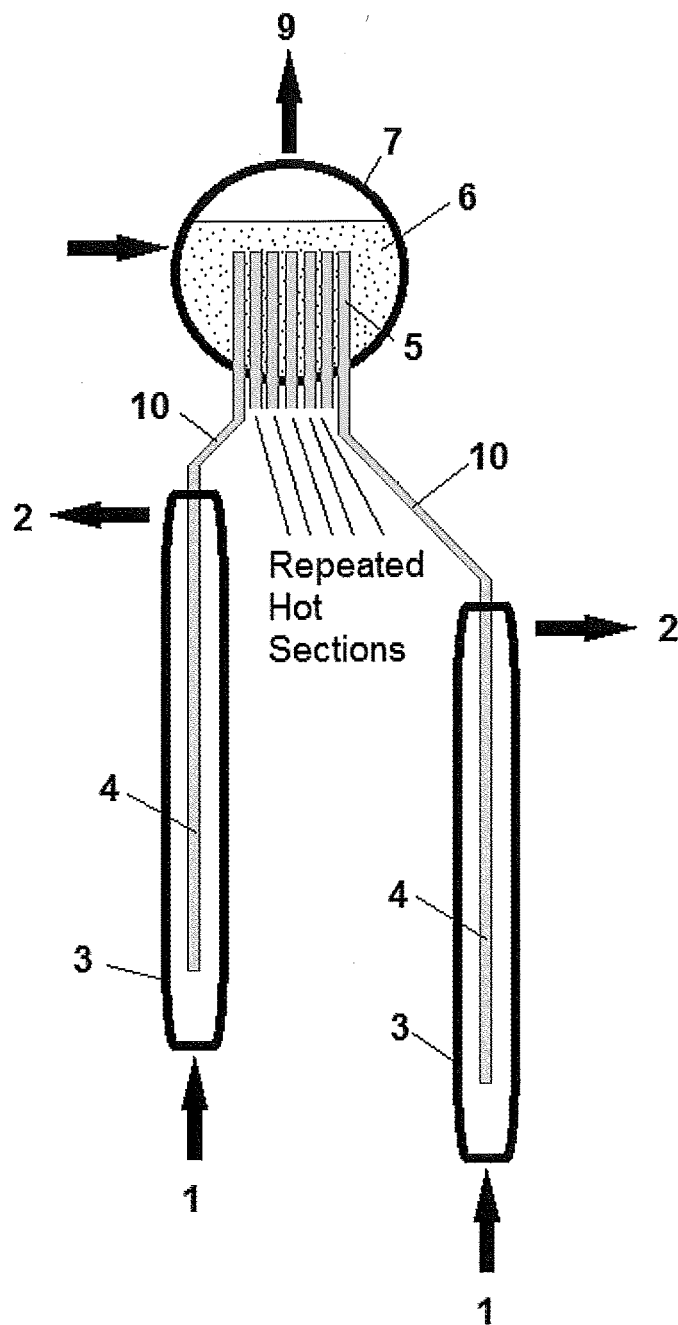


FIGURE 3



CRACKED GAS QUENCH HEAT EXCHANGER USING HEAT PIPES

TECHNICAL FIELD

[0001] The present invention relates to the use of heat pipes (sometimes called heat tubes) to recover heat from the hot section of a reactor, such as an alkane or ethane steam cracker or pyrolysis furnace and transfer it to a cooler unit operation such as a steam generator or a pre heater for the feed stream to the cracker. Ethane or alkane steam cracking is a highly endothermic process and any improvement in the recovery of heat from the reactor saves operating costs and reduces greenhouse gas emissions.

BACKGROUND ART

[0002] In alkane such as ethane steam cracking the cracked gas leaving the cracker enters a transfer line and is directed to a heat exchanger. The heat exchanger is typically a tube and shell heat exchanger with the hot cracked gasses passing through the tubes and a cooling medium, typically water, flowing through the shell. In many designs the heat exchanger is above the transfer line. That is the hot cracked gasses flow up through the heat exchanger. Occasionally, tube failure will occur in the exchanger, resulting in water leakage into the tubes. The water will then flow into the inlet cone to the heat exchanger. In general, inlet cones are made of metal casting or fabricated metal and will fail when suddenly quenched by a water leak of the aforementioned type. The failure may allow the process gas to escape to the atmosphere where it will burn. This presents a potential safety hazard as personnel may be burned by the hot gas leakage. Under these circumstances, the cracker (furnace) must be shut down, which will adversely impact plant production.

[0003] An older design of a heat exchanger used to cool cracked gasses is illustrated by U.S. Pat. No. 3,306,351 issued Feb. 28, 1967 to Vollhardt assigned to Schmidt'sche Heissdampf—Gesellschaft m.b. H.

