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[54] **HEAT EXCHANGER FOR COOLING HOT GASES**

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[51] **Int. Cl.²** **F28F 13/00**

[58] **Field of Search** .... 165/74, 75, 134, 135, 156, 165/180; 431/DIG. .011, DIG. .012, 9, 115, 12; 126/109; 122/149

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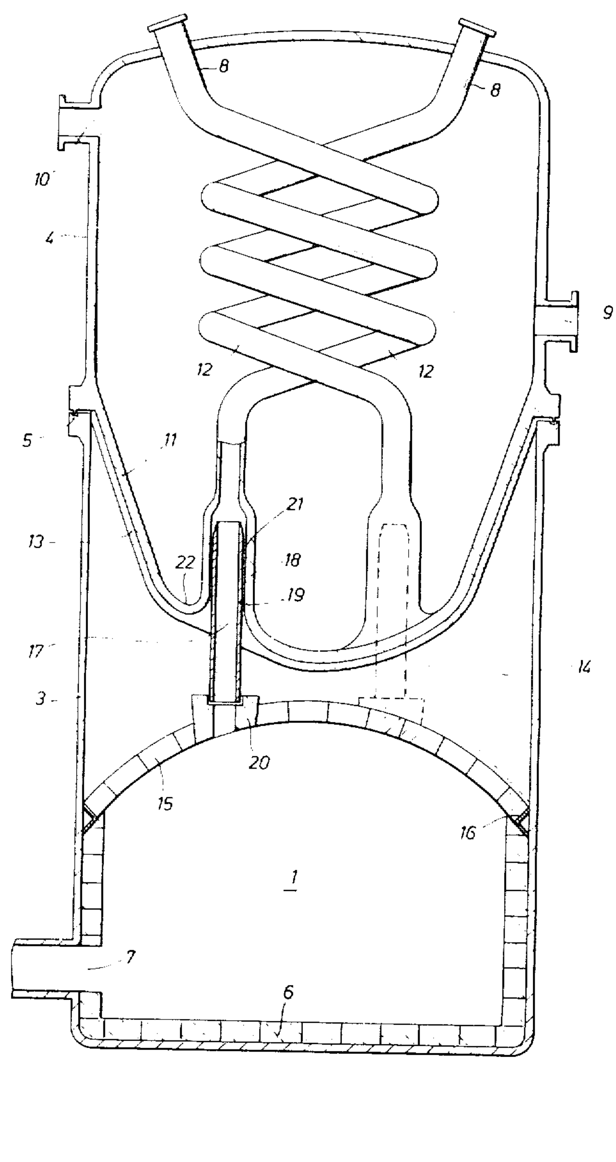
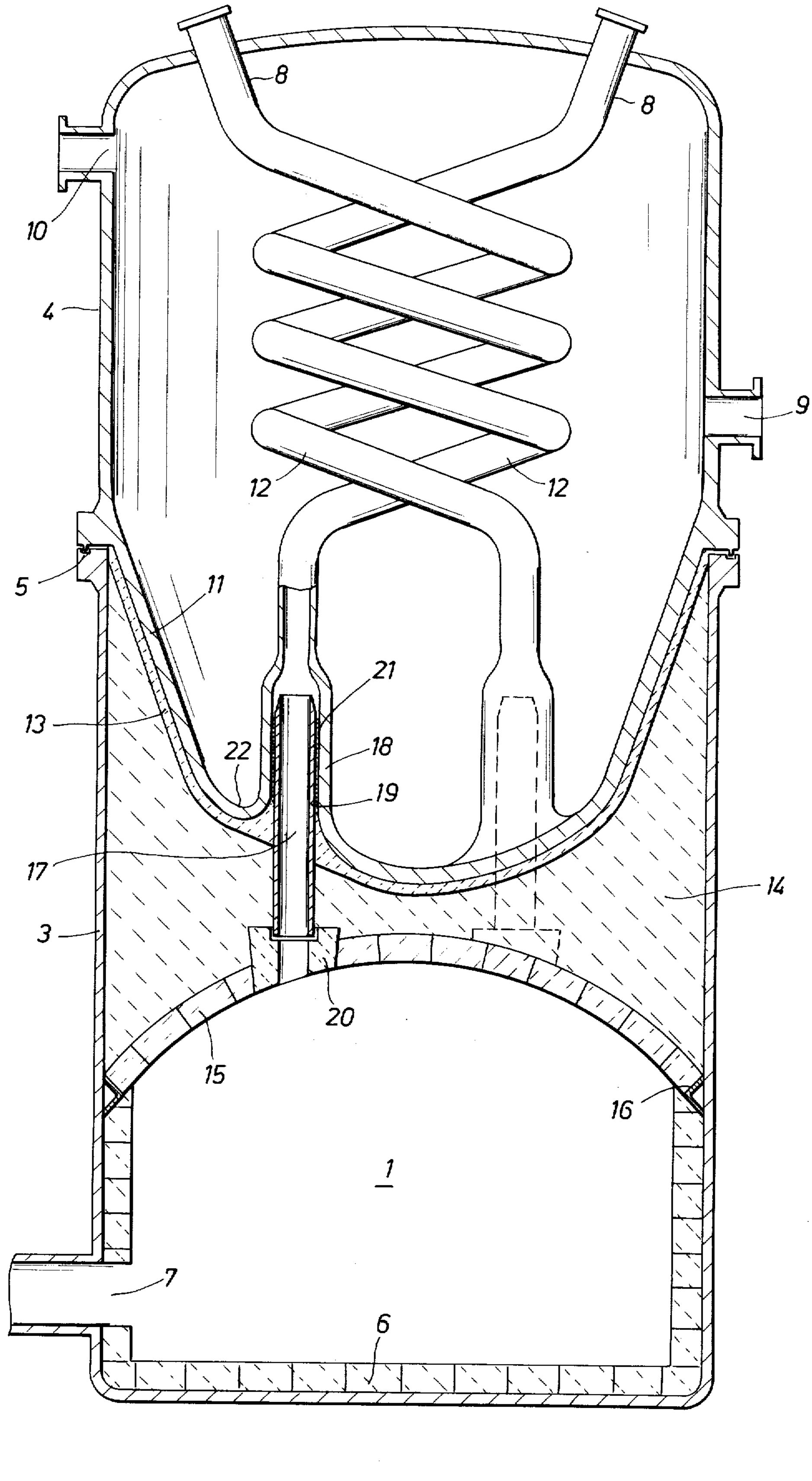
[57] **ABSTRACT**

