PATENT SPECIFICATION

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(54) METHOD AND APPARATUS FOR RECOVERY OF WASTE HEAT FROM COKE OVENS

(71) We, BERGWERKSVERBAND G.m.b.H., of Franz-Fischer-Weg 61 Essen (formerly of Frillendorfer Strasse 351), and DIDIER ENGINEERING G.m.b.H., of Alfredstrasse 28, Essen, both of Germany (Fed. Rep.), and both German Bodies Corporate, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method of recovery of waste heat from coke ovens, and to an aparatus therefore.

It is known to heat indirectly the stationary coal lining in a coke oven after the charging into the chambers. The heat necessary for the coking is created by the combustion of heating gases in heating flues, which are constructed from the walls of the coking chamber by girders arranged at right angles thereto. The heat is conveyed to the chamber walls by radiation and convection from the flame and the reaction products. It then reaches the inside of the chambers by conduction, from where it is again transmitted, substantially by conduction, to a lesser extent by convection through the degassing products acting as heat transfer media, and by solid body radiation. This form of heating, because of the high coking end temperatures of approx. 1000 to approx. 1200°C, leads inevitably to high waste gas temperatures.

The recovery of the heat contained in the waste gases occurs in known manner either in periodically operating regenerators or in continuously driven recuperators. In these, the air required for combustion, and, in some cases, the combustion gases, are pre-heated. Because of the high temperatures which obtain in the coke oven, these units are constructed of ceramic materials. The heat transport in the ceramic storage material of a regenerator occurs by conduction, likewise in the recuperator, through the partitions between the heat-exchanging media, waste gas and air.

With ceramic regenerators and/or recuperators in the coke oven construction there exists the possibility of recovering the waste gas heat in a most extensive manner and conveying it back again to the combustion process. However, a drawback is that, for example due to the use of the ceramic material, a high capital expenditure is necessary. Because of the desired extensive heat recovery, the regenerators or recuperators must have a considerable constructional height. Due to the sealing problems which exist, the use of ceramic materials for the refrigerators or recuperators does not permit large pressure differences on the gas sides. This has the consequence that the heat-exchanging gases can only be conveyed with small or moderate flow speed. The deficiencies of sealing which arise in some cases due to the pressure differences of the heat-exchanging media may present a source of danger or may considerably lower the combustion efficiency.

The heat-exchange in the high temperature region on the waste gas side could theoretically be determined principally by radiation of the waste gas components, water vapour and carbon dioxide. However, in this region of the heat exchange, the ceramic material of the partitions or of the storage masses impedes the heat flux, due to the high heat conduction resistance of these materials. Moreover, the spaces in which the gas radiation is the predominant influence on the transfer of heat are so constructed, for reasons of space-saving, that no large layer thicknesses for the gas radiation are available. Thus the intensity of the heat radiation cannot be fully utilized. This inevitably causes a shift of the share of the heat transmission by gas radiation to heat transmission by convection, in respect of which the heat transfer coefficients are lower than those which apply in the case of gas radiation. The consequences of this are larger constructional volumes and higher costs.

The heat transmission coefficient in the low temperature region on the waste gas side could theoretically be raised by increase of the degree of turbulence, by means of which convection heat is transmitted. However, this can only be achieved by an increase in the flow speed. But the ceramic material of known coke ovens excludes the possibility of such a raising of the degree of turbulence, on account of the above-mentioned deficiences in sealing.

The relatively high excess of air, which is necessary due to the current relationships in operation of the usual coke ovens, which have regenerators or recuperators equipped with ceramic material, reduces the firing efficiency. It would be desirable to have a nearly stoichiometric conversion of combustion gas and oxygen from the air, resulting in a low oxygen content of the waste gases and thereby in an optimum firing efficiency. However, for the reasons mentioned above, coke ovens of the known type of construction do not permit such a combustion setting.

The present invention provides a method of recovering heat from a coke oven by carrying out heat transmission from the waste gas of the coking process in two stages, wherein the waste gas is cooled down in a first stage, being a heat recovery section constituted by a recuperator or regenerator of the coke oven, only to a temperature of not less than about 400°C, preferably not less than about 800°C, a heat-absorbing fluid, preferably air, flowing at comparatively high speed in the first stage while the waste gas flows at comparatively low speed so that the waste gas gives up its heat predominantly by radiation, and wherein the waste gas is further cooled down in a second stage, being a separate heat-exchanger, preferably a directly opeating heat-exchanger, through which a heat-absorbing medium passes and in which the waste gas flows at a relatively high spped so that the waste gas gives up its heat predominantly by convection.