[0004] U.S. Pat. No. 5,813,453 issued Sep. 29 1998 to Brucher assigned to Deutsche Babcock—Borsig AG, discloses one type of heat exchanger which may be used to cool cracked gasses.

[0005] Heat pipes have been known since the late 1960's as illustrated by U.S. Pat. No. 3,229,759 in the name of Grover assigned to the United States of America as represented by the United States Atomic Energy Commission, issued Jan. 18, 1966. The patent teaches a heat pipe comprising a closed pipe, an internal working medium and a wick. The working medium evaporates at the hot end of the pipe and rises to the cool end where it gives off heat and condenses. The condensed fluid flow down the wick and returns to the hot end of the heat pipe.

[0006] There are a number of patents and applications in the name of Fectu, assigned to Econotherm UK Limited illustrated by for example by published United States Patent application 20130233512 published Sep. 12, 2012. This patent application discloses the use of heat pipes in heat exchangers. A hot gas flows over heat pipes in a first chamber and the heat pipes extend into a second chamber where a cool fluid flow over an array of the heat pipes and extracts heat from them. The first and second chambers are separated by a plate but the gas from the first chamber also

flows through a duct in the second chamber. The reference does not teach chambers in which the hot fluid does not flow through the second chamber.

[0007] The present invention seeks to provide an improved heat exchanger and a method for cooling a hot hydrocarbon gas such as a cracked gas using heat pipes connecting two separate chambers.

DISCLOSURE OF INVENTION

[0008] In one embodiment the present invention provides a heat exchanger for use with a hot fluid stream leaving a high temperature process comprising a hot section and a cold section which have no common or adjoining external surfaces wherein one or more heat pipes extend from the interior of the hot section traverse the open space between the hot section and cold section at an angle of inclination from 10° to 90° and extend into the cold section.

[0009] In a further embodiment the present invention provides the above heat exchanger wherein the temperature differential between the hot section and the cold section is not less than 200° C.

[0010] In a further embodiment the present invention provides the above heat exchanger wherein the hot section is at a pressure from 85 to 150 kPa gage and a temperature from 800° C. to 1000° C.

[0011] In a further embodiment the present invention provides the above heat exchanger wherein the cold section is at a temperature from 250° C. to 600° C. and a pressure from 5 to 9 MPa.

[0012] In a further embodiment the present invention provides the above heat exchanger wherein the fluid passing through the hot section is cracked gas.

[0013] In a further embodiment the present invention provides the above heat exchanger wherein the fluid in the cold section is water.

[0014] In a further embodiment the present invention provides the above heat exchanger wherein the working fluid in the heat pipe is selected from the group consisting of sodium, potassium, and cesium.

[0015] In a further embodiment the present invention provides the above heat exchanger wherein the heat pipes have an outer diameter from 1 cm (0.5 inches) to 10 cm (4 inches).

[0016] In a further embodiment the present invention provides the above heat exchanger wherein the heat pipe has a length up to 10 meters.

[0017] In a further embodiment the present invention provides the above heat exchanger wherein the heat pipe has one or more of internal capillaries and internal wicking.

[0018] In a further embodiment the present invention provides the above heat exchanger wherein the end of the heat pipe in the hot section has a surface resistant to coking.

[0019] In a further embodiment the present invention provides the above heat exchanger wherein the end of the heat exchanger in the hot section has a surface having a thickness from 100 to 5,000 microns comprising from 40 to 60 weight % of compounds of the formula $Mn_xCr_{3-x}O_4$ wherein x is from 0.5 to 2 and from 60 to 40 weight % of oxides of Mn and Si selected from the group consisting of MnO, MnSiO₃, Mn₂SiO₄ and mixtures thereof provided that the surface contains less than 5 weight % of Cr₂O₃.

[0020] In a further embodiment the present invention provides the above heat exchanger wherein the heat pipe comprises from about 55 to 65 weight % of Ni; from about

20 to 10 weight % of Cr; from about 20 to 10 weight % of Co; and from about 5 to 9 weight % of Fe and the balance one or more of the trace elements.

[0021] In a further embodiment the present invention provides the above heat exchanger wherein the heat pipe further comprising from 0.2 up to 3 weight % of Mn; from 0.3 to 2 weight % of Si; less than 5 weight % of titanium, niobium and all other trace metals; and carbon in an amount of less than 0.75 weight % the sum of the components adding up to 100 weight %.

[0022] In a further embodiment the present invention provides the above heat exchanger wherein the heat pipe comprises from 40 to 65 weight % of Co; from 15 to 20 weight % of Cr; from 20 to 13 weight % of Ni; less than 4 weight % of Fe and the balance of one or more trace elements and up to 20 weight % of W the sum of the components adding up to 100 weight %.