A heat exchanger especially adapted for cooling of hot gases at a high pressure differential between the hot gases being cooled and the coolant is described wherein the hot gases pass from a gas inlet chamber, into a cooling chamber via one or more gas tubes extending through the interior of the cooling chamber, said cooling chamber being supplied continuously with coolant and being separated from the gas inlet chamber by means of a gas inlet plate, both the surface of the gas inlet plate exposed to the gas inlet chamber being provided with a refractory cladding and the initial lengths of the inner surfaces of the gas tubes being provided with refractory linings.

15 Claims, 1 Drawing Figure

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HEAT EXCHANGER FOR COOLING HOT GASES

BACKGROUND OF THE INVENTION

The present invention relates to an apparatus for cooling hot gases. More particularly, it relates to a heat exchanger having utility in the cooling of extremely hot gases, such as hot gases produced by the partial combustion of hydrocarbons wherein the heat exchange surface is subject to high pressure and thermal stresses.

For economic reasons it is very often desirable to operate a heat exchanger cooling hot gases at a high pressure differential between the hot gases being cooled and the coolant. This occurs, for example, in the case of a heat exchanger which uses water as the coolant and in which, for reasons of efficiency, steam having a much higher pressure than the gases being cooled is generated. Such operation, however, imposes a very severe mechanical strain on the heat exchanger primarily because of the high temperature and high pressure differential conditions under which it operates and, consequently, the design of such a heat exchanger poses a major technical problem. The gas inlet plate and the initial length of the gas tube of the heat exchanger are subjected to the most severe conditions since it is these parts of the heat exchanger which experience the highest temperature. Accordingly they must be designed so as to withstand these conditions.

