Title: APPAREATUS FOR COOLING SOLIDS LADEN HOT GASES

Abstract:
A self-cleaning apparatus for cooling a solids laden hot gas. The apparatus comprises a vessel with a gas inlet and a gas outlet and a plurality of (convective) heat transfer surfaces, extending longitudinally and forming a plurality of gas passages. The overall cross-
sectional inlet area of the passages between the heat transfer surfaces decreases in the direction of decreasing process temperature in such a manner that the gas velocity is kept constant.
ABSTRACT

AN APPARATUS FOR COOLING SOLIDS LADEN HOT GASES

A self-cleaning apparatus for cooling a solids laden hot gas. The apparatus comprises a vessel with a gas inlet and a gas outlet and a plurality of (convective) heat transfer surfaces, extending longitudinally and forming a plurality of gas passages. The overall cross-sectional inlet area of the passages between the heat transfer surfaces decreases in the direction of decreasing process temperature in such a manner that the gas velocity is kept constant.

(fig. 1)
AN APPARATUS FOR COOLING SOLIDS LADEN HOT GASES

The present invention to an apparatus for cooling solids laden hot gases.

A solids laden gas is, for example, synthesis gas obtainable from a coal gasification process. The coal gasification process is a well-known process for partial oxidation of finely divided solid carbonaceous fuel wherein an oxygen-containing gas, which is applied as an oxidiser, and a finely divided solid carbonaceous fuel are supplied to a gasification zone wherein substantially autothermically under appropriate conditions of temperature and pressure a gaseous stream containing synthesis gas (which is substantially a gaseous mixture of hydrogen and carbon monoxide) is produced. Further, solid impurities such as fly ash particles are usually present in the synthesis gas. Such particles may be sticky. The oxygen-containing gas, which is applied as an oxidiser, is usually air or (pure) oxygen or steam or a mixture thereof.

The above partial oxidation reaction usually takes place in a gasification reactor. In order to control the temperature in the reactor a moderator gas (e.g. steam, water or carbon dioxide or a combination thereof) can be supplied to said reactor.

Those skilled in the art will know the conditions of supplying oxidiser and moderator to the reactor.

Advantageously, the said carbonaceous fuel (optionally with a moderator gas) and the said oxygen-containing gas, applied as oxidiser (optionally with a moderator gas) are supplied to the reactor via at least a burner. The hot raw effluent gas stream leaving the reactor, usually at or near its top, is optionally
quenched and is usually cooled in an indirect heat exchanger such as a convection cooler.

Conventionally, the raw gas stream is cooled off by means of convective heat transfer surfaces arranged in a gascooler located next to the gasification reactor and connected through a duct to the said reactor.

The gases are solids laden and therefore problems may arise with respect to erosion of the heat transfer surfaces (when the gas velocity is too high) or with respect to fouling/blocking the gas passages between the heat transfer surfaces (when the gas velocity is too low).

Generally, during cooling processes the gas velocity will decrease when operating at a constant throughput and pressure, to such an extent that fouling/blocking of the equipment may occur (e.g. by sticky particles) and expensive rapping devices are required to avoid fouling/blocking.

Therefore, there is a need for coolers which rely on a self-cleaning effect of the solids laden gas, are fouling/blocking-free and erosion-free and under normal operating conditions can be operated without the use of (complicated) rapping equipment.

The invention therefore provides an apparatus with reduced fouling and erosion for cooling a solids laden hot gas, said apparatus comprising a vessel with a gas inlet and a gas outlet and heat transfer structure comprising a plurality of heat transfer surfaces extending in the vessel between said inlet and said outlet in a longitudinal direction and forming a plurality of gas passages in the said structure, wherein the said plurality of heat transfer surfaces is arranged in such a way that the overall cross-sectional inlet area of the said gas passages in the said structure is larger than the overall cross-sectional outlet area between said gas passages and that
the said gas passages are arranged in such a manner that, in operation, the velocity of the gas flowing through the said gas passages, is kept substantially constant between the cross-sectional inlet area of the said gas passages and the cross-sectional outlet area of the said gas passages.

The invention will now be described in more detail by way of example by reference to the accompanying drawings, in which:

fig. 1 represents schematically a longitudinal section of a gascooler of the invention;

figs. 2a and 2b represent schematically partial side views of header arrangements applied in the gascooler of fig. 1;

figs. 3a and 3b represent schematically cross-sectional views of the heat transfer structure applied in the gascooler along the lines I-I and II-II respectively of fig. 1; and

fig. 4 represents a partial side view of an advantageous embodiment of a detail of figs 3a and 3b.