[0023] In a further embodiment the present invention provides the above heat exchanger wherein the heat pipe further comprising from 0.2 up to 3 weight % of Mn; from 0.3 to 2 weight % of Si; less than 5 weight % of titanium, niobium and all other trace metals; and carbon in an amount of less than 0.75 weight %. In a further embodiment the present invention provides the above heat exchanger wherein the heat pipe comprises from 20 to 38 weight % of chromium from 25 to 48, weight % of Ni.

[0024] In a further embodiment the present invention provides the above heat exchanger wherein the heat pipe further comprising from 0.2 up to 3 weight % of Mn, from 0.3 to 2 weight % of Si; less than 5 weight % of titanium, niobium and all other trace metals; and carbon in an amount of less than 0.75 weight % and the balance substantially iron.

[0025] In a further embodiment the present invention provides the above heat exchanger wherein at least a portion of the heat pipe between the hot section and the cold section is helical.

[0026] In a further embodiment the present invention provides the above heat exchanger wherein at least a portion of the heat pipe between the hot section and the cold section is in the shape of a "Z".

[0027] In a further embodiment the present invention provides the above heat exchanger wherein there is thermal insulation on at least a portion of the heat pipe between the hot box and the cold box.

[0028] In a further embodiment the present invention provides the above heat exchanger wherein the wick inside the heat pipe is made of nickel, copper, molybdenum, niobium, aluminium, iron, cobalt or alloys based on these metals, and ceramic.

[0029] In a further embodiment the present invention provides the above heat exchanger where in the wick has a pore size from 50 to about 1,000 microns.

[0030] In a further embodiment the present invention provides the above heat exchanger where in the wick has a bi modal pore size and the second pore size from 0.5 to 50 microns.

[0031] In a further embodiment the present invention provides the above heat exchanger having on its hot end, its cold end or both of the heat pipe a surface modification selected from the group consisting of fins, ribs, protuberances and pins.

[0032] In a further embodiment the present invention provides the above heat exchanger wherein the distance between the hot section and the cold section is from 30 cm to 6 meters.

[0033] In a further embodiment the present invention provides a heat pipe having on its hot end, its cold end or both a surface modification selected from the group consisting of fins, ribs, protuberances and pins.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] FIG. 1 is a schematic diagram of a heat exchanger in accordance with the present invention where the hot section and cold section are vertically aligned, yet physically separated.

[0035] FIGS. 2A and 2B is a schematic diagram of a heat exchanger in accordance with the present invention where the cracked gas from the cracker is divided into multiple streams each having its own heat tube which transfers heat to the cooling section.

[0036] FIG. 3 shows a variant with multiple hot sections but a combined cold section.

[0037] FIGS. 2A, 2B and 3 show a variant of a heat tube arrangement with an offset in the tube between the hot and cold sections.

BEST MODE FOR CARRYING OUT THE INVENTION

[0038] Numbers Ranges

[0039] Other than in the operating examples or where otherwise indicated, all numbers or expressions referring to quantities of ingredients, reaction conditions, etc. used in the specification and claims are to be understood as modified in all instances by the term "about". Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification and attached claims are approximations that can vary depending upon the properties that the present invention desires to obtain. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques.

[0040] Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical values, however, inherently contain errors necessarily resulting from the standard deviation found in their respective testing measurements.

[0041] Also, it should be understood that any numerical range recited herein is intended to include all sub-ranges subsumed therein. For example, a range of "1 to 10" is intended to include all sub-ranges between and including the recited minimum value of 1 and the recited maximum value of 10; that is, having a minimum value equal to or greater than 1 and a maximum value of equal to or less than 10. Because the disclosed numerical ranges are continuous, they include every value between the minimum and maximum values. Unless expressly indicated otherwise, the various numerical ranges specified in this application are approximations.

[0042] All compositional ranges expressed herein are limited in total to and do not exceed 100 percent (volume

percent or weight percent) in practice. Where multiple components can be present in a composition, the sum of the maximum amounts of each component can exceed 100 percent, with the understanding that, and as those skilled in the art readily understand, that the amounts of the components actually used will conform to the maximum of 100 percent.

[0043] Typically a heat pipe or tube comprises a sealed tube, preferably metallic containing a working fluid and an internal capillary to transport the condensed working fluid from the end of the heat pipe in the cold section to the end of the heat pipe in the hot section. The tube material must have a melting point above the highest expected temperature in the hot section. Preferably the melting temperature of the material forming the pipe or tube will be at least 50° C., preferably at least 80° C. above the maximum anticipated temperature in the hot section. Additionally, the tube structure and particularly crystal structure should not change over the working temperature range for the heat pipe. The material forming the pipe needs to have a high (good) thermal conductivity. Additionally, the material from which the pipe is made needs to be workable—formable and weldable.