In the case of heat exchangers having small diameters where the force on the gas inlet plate due to the high pressure differential is relatively low it is possible to overcome the above-mentioned design problem by increasing the thickness, and therefore, the strength of the metal of the gas inlet plate and the gas tubes. However, with large diameter heat exchangers in which the force on the gas inlet plate due to the high pressure differential becomes very high this expedient is no longer practical or even viable because increasing the thickness of the metal also has the effect of increasing the average temperature of the metal and thus reducing its strength. The strengthening effect of using thicker metal is then more than offset by the weakening effect of the higher average temperature of the metal. The present invention provides a heat exchanger which simply and economically overcomes this design problem and allows safe operation even in very large diameter heat exchangers.

SUMMARY OF THE INVENTION

The present invention therefore relates to a heat exchanger for cooling hot gases comprising a gas inlet chamber provided with one or more gas inlets, a cooling chamber provided with one or more gas outlets, a gas inlet plate which forms a common wall and separates the gas inlet chamber from the cooling chamber and to which one or more gas carrying tubes extending through the interior of the cooling chamber are connected and project through to provide fluid communication with the gas inlet chamber, and one or more pipes for coolant supply to and discharge from the cooling chamber; the surface of the gas inlet plate exposed to the gas inlet chamber being provided with a refractory cladding and the initial lengths of the inner surfaces of the gas tubes, including at least the surfaces in the vicinity of their connection with the gas inlet plate, being provided with refractory linings. The average temperature of the metal of the gas inlet plate and the metal of the initial lengths of the gas tubes is thereby maintained at a low level with the result that the pressure differential which the heat exchanger can withstand is significantly increased. The average temperature of the metal of the gas inlet plate and of the gas tubes is defined as the average of the temperatures existing on the metal surface on the gas side and the metal surface on the coolant side of the gas inlet plate and of the gas tubes, respectively.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An essential feature of the present invention is that at least the inner surfaces of the gas carrying tubes in the vicinity of their connection with the gas inlet plate, otherwise expressed as the end of the gas carrying tubes in fluid communication with the gas inlet chamber, are provided with refractory linings. Since the surfaces of the gas inlet plate exposed to the gas inlet chamber are also provided with a refractory cladding, both the metal of the gas tubes and the metal of the gas inlet plate in the vicinity of the connection of the gas tubes with the gas inlet plate do not come into direct contact with the hot gases. The temperature of the metal of the gas inlet plate and the gas tubes in the vicinity of the connection is therefore low. This is important because the connection, in most cases a weld, is one of the most vulnerable parts of a heat exchanger to failure because of the large thermal stresses which occur in the neighborhood of the weld, particularly at high temperatures. According to the present invention, however, these thermal stresses are very much reduced because of the low temperature of the metal which results in the vicinity of the weld. The heat exchanger according to the present invention therefore allows operation at high pressure differentials without risk of the weld failing.

In addition to merely lowering the temperature of the metal in the vicinity of the weld the present invention allows, by suitable selection of the thickness and thermal conductivity of the refractory cladding and refractory linings, the temperature of the metal of the gas inlet plate and the metal of the gas tubes in the vicinity of the weld to be substantially equalized during operation. As a result the thermal stresses occuring at the weld are to a large extent eliminated and the strength of the weld is greatly increased. In this way the heat exchanger according to the present invention allows safe operation at very high gas temperatures and pressure differentials such as, for example, a gas temperature of 1500°C and a pressure differential of more than 100 atmospheres.

Any suitable refractory linings may be used in the ends of the gas carrying tubes in fluid communication with the gas inlet chamber according to the present invention. Particularly preferred refractory linings comprise hollow refractory elongated cylinders, one end of the cylinders being inserted into the gas tubes and the other end being held in position by the refractory cladding. The main advantage of such refractory linings lies in the ease with which they can be installed in and removed from the initial lengths of the gas tubes. This derives from the fact that the hollow refractory elongated cylinders are loose inserts and are not directly attached to the inner surfaces of the gas tubes. It is therefore a relatively simple procedure during shutdown to replace worn inserts either with similar new inserts or with inserts having a different thickness or thermal conductivity if, for example, a change in operating conditions is envisaged.