Referring to fig. 1 a vessel 1, made of any material suitable for the purpose, is shown. The vessel 1 has a vessel wall 1a and is provided at its upstream side with an inlet 2 for solids laden gas A from a reactor (not shown for reasons of clarity) and at its downstream side with an outlet 3 for cooled gas B which is supplied in any suitable manner to any suitable further gas treating and processing equipment (not shown for reasons of clarity). Advantageously, the inlet 2 is located at or near the top of vessel 1 and the outlet 3 is located at or near the bottom of vessel 1.

Generally, the gascooler is substantially cylindrical and arranged substantially vertically, but it will be appreciated by those skilled in the art that any arrangement suitable for the purpose can be applied. The
cooler 1 is internally provided in any suitable manner with a heat transfer structure comprising a plurality of panels 4 of (convective) heat transfer surfaces arranged in such a manner, that a plurality of gas passages 13 from said inlet to said outlet extending in downstream direction is provided (i.e. in the direction of decreasing process temperature). In particular, the arrangement of the heat transfer surfaces is such that the overall cross-sectional inlet area of the gas passages 13 is larger than the overall cross-sectional outlet area of the gas passages 13. For reasons of clarity only nine panels 4 have been shown in fig. 1 but it will be appreciated any number of panels suitable for the purpose can be applied. The height of the heat transfer structure is M, whereas the distances between the outer heat transfer surfaces of said structure are W1 (inlet) and W2 (outlet) respectively.

Advantageously, each panel 4 of heat transfer surfaces arranged in the gas cooler comprises a plurality of cooling tubes (not shown in fig. 1 for reasons of clarity) in mutual mechanical connection by any suitable means such as a webbing, through which tubes any suitable cooling fluid flows (e.g. water or steam, advantageously in counter current flow with the gas) and these panels are designed such that the cross-sectional areas of the passages between the heat transfer surfaces are in tapering arrangement aiming at keeping the gas velocity substantially constant, advantageously in the velocity region of 6-12 m/s. Advantageously, the tubes are provided with fins.

The overall cross-sectional area decrease of the gas passages between the said heat transfer surfaces is such that the gas flow A is smoothly directed to the said surfaces and the gas flow impingement represented by the arrow C on the heat transfer surfaces is at small angles
\( \alpha \) such that the gas flows substantially parallel to the said surfaces from erosion point of view. The angle \( \alpha \) is defined as follows:

\[
\alpha = \tan \frac{\frac{1}{2}(W_1 - W_2)}{M}
\]

An advantageous impact angle \( \alpha \) of the gas flow is 2.5 degrees.

The gascooler is provided at its one end with a plurality of inlet headers feeding the panels of cooling tubes with any suitable cooling medium.

The gascooler is provided at its other end with a plurality of outlet headers. For reasons of clarity the inlet headers, outlet headers and the mechanical connections of the tubes with said headers have not been shown in fig. 1.

Each end of a cooling tube of a panel is connected to an outlet header 6 and inlet header 5 respectively as will be explained in more detail below referring to figs. 2a and 2b.

Further, in practice, the arrangement of the panels and tubes is such that a so-called membrane pipe wall is formed, the (ring-shaped) inlet of which and the (ring-shaped) outlet of which have been represented schematically in fig. 1 by reference numerals 8 and 9 respectively. The membrane pipe wall forms within the vessel 1a a "cage" surrounding the said panels and will be shown in more detail below by reference to figs. 3a and 3b.

Fig. 2a represents a partial side view of the inlet header arrangement applied in the gascooler of the invention as shown in fig. 1. For reasons of clarity only 7 tubes have been shown. The inlet header 5 is in any
suitable manner connected to each cooling tube 10 of a panel 4. Reference numeral 1a represents the vessel wall. The tubes 10 of the panel 4 are mechanically connected via webbings 10a (e.g. by welding).

Further, the end or outer tube 10' of a panel 4 is part of the "cage" formed by the membrane pipe wall and is in fluid-connection to the inlet 8 (Fig. 1). The membrane pipe wall tube is not connected to the inlet header 5. It will be appreciated that where appropriate the tubes of the membrane pipe wall are suitably bent to provide space for the connecting tubes between the panel 4 and the inlet header 5.

Fig. 2b represents a partial side view of a similar arrangement for an outlet header 6 applied in the gascooler of the invention as shown in fig. 1. For reasons of clarity only 7 tubes have been shown. The same reference numerals as in fig. 2a have been used and where appropriate the tubes of the membrane pipe wall are suitably bent. The end or outer tube 10' is part of the "cage" and is in fluid-connection to the outlet 9 (fig. 1).

Fig. 3a represents a cross-sectional view of the arrangement of heat transfer surfaces along the line I-I of fig. 1. In this case thirteen panels 4 have been shown, each panel 4 comprising a plurality of cooling tubes 10 and end or outer tubes 10'.

The tubes 10 of each panel are connected via webbings 10a.

The end or outer tubes 10' of each panel 4 are connected to the end or outer tubes 10' of the adjacent panel 4 via tubes 7. The outer tubes 7 and 10' form the "cage" 11.