[0044] The working fluid in the heat pipe should vaporize at a temperature at least 50° C., in some embodiments at least 80° C. below the minimum anticipated temperature of the hot cracked gas. The working fluid in the heat pipe should condense at a temperature at least 25° C., in some instances at least 50° C. above the maximum anticipated temperature of the cooling medium (e.g. the cooling medium has to be below the condensation temperature of the working fluid in the heat pipe). The working fluid in the heat pipe should not form a complex or amalgam with the material from which the pipe is made or the material from which the capillary or wick is made. The pipe needs to withstand the pressures generated by the working fluid when it has evaporated. Finally, the pipe needs to have sufficient thermal and mechanical stability to withstand the operating conditions of the unit. The capillary or wick needs to be inert to the working fluid over the operating temperature range and structurally stable over the life span of the unit.

[0045] In operation, the working fluid in the heat tube is boiled or evaporated in the hot section taking heat from the hot fluid. The resulting vapor moves up the heat tube to the cold section. The vapor then condenses in the cold section giving up heat to the medium passing through the cold section. The resulting condensed liquid is transported through the capillary or wick in the tube to the hot section by gravity and capillary forces where it again evaporates.

[0046] Generally, the heat pipe will be at an angle from horizontal from 10° up to 90°.

[0047] In a steam cracker, the cracked gas at the exit has a temperature ranging from 800° C. to 1000° C., typically, from 900° C. to 950° C. The pressure in the hot section will typically be at near atmospheric pressure, from about 85 kPa (gauge) to about 150 kPa (gauge). In the cold section, the temperature may range from 250° C. to 600° C. at pressures from 4.5 MPa to 9 MPa. Typically, the fluid in the cold section is water to generate medium pressure steam.

[0048] Given the above operating conditions, and the *desiderata* for the components for the heat pipe, some of the following components may be useful. Sodium (melting point 97.6° C. boiling point 892° C.) may be used at the working medium. It has a working temperature range from about 600° C. to about 1200° C. Other potential working

mediums include potassium (melting point 63° C. and a boiling point of 770° C.) and cesium (melting point of 28° C. and a boiling point of 705° C.). As these metals are potentially corrosive, care needs to be taken in selecting the composition of the pipe metal to minimize the potential for corrosion and rupture of the pipe or tube. Also, as these metals are extremely reactive with water, care needs to be taken to avoid contact of the working fluid with water.

[0049] If sodium is used as the working fluid it should be a free of hydrogen as possible (e.g. hydrogen from NaH should be removed from the heat pipe prior to sealing).

[0050] There are a number of metals or alloys suitable for the heat pipe. Copper is useful. Its melting point 1083° C., which is about 80° C. above the anticipated maximum temperature of the hot section. Copper has a high ductility and thermal conductivity.

[0051] The heat pipe could be made of stainless steel selected from the group consisting of wrought stainless, austenitic stainless steel and HP, HT, HU, HW and HX stainless steel, heat resistant steel, and nickel based alloys. The heat pipe may be a high strength low alloy steel (HSLA); high strength structural steel or ultra high strength steel. The classification and composition of such steels are known to those skilled in the art.

[0052] In one embodiment the stainless steel, preferably heat resistant stainless steel typically comprises from 20 to 38 weight % of chromium. The stainless steel may further comprise from 25 to 50, most preferably from 25 to 48, desirably from about 30 to 45 weight % of Ni. The balance of the stainless steel may be substantially iron.

[0053] The present invention may also be used with nickel and/or cobalt based extreme austenitic high temperature alloys (HTAs). Typically, the alloys comprise a major amount of nickel or cobalt. Typically, the high temperature nickel based alloys comprise from about 50 to 70, preferably from about 55 to 65 weight % of Ni; from about 20 to 10 weight % of Cr; from about 20 to 10 weight % of Co; and from about 5 to 9 weight % of Fe and the balance one or more of the trace elements noted below to bring the composition up to 100 weight %. Typically, the high temperature cobalt based alloys comprise from 40 to 65 weight % of Co; from 15 to 20 weight % of Cr; from 20 to 13 weight % of Ni; less than 4 weight % of Fe and the balance one or more trace elements as set out below and up to 20 weight % of W. The sum of the components adding up to 100 weight %.

[0054] In some embodiments of the invention the steel may further comprise a number of trace elements including at least 0.2 weight %, up to 3 weight % typically 1.0 weight %, up to 2.5 weight % preferably not more than 2 weight % of manganese; from 0.3 to 2, preferably 0.8 to 1.6 typically less than 1.9 weight % of Si; less than 3, typically less than 2 weight % of titanium, niobium (typically less than 2.0, preferably less than 1.5 weight % of niobium) and all other trace metals; and carbon in an amount of less than 2.0 weight %. The trace elements are present in amounts so that the composition of the steel totals 100 weight %.