The initial lengths of the inner surfaces of the gas tubes which are refractory lined depend largely on the operating conditions for which the heat exchanger is designed. Preferably however they lie between one and fifteen times the inner diameter of the gas tubes. The thickness and thermal conductivity of the refractory linings may vary widely although preferably the thickness lies between **5** and **25** percent of the inner diameter of the gas tubes and the thermal conductivity lies between **40** and **0.4** kcals/m.h.°C. Any suitable refractory material may be used for the refractory linings, as, for example, a silica alumina composite. A particularly preferred refractory material is a high-alumina fused-mullite composition which is highly resistant to thermal shock, erosion and chemical attach by slags.

It is, of course, desirable that the refractory linings do not take up too large a proportion of the total cross-sectional area of the gas tubes since the total flow of gases which can pass through the gas tubes is then very much reduced. Accordingly, it is advantageous to use relatively thin refractory linings. However, this often means that the insulating effect of the refractory linings is not sufficient to reduce the temperature of the metal of the gas tubes as far as is desired. In such a case it is advantageous to position thin layers of highly insulating material between the inner surfaces of the gas tubes and the refractory linings. In this way desired insulating effect is achieved while at the same time the combination of the refractory linings and the thin layers of highly insulating material is relatively thin. Preferably the thickness of the thin layers of highly insulating material lies between **0.5** and **10** millimeters and the thermal conductivity lies between **0.05** and **0.5** kcals/m.h.°C. A particularly suitable highly insulating material is a ceramic fiber paper based on aluminum silicate fiber.

The gas inlet plate to which the gas tubes are connected and project through to provide fluid communication with the gas inlet chamber may have any shape and, for example, may be flat. However, in order to maximize its strength and therefore increase the pressure differential at which the heat exchanger can be allowed to operate preferably at least that part of the gas inlet plate to which the gas tubes are connected is substantially spherically-shaped. A further preferred embodiment aimed at maximizing the strength of the heat exchanger is that the gas tubes are preferably connected to and project through the gas inlet plate such that no part of the tubes protrudes into the gas inlet chamber.

Any suitable refractory material or materials may comprise the refractory cladding which protects the gas inlet plate from the hot gases present in the gas inlet chamber. A particularly suitable refractory cladding comprises a thin layer of a compressible refractory material immediately adjacent to the gas inlet plate and a thick layer of a substantially non-compressible refractory material covering said thin layer. An advantage of this form of refractory cladding is that the thin layer of compressible refractory material allows for thermal expansion of the gas inlet plate and being compressible does not transmit movement due to expansion of the gas inlet plate to the non-compressible thick outer layer exposed to the hot gases in the gas inlet chamber. The rigid outer layer and its support are therefore not sub-

jected to stresses and strains on account of thermal expansion of the gas inlet plate and are accordingly strengthened.

The thickness of the thin layer of compressible refractory material may be chosen between wide limits with the limitation that it should be thick enough to absorb any expansion of the gas inlet plate occurring during operation. Preferably its thickness lies between **10** and **100** millimeters. The thickness of the thick layer varies between even wider limits and depends of course to a large extent on the thermal conductivity of the material used. A thickness within the range of **50** and **1,000** millimeters is preferred however. The thermal conductivity of the material of the thin layer preferably lies between **0.1** and **0.5** kcals/m.h.°C. and the thermal conductivity of the material of the thick layer preferably lies between **0.3** and **3** kcals/m.h.°C. Particularly preferred materials comprising the thin layer are ceramic fiber blanket and/or ceramic fiber wool and for the thick layer, insulating refractory castable.

Any suitable means may be used in order to hold the refractory cladding in position against the gas inlet plate on the gas inlet chamber side of the common wall formed by the gas inlet plate disposed between the gas inlet chamber and the cooling chamber. In a preferred embodiment of the present invention where the cooling chamber is positioned vertically above the gas inlet chamber within a substantially cylindrical vessel the refractory cladding covering the gas inlet plate is supported by an ark of refractory bricks consisting of an outer ring of inwardly and upwardly directed support bricks resting on a support rim secured to the wall of the vessel and a number of inner rings of successively more inwardly inclined bricks rising to form an apex at the center of the vessel, each ring of bricks being supported by the ring of bricks immediately below it and held in position by the weight of the ring of bricks immediately above it. The advantage of this form of support is that it is self-supporting and does not need to be connected by to the gas inlet ties inlet plate. The problem of local heat spots occurring on the gas inlet plate around the connecting points of the metal ties caused by direct conduction of the heat of the hot gases via the metal ties to the gas inlet plate does not therefore arise. This means that potential weak points of the gas inlet plate in the form of these heat spots are eliminated and the gas plate accordingly strengthened.