The tubes 7 (except two which are arranged in a symmetry-plane of the arrangement) are diminishing in diameter from top to bottom so that a tapering
arrangement and a sloping position of the panels 4 at both sides of a symmetry-plane are obtained. For reasons of clarity, only a limited number of tubes 10 of each panel 4 is represented.

Reference numeral 13 represents the gas passages between the heat transfer surfaces.

The panel distance C₁ at the inlet side of the panels is larger than the panel distance at the outlet side (C₂) due to the arrangement of tapering tubes 7 arranged between the outer tubes 10' of each panel 4.

Thus, the cage overall dimensions are V x W₁ (inlet) and V x W₂ (outlet) wherein W₁ > W₂ and V remaining constant.

Fig. 3b represents a top view of the outlet header arrangement of fig. 1. The same reference numerals have been used as in previous figures.

Fig. 4 represents an advantageous embodiment (partially represented) of a tapering tube 7 of the "cage", arranged between the outer tubes 10' of each panel 4 (vide figs. 3a and 3b). Z represents a tapered webbing.

The diameter of the tube 7 decreases gradually from inlet end to outlet end with a suitable tapering angle β (e.g. 2.5°) for the plurality of tapered parts of the said tube. In an advantageous embodiment of the invention the diameter of the tube is gradually decreasing in downflow direction from 60 to 30 mm and the length M is 25-35 m.

It will be appreciated by those skilled in the art that any number of headers suitable for the purpose can be applied. E.g. two headers per panel of tubes can be used.

It will also be appreciated by those skilled in the art that the invention is not restricted to counter
current flow of the cooling fluid with the process gas. Advantageously, co-current flow can be applied.

In an advantageous embodiment of the invention the webbings between the tubes are provided with openings. More advantageously, the webbings are 25-90% open.

Various modifications of the present invention will become apparent to those skilled in the art from the foregoing description. Such modifications are intended to fall within the scope of the appended claims.
CLAIMS:

1. An apparatus with reduced fouling and erosion for cooling a solids laden hot gas, said apparatus comprising:
   a vessel with a gas inlet and a gas outlet and a heat transfer structure,
   said heat transfer structure comprising a plurality of heat transfer surfaces extending in the vessel between said inlet and said outlet in a longitudinal direction and forming a plurality of gas passages in said structure,
   wherein said plurality of heat transfer surfaces is arranged in such a way that the overall cross-sectional inlet area of said gas passages in said structure is larger than the overall cross-sectional outlet area between said gas passages, and said gas passages being arranged in such a manner that, in operation, the velocity of a gas flowing through said gas passages is kept substantially constant between the cross-sectional inlet area and the cross-sectional outlet area of said gas passages.

2. The apparatus as claimed in claim 1, wherein the vessel is substantially cylindrically shaped.

3. The apparatus as claimed in claim 1 or 2, wherein the vessel is arranged substantially vertically.

4. The apparatus as claimed in any one of claims 1 to 3, wherein the gas inlet is at or near the top of the vessel and the gas outlet is at or near the bottom of the vessel.

5. The apparatus as claimed in any one of claims 1 to 4, wherein the heat transfer structure is a membrane pipe wall.

6. The apparatus as claimed in any one of claims 1 to 5, wherein the heat transfer surfaces are convection heat transfer surfaces.
7. The apparatus as claimed in any one of claims 1 to 6, wherein each heat transfer surface comprises panels of cooling tubes through which, in operation, a cooling medium flows.

8. The apparatus as claimed in claim 7, wherein, in operation, the cooling medium is in counter current flow with a gas flowing through said gas passages.

9. The apparatus as claimed in claim 7 or 8, wherein the cooling medium is water or steam.

10. The apparatus as claimed in any one of claims 1 to 4, wherein the heat transfer structure comprises a plurality of spaced-apart panels of cooling tubes in a cage arrangement.

11. The apparatus as claimed in any one of claims 1 to 10, wherein the overall cross-sectional area of the gas passages between adjacent heat transfer surfaces decreases gradually in downstream direction, thus forming a tapering arrangement of heat transfer surfaces.

12. The apparatus as claimed in any one of claims 1 to 11, wherein the gas velocity is in the range of 6 to 12 m/s.

13. The apparatus as claimed in claim 11 or 12, wherein said heat transfer surfaces are arranged under an angle $\alpha$ wherein:

$$\alpha = \tan \frac{1}{2}(W_1 - W_2)/M;$$

$M$ being the height of the heat transfer structure; and $W_1$ and $W_2$ representing the distances between the outermost heat transfer surfaces of said heat transfer structure at its inlet and outlet, respectively.

14. The apparatus as claimed in claim 13, wherein $\alpha$ is not larger than 2.5°.