[0055] When the heat pipe is in contact with the cracked gases it is desirable if it has a surface which is resistant to coking. The heat pipe may be treated to create a spinel surface on the external surface at least at the end in the hot zone. There are a number of treatments which may create a spinel surface. One treatment comprises (i) heating the heat pipe steel in a reducing atmosphere comprising from 50 to 100 weight % of hydrogen and from 0 to 50 weight % of one

or more inert gases at rate of 100° C. to 150° C. per hour to a temperature from 800° C. to 1100° C.; (ii) then subjecting the heat pipe to an oxidizing environment having an oxidizing potential equivalent to a mixture of from 30 to 50 weight % of air and from 70 to 50 weight % of one or more inert gases at a temperature from 800° C. to 1100° C. for a period of time from 5 to 40 hours; and (iii) cooling the heat pipe to room temperature at a rate of less than 200° C. per hour.

[0056] This treatment should be carried out until there is an external surface at least on the “hot” end of the heat pipe, having a thickness greater than 100 microns, typically from 100 to 5,000 microns preferably from 150 to 4,000 microns desirably from 200 to 3,500 microns and substantially comprising a spinel of the formula $Mn_xCr_{3-x}O_4$ where x is a number from 0.5 to 2, typically from 0.8 to 1.2. Most preferably X is 1 and the spinel has the formula $MnCr_2O_4$.

[0057] Typically the spinel surface covers not less than 55%, preferably not less than 60%, most preferably not less than 80%, desirably not less than 95% of the external stainless steel surface at the hot end of the heat pipe.

[0058] In a further embodiment there may be a chromia (Cr_2O_3) layer between the surface spinel and the substrate stainless steel. The chromia layer may have a thickness up to 100 microns generally from 15 to 70 microns, preferably from 10 to 50 microns. As noted above the spinel overcoats the chromia geometrical surface area. There may be very small portions of the surface which may only be chromia and do not have the spinel overlayer. In this sense the layered surface may be non-uniform. Preferably, the chromia layer underlies or is adjacent not less than 80%, preferably not less than 95%, most preferably not less than 99% of the spinel.

[0059] In a further embodiment the internal surface of the transfer line and the optionally the quench exchanger may comprise from 15 to 85 weight %, preferably from 40 to 60 weight % of compounds of the formula $Mn_xCr_{3-x}O_4$ wherein x is from 0.5 to 2 and from 85 to 15 weight %, preferably from 60 to 40 weight % of oxides of Mn and Si selected from the group consisting of MnO , $MnSiO_3$, Mn_2SiO_4 and mixtures thereof provided that the surface contains less than 5 weight % of Cr_2O_3 .

[0060] The heat pipe further comprises one or more of a wick and one or more capillary channels. The wick may be a porous metal substrate foam, felt, mesh, or screen which does not react with the working fluid. Some examples of a suitable material from which the wick may be made include but are not limited to, nickel, copper, molybdenum, niobium, aluminium, iron, cobalt or alloys based on these metals, and the above noted steels useful for the tube or any combination of the metals suitable for the application. The wick could also be a ceramic. Generally the wick may have a pore size from about 50 to about 1,000 microns, typically from about 300 to 700 microns, in some embodiments from 300 to 500 microns. In a further aspect of the invention it is desirable for the wick to have two different pore sizes (i.e. a bimodal pore size) in the hot end of the heat pipe. The larger pores are as described above. The smaller pores may have a size from 0.5 to 50 microns. The small pore size may be created by depositing metal particles on or within the larger pores. The smaller pore help with capillary pumping and are preferably at the hot end of the heat pipe. Depending on the configuration of the heat pipe the small pores may also be radially distributed preferably in the hot end of the heat pipe.

[0061] The wick permeability increases with pore size but the capillary head increases with decreasing pore size.

[0062] In some embodiments of the invention the wick may be displaced from the side wall of the tube by a spacer such as a helical spring.

[0063] The heat pipes may have an outer diameter from 1 cm (0.5 inches) to 10 cm (4 inches) and a length up to 10 meters. Due to the separation of the hot section and the cold section, at least a portion of the heat pipe between the hot section (hot box) and the cold section (cold box) should be insulated.

[0064] In some embodiments the inner surface of the heat pipe is scored with capillary striations to transport the condensed liquid back to the hot end of the heat pipe. The capillary striations may have a width the same size as the large pore size in the wick.