As has already been mentioned the heat exchanger according to the present invention is very suitably sealed up and may have a very high diameter by present-day standards. Accordingly, heat exchangers designed according to the present invention may have diameters in excess of **4** meters and still be able to operate at high temperatures and pressure differentials without risk of the gas inlet plate or the gas tubes failing. The diameter of the heat exchangers according to the present invention preferably lies between **1.5** and **3** meters. The number of gas tubes and the inner diameter of the gas tubes may vary widely but preferably lie between **4** and **20** and **70** and **200** millimeters, respectively.

The heat exchanger according to the present invention is designed to operate at high temperatures and high pressure differentials. Such temperatures range for example from **700°C**. to **1,600°C** or more. The pressure differentials are usually above **20** atmospheres and preferably between **25** and **150** atmospheres. Any suitable coolant may be used in the heat exchanger although water is generally preferred.

The present heat exchanger is particularly suitable for use as a waste heat boiler for cooling hot gases produced by the partial combustion of hydrocarbons and simultaneously generating high pressure steam. In this case the pressure of the hot gases preferably lies between **10** and **100** atmospheres and the pressure of the steam generated preferably lies between **40** and **160** atmospheres. The temperature of the gases entering the cooling chamber preferably lies between **800°** and **1,500°C** and the temperature of the water entering the cooling chamber preferably lies between **20°** and **360°C**.

As has been discussed before the refractory cladding and refractory linings are preferably installed such that the hot gases do not come into direct contact with the gas inlet plate or the initial lengths of the inner surface of the gas tubes. As a result the average temperature of the metal of the gas inlet plate and the metal of the initial lengths of the gas tubes is very easily kept below **500°C**. At or below this temperature the metal of the gas inlet plate and the gas tubes maintains a high strength. Preferably the thickness and thermal conductivity of the refractory cladding and the refractory linings are chosen such that the temperature differential between the gas tubes and the gas inlet plate in the vicinity of their connection with each other does not exceed **150°C**. As has previously been explained the connection (or weld) is then not significantly weakened by thermal stresses and strains.

The invention will now be further elucidated with reference to the drawing. This drawing which represents a preferred embodiment of the invention is intended to be illustrative of the invention rather than limiting on its scope.

The drawing illustrates a cylindrical heat exchanger comprising a gas inlet chamber **1** and a cooling chamber **2**. The metal casing of the gas inlet chamber is denoted by numeral **3** and of the cooling chamber by numeral **4**. The cooling chamber is positioned vertically above the gas inlet chamber the two metal casings thereof being connected to each other by a flange **3**. The gas inlet chamber, which is lined with refractory bricks **6**, is provided with a gas inlet **7**. The cooling chamber is provided with two gas outlets **8**, an inlet for coolant **9**, and outlet for coolant **10** and a gas inlet plate **11** which forms a common wall between the gas inlet chamber and the cooling chamber and to which two helical gas carrying tubes **12** extending through the interior of the cooling chamber are connected. The surface of the gas inlet plate exposed to the gas inlet chamber is provided with a refractory cladding comprising a thin layer of compressible refractory material **13** and a thick layer of substantially non-compressible refractory material **14**. The refractory cladding is supported by an ark of refractory bricks **15** the outer bricks of which are supported by a metal rim **15** attached to the cooling chamber casing.

The heat exchanger has two gas inlets **17** in the gas inlet plate the left-hand of which is shown in half cross-section and the right-hand in half view. Referring to the left-hand gas inlet numeral **18** designates the initial length of the end of the gas carrying tube in fluid communication with the gas inlet chamber into which the hollow refractory elongated cylinder **19** is inserted. The bottom of this cylinder rests on a support brick **20** which is held in position by the ark of refractory bricks. Between the hollow refractory elongated cylinder and the inner surface of the initial length of the gas tube a thin layer of highly insulating material **21** is positioned.