[0065] The heat pipe is formed in methods well known to those skilled in the art. Typically the wick, where required, and working material, which may be a solid at room temperature, are placed in an open tube. The tube is then evacuated and sealed. In some cases such as sodium the tube may be heated to drive out hydrogen impurities from the sodium before it is sealed.

[0066] In FIG. 1, (1) and (2) indicate the cracked gas entering and exiting the hot section (3) vessel. (4) is the hot end of the heat pipe(s). (5) is the cold end of the heat pipe(s) submerged in the cooling medium, typically boiler feed water (6) that may or may not completely fill the vessel (7). (8) indicates the cooling medium typically boiler feed water entering the cold section (7) vessel. (9) is the cooling medium typically water vapor (steam) exit.

[0067] The exact arrangement of the heat pipes within the hot section or cold section allows for many arrangements. The flow of cracked gas in the hot section can be across or normal to the heat pipes, along or parallel the heat pipes or a combination. There can also be baffles within the vessel to aid in flow distribution and/or heat transfer around the heat pipe(s) hot end. The cold section can have numerous entry and exit configurations as well. The heat pipe(s) hot and cold ends could have fins on their exterior surface to improve heat transfer to the heat pipe between the cracked gas or boiler water. The section of the heat pipe between the hot section and cold section vessels (10) can be straight or have bends (“Z”) or twists (helical) to allow for thermal expansion of the heat pipe(s) and vessels. In FIG. 1 the cold section is shown directly above the hot section, however, the heat pipes can be bent such that the two vessels are offset from each other.

[0068] Arrangements of the nature described allow the hot section and cold section of the heat transfer device to be decoupled with respect to design. The hot section vessel, geometry of the hot end heat pipe(s), baffles, fins, etc. can be optimized for removing heat from the cracked gas independent of the requirements for the cold section. The temperature, pressure and erosive characteristics of the cracked gas will direct the designer to specific materials, wall thickness and dimensions of the vessel and heat pipe(s) hot end. A similar comment applies to the cold end which also has additional demands due to the corrosive nature of high temperature boiler feed water. Both can be optimized independently or semi-independently due to the separation allowed by the efficient transfer of heat by the heat pipe(s) from hot to cold end(s). The heat pipe(s) can be welded to the vessel where they penetrate and will be at a relatively uniform temperature; this is unlike a conventional heat

exchanger's tube sheet which would have the hot temperature on one side and the cold temperature on the other side which creates considerable differential temperature induced stresses that might require material selection based on structural strength vs. optimal for heat transfer, erosion or corrosion. The dimensional changes due to temperature can be accommodated by bends, etc. mentioned above or by mounting of either or both of the hot and cold section vessels on flexible supports.

[0069] The hot end, the cold end or both of the heat pipe may be modified to increase the heat transfer to or from, the heat pipe respectively.

[0070] In one embodiment the ends of the heat pipe may have one or more longitudinal fins. The fins, independently have

[0071] i) a length from 10 to 100% of the length of the hot or cold end or both of the heat pipe;

[0072] ii) a cross section that is selected from the group consisting of a parallelogram, a triangle, and a trapezoid;

[0073] iii) a base having a width from 3% to 30% of the outer diameter of the heat pipe, which base has continuous contact with, or is integrally part of the heat pipe;

[0074] iv) a height from 10% to 50% of the outer diameter of the heat pipe, and

[0075] v) a weight from 3% to 45% of the total weight of the heat pipe.

[0076] The fins could be straight or could be spiral about the hot or cold end of the heat pipe. Preferably the fin is made of the same metal or a metal compatible with the heat pipe. The fins may be cast as part of the heat pipe or cold be joined to it by a suitable means such as welding.

[0077] In a further embodiment the hot end, the cold end or both of the heat pipe could have annular fins or ribs. Typically, the fins or ribs have:

[0078] (i) a ratio of the rib height to the diameter of the heat pipe (e/D) from 0.05 to 0.35, preferably from 0.1 to 0.35;

[0079] (ii) a ratio of the distance between the leading edge of consecutive ribs to rib height (P/e) less than 40 preferably from 2 to 20, most preferably from 4 to 16; and

[0080] (iii) a ratio of the thickness of the rib to the height of the rib (t/e) from 0.5 to 3 preferably from 1 to 2.

[0081] The ribs may be machined into the heat tube or cast as a part of the heat tube, or welded onto the heat tube.

[0082] In a further embodiment the hot or cold end or both of the heat pipe could have the external surface of the heat pipe augmented with plurality of low profile protuberances, said protuberances having:

[0083] i) geometrical shape, having a relatively large external surface that contains a relatively small volume, (such as e.g. tetrahedrons, pyramids, cubes, cones, etc.);

[0084] ii) a maximum height from 3.0% to 15% of the outer diameter of the heat pipe;

[0085] iii) a base area, which is a surface in contact with the heat pipe, that should not exceed 0.1%-10% of the outer cross section area of the heat pipe.

[0086] The protuberance may have geometrical shape, having a relatively large external surface that contains a relatively small volume, such as for example tetrahedrons, pyramids, cubes, cones, a section through a sphere (e.g. hemispherical or less), a section through an ellipsoid, a section through a deformed ellipsoid (e.g. a tear drop), etc. Some useful shapes for a protuberance include:

[0087] a tetrahedron (pyramid with a triangular base and 3 faces that are equilateral triangles);

[0088] a Johnson square pyramid (pyramid with a square base and sides which are equilateral triangles);

[0089] a pyramid with 4 isosceles triangle sides;

[0090] a pyramid with isosceles triangle sides (e.g. if it is a four faced pyramid the base may not be a square it could be a rectangle or a parallelogram);

[0091] a section of a sphere (e.g. a hemi sphere or less);

[0092] a section of an ellipsoid (e.g. a section through the shape or volume formed when an ellipse is rotated through its major or minor axis);

[0093] a section of a tear drop (e.g. a section through the shape or volume formed when a non uniformly deformed ellipsoid is rotated along the axis of deformation); and

[0094] a section of a parabola (e.g. section through the shape or volume formed when a parabola is rotated about its major axis—a deformed hemi-(or less) sphere), such as e.g. different types of delta-wings.

[0095] The selection of the shape of the protuberance is largely based on the ease of manufacturing the heat tube. One method for forming protuberances on the pass is by casting in a mold having the shape of the protuberance in the mold wall. This is effective for relative simple shapes. The protuberances may also be produced by machining the external surface of a cast tube such as by the use of knurling device for example a knurl roll.

[0096] The protuberances are solids.

[0097] In a further embodiment the hot or cold end of the heat tube, or both may have an array of pins parallel to the longitudinal axis of the tube, said pins having:

[0098] i) a height from about 12% to about 50% of the outer diameter of the heat pipe; (typically from 2 cm to 4.8 cm (0.80 inches to 1.90 inches));

[0099] ii) a contact surface with the tube, having an area from 0.1%-10% of the external cross section area of the heat pipe; and

[0100] iii) length to diameter ratio from 4:1 to 2:1

[0101] In a further embodiment the distance between consecutive pins within a given linear array is from 1 to 5 times the maximum cross section of the pin.

[0102] The pins or studs may have any cross section such as a quadrilateral (e.g. rectangular or square) or round or oval. Typically, the pin or stud will have a length from about 12 to 50% of the outer diameter of the heat pipe, typically from 2 to 4.8 cm (0.80 inches to 1.90 inches). The base of the pin may cover from 0.1 to 10%, preferably from 1 to 8%, most preferably from 2 to 5% of the external cross section of the pipe or tube. The length to diameter ratio of the pin may be from 4:1 to 2:1 typically from 4:1 to 3:1. In a longitudinal array the spacing of the pins may be from 5 D (diameter of the pin) to D/10, typically from 0.5 D to 5 D, preferably from 1 D to 3 D. However, it should be noted that in any array the spacing of the pins need not be uniform. For example, the spacing could be wider at the middle of the tube and closer towards the end of the tube.

[0103] Other arrangements are shown in FIGS. 2A, 2B and 3 in which like parts have the same designations as FIG. 1. FIG. 1 is reminiscent of a Transfer Line Exchanger (TLE) in which the cracked gas from one or more furnace cracking coils flows through a heat exchanger with multiple tubes. In

some of the figures the arrangement provides is one heat transfer system per coil or multiple, separate boiling sections.

[0104] FIG. 2B shows an arrangement in which the hot end of the heat pipe is formed by an annular space surrounding the cracked gas flow which is in a tube or pipe. This arrangement has structural, heat transfer and erosive benefits. This is reminiscent of an ultra-selective exchanger (USX) wherein the cooling medium is boiling water.

[0105] FIG. 3 shows obviously, the arrangement of the hot section and cold section connected by a heat pipe can have numerous configurations composed of rearrangement of what is seen below.

[0106] In some embodiments it may be desirable to have the cold end of the heat pipe give up its energy to an intermediate heat transfer fluid to prevent for example hot sodium being in contact with water in the event of a pipe rupture at the cold end of the heat pipe.

INDUSTRIAL APPLICABILITY

[0107] Gases from a cracking furnace may be cooled using heat pipes which reduces the potential for rupture of the transfer line exchanger.

1. A heat exchanger for use with a hot fluid stream leaving a high temperature process comprising a hot section and a cold section which have no common or adjoining external surfaces wherein one or more heat pipes extend from the interior of the hot section traverse the open space between the hot section and cold section at an angle of inclination from 10° to 90° and extend into the cold section.