The refractory cladding and refractory lining illustrated in this drawing ensures that the temperature of the gas inlet plate is maintained at a low level during passage of hot gases through the heat exchanger. In particular the weld **22** is kept at a low temperature, the metal of the gas inlet plate and the gas tube in the vicinity of the weld having a similar temperature level. The thermal stresses and strains to which the weld is prone are therefore very much reduced and the heat exchanger is thereby capable of operating safely at very high pressure differentials between the hot gases and the coolant.

What is claimed is:

1. A heat exchanger for cooling hot gases which comprises

a. A gas inlet chamber provided with at least one gas inlet;

b. A cooling chamber provided with at least one gas outlet;

c. A gas inlet plate disposed between said gas inlet chamber and said cooling chamber and forming a common wall with said chambers, the surface of said gas inlet plate exposed to said gas inlet chamber being provided with a refractory cladding;

d. At least one gas carrying tube having one end connected to and projecting through said gas inlet plate to allow fluid communication with said gas inlet chamber and having the other end extend through said cooling chamber to form the aforesaid gas outlet for said cooling chamber, the initial length of the inner surface of the end of the gas carrying tube in fluid communication with the gas inlet chamber being provided with a refractory lining, and

e. At least one pipe interconnected with said cooling chamber for coolant supply and discharge from the cooling chamber.

2. A heat exchanger according to claim **1**, wherein the initial lengths of the inner surfaces of the gas tubes which are refractory lined lie between one and fifteen times the inner diameters of the gas tubes.

3. A heat exchanger according to claim **2**, wherein the refractory linings comprise hollow refractory elongated cylinders, one end of the cylinders being inserted into the gas carrying tubes and the other end being held in position by the refractory cladding.

4. A heat exchanger according to claim **2**, wherein the thickness of the refractory linings lies between **5** and **25** percent of the inner diameters of the gas tubes and the thermal conductivity lies between **40** and **0.4** kcals/m.h.°C.

5. A heat exchanger according to claim **2**, wherein thin layers of highly insulating material are positioned between the inner surfaces of the gas tubes and the refractory lining.

6. A heat exchanger according to claim **5**, wherein the thickness of the highly insulating material lies between **0.5** and **10** millimetres and the thermal conductivity lies between **0.05** and **0.5** kcals/m.h.°C.

7. A heat exchanger according to claim **1**, wherein the gas tubes are connected to and project through the gas inlet plate such that no part of the tubes protrudes into the gas inlet chamber.

8. A heat exchanger according to claim 1, wherein the gas inlet plate disposed between the gas inlet chamber and the cooling chamber and forming a common wall with said chamber is substantially spherically-shaped.

9. A heat exchanger according to claim 5, wherein the refractory cladding comprises a thin layer of a compressible refractory material immediately adjacent to the gas inlet plate and a thick layer of a substantially non-compressible refractory material covering said thin layer.

10. A heat exchanger according to claim 9, wherein the thickness of the thin layer is sufficient to allow for thermal expansion of the gas inlet plate.

11. A heat exchanger according to claim 10, wherein the thickness of the thin layer lies between 10 and 100 millimeters.

12. A heat exchanger according to claim 11, wherein the thermal conductivity of the material of the thin layer lies between 0.1 and 0.5 kcals/m.h.°C and the thermal conductivity of the material of the thick layer

lies between 0.3 and 3 kcals/m.h.°C.

13. A heat exchanger according to claim 9, wherein the refractory material comprising the thin layer is ceramic fiber blanket and/or ceramic fiber wool.

14. A heat exchanger according to claim 13, wherein the refractory material comprising the thick layer is insulating refractory castable.

15. A heat exchanger according to claim 1, wherein the cooling chamber is positioned vertically above the gas inlet chamber within a substantially cylindrical vessel, the refractory cladding covering the gas inlet plate being supported by an ark of refractory bricks consisting of an outer ring of inwardly and upwardly directed support bricks resting on a support rim secured to the wall of the vessel and a number of inner rings of successively more inwardly inclined bricks rising to form an apex at the center of the vessel, each ring of bricks being supported by the ring of bricks immediately below it and held in position by the weight of the ring of bricks immediately above it.

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