2. A heat exchanger according to claim 1, wherein the temperature differential between the hot section and the cold section is not less than 200° C.

3. The heat exchanger according to claim 2, wherein the hot section is at a pressure from 85 to 150 kPa gage and a temperature from 800° C. to 1000° C.

4. The heat exchanger according to claim 3, wherein the cold section is at a temperature from 250° C. to 600° C. and a pressure from 5 to 9 MPa.

5. The heat exchanger according to claim 4, wherein the fluid passing through the hot section is cracked gas.

6. The heat exchanger according to claim 5, wherein the fluid in the cold section is water.

7. The heat exchanger according to claim 6, wherein the working fluid in the heat pipe is selected from the group consisting of sodium, potassium, and cesium.

8. The heat exchanger according to claim 7, wherein the heat pipes have an outer diameter from 1 cm (0.5 inches) to 10 cm (4 inches).

9. The heat exchanger according to claim 8, wherein the heat pipe has a length up to 10 meters.

10. The heat exchanger according to claim 7, wherein the heat pipe has one or more of internal capillaries and internal wicking.

11. The heat exchanger according to claim 10, wherein the end of the heat pipe in the hot section has a surface resistant to coking.

12. The heat exchanger according to claim 11, wherein the end of the heat pipe in the hot section has a surface having a thickness from 100 to 5,000 microns comprising from 40 to 60 weight % of compounds of the formula $Mn_xCr_{3-x}O_4$ wherein x is from 0.5 to 2 and from 60 to 40 weight % of oxides of Mn and Si selected from the group consisting of

MnO, $MnSiO_3$, Mn_2SiO_4 and mixtures thereof provided that the surface contains less than 5 weight % of Cr_2O_3 .

13. The heat exchanger according to claim 12, wherein the heat pipe comprises from about 55 to 65 weight % of Ni; from about 20 to 10 weight % of Cr; from about 20 to 10 weight % of Co; and from about 5 to 9 weight % of Fe and the balance one or more of the trace elements.

14. The heat exchanger according to claim 13, wherein the heat pipe further comprising from 0.2 up to 3 weight % of Mn; from 0.3 to 2 weight % of Si; less than 5 weight % of titanium, niobium and all other trace metals; and carbon in an amount of less than 0.75 weight % the sum of the components adding up to 100 weight %.

15. The heat exchanger according to claim 12, wherein the heat pipe comprises from 40 to 65 weight % of Co; from 15 to 20 weight % of Cr; from 20 to 13 weight % of Ni; less than 4 weight % of Fe and the balance of one or more trace elements and up to 20 weight % of W the sum of the components adding up to 100 weight %.

16. The heat exchanger according to claim 15, wherein the heat pipe further comprising from 0.2 up to 3 weight % of Mn; from 0.3 to 2 weight % of Si; less than 5 weight % of titanium, niobium and all other trace metals; and carbon in an amount of less than 0.75 weight %.

17. The heat exchanger according to claim 12, wherein the heat pipe comprises from 20 to 38 weight % of chromium from 25 to 48, weight % of Ni.

18. The heat exchanger according to claim 17, wherein the heat pipe further comprising from 0.2 up to 3 weight % of Mn, from 0.3 to 2 weight % of Si; less than 5 weight % of titanium, niobium and all other trace metals; and carbon in an amount of less than 0.75 weight % and the balance substantially iron.

19. The heat exchanger according to claim 11, wherein at least a portion of the heat pipe between the hot section and the cold section is helical.

20. The heat exchanger according to claim 11, wherein at least a portion of the heat pipe between the hot section and the cold section is in the shape of a "Z".

21. The heat exchanger according to claim 9, wherein there is thermal insulation on the heat pipe between the hot box and the cold box.

22. The heat exchanger according to claim 10, wherein the wick is made of nickel, copper, molybdenum, niobium, aluminum, iron, cobalt or alloys based on these metals, and ceramic.

23. The heat exchanger according to claim 22, wherein the wick has a pore size from 50 to about 1,000 microns

24. The heat exchanger according to claim 23, where in the wick has a bi modal pore size the first pore size is from 300 to 700 microns and the second pore size from 0.5 to 50 microns.

25. The heat exchanger according to claim 10 having on its hot end, its cold end or both a surface modification selected from the group consisting of fins, ribs, protuberances and pins.

26. The heat exchanger according to claim 10, wherein the distance between the hot section and the cold section is from 30 cm to 6 meters.

27. A heat pipe having on its hot end, its cold end or both a surface modification selected from the group consisting of fins, ribs, protuberances and pins.

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