The basic concept of the above invention is therefore to avoid the waste gas from the coke oven being fully cooled down in the recuperator or regenerator of ceramic material which is provided, but to use the recuperator or regenerator only for the heat transmission in the high temperature region, in which the heat transmission takes place chiefly by radiation; then, at a temperature at which the efficiency of the radiation approaches the economically lower limit, they are led out of the recuperator or regenerator and supplied, for further cooling-down, e.g. to approx. 180°C to approx. 2000°C, to a heat exchanger which itself can be optimally constructed for the low temperature region for the heat recovery by convection. The method according to the invention has therefore, with respect to the known method of procedure in coke ovens with regenerators or recuperators which carry out a single-stage complete cooling down of the waste gases, the considerable advantage that both basic principles of heat recovery, namely that of heat recovery by radiation and that of heat recovery by convection can each be utilized in an optimal manner. Because of the fact that, in the regenerators or recuperators belonging to the coke ovens, the cooling down of the waste gases only occurs down to a relatively high temperature, i.e. to a temperature of not less than approx. 400°C, these recuperators or regenerators can have a substantially lower height than those of the usual coke ovens, thus enabling the capital cost to be reduced by up to 20%. Coking ovens suitable for the carrying out of the invention accordingly possess a heat recovery section of height lying as a maximum at 1/3—1/6 of the height of the oven chamber, whereas in the normal case the height of the heat recovery section is about the same as that of the oven chamber.

The further cooling-down, as will be made clear hereinbelow, can be carried out in apparatus which must in any case be provided at the coke oven and which functions by utilizing predominantly convection. No additional capital costs are therefore required to replace the sections of the regenerator or recuperator which are dispensed with.

When above mention is made of "predominant utilization of the heat radiation" or "predominant utilization of convection", these terms are to be understood in the sense of the invention to mean that in the first stage the heat transmission, in comparison with the usual regenerators or recuperators, depends to an increased proportion on heat radiation and in the second stage, in comparison with the usual regenerators or recuperators, depends to an increased proportion on convection. When further in the above connection mention is made of a "practically complete cooling down of the waste gas", what is meant is a cooling-down of the waste gases such as formerly usually took place in regenerators or recuperators.

As the first stage there is preferably employed a recuperator which operates, on the waste gas side, in a temperature between about 1450°C and about 400°C, preferably between about 1300°C and about 800°C, and, on the air side, between about ambient temperature and about 700°C. In these temperature ranges there is achieved, on the waste gas side, optimum heat recovery by utilization of the heat radiation of the waste gas, a recuperator with waste gas channels which are of relatively large cross-section can be used as the first stage. This increase in the layer thicknesses of the waste gas current results in an increased intensity of heat radiation. "Relatively large cross-section" means in this connection that the cross-section of the waste gas channels, taking into account all the circumstances of the apparatus, is larger than that in the known recuperators. These have a cross-section of about 0.025 m^2, whereas the cross-section of the waste gas channels of the recuperators of the invention may be about 0.05 m^2 to about 0.15 m^2, preferably 0.1 m^2.

To raise the convection heat transmission coefficients on the air side a recuperator may be used which has air channels of relatively small cross-section, to increase the air stream speed. "Relatively small cross-section" has in this connection a meaning corresponding to that explained above of the term "relatively large cross-section", i.e. that the cross-section of the air channels according to the invention may be about 0.01 m^2 or less, while hitherto the cross-section of the air channels has been about 0.025 m^2.

The heat recovery in the first stage can be further improved in comparison with the usual regenerators or recuperators by using as a first stage a recuperator which employs relatively thin closely arranged (or "dense") partitions between the heat-exchanged media, waste gas and air, of a material of high heat conductance, preferably metal. The use of thin partitions between the heat-exchanging media, made of a metal with high heat conductance, ensures good and rapid heat conduction from the waste gas to the air. The provision of closely-arranged partitions makes it possible for a nearly stoichiometric combustion process to take place, even with large pressure differences of the heat-exchanging media. When in this connection mention is made of "relatively thin" and "material of high heat conductance" these terms are again to be seen in comparison with the corresponding factors of the usual regenerators or recuperators. The partitions should therefore be "thin" in comparison with the ceramic partitions provided in the usual recuperators, and the partition material in the invention should have a higher heat conductance than the ceramic material which is usually employed. In particular steele is specially suitable, because from steel for example tubular, thin, and closely arranged (or "dense") partitions can be made, and metal in the sense of the invention has a high heat conductance. A so-constructed, continually operated, metal recuperator affords the possibility of 10 to 30-fold reduction of the resistance to heat transmission with respect to ceramic materials due to the higher heat conduction coefficient and additionally of 5 to 15-fold reduction due to the decreased wall thickness. Additionally, the metal recuperator offers the possibility of permitting high pressure differences between the heat-exchanging media, which enables an increase in the flow speed on the combustion air side. These two effects result in a diminution in the size of the heat exchanging surfaces of known heat exchanging parts with respect to ceramic recuperators or regenerators.

As the second stage there is preferably employed a heat-exchanger with relatively thin, closely arranged ("dense") partitions between the heat-exchanging media, if the heat absorbing medium is also gaseous. A material with relatively high heat conductance, preferably metal, can be used for the partitions or the partitions between the heat-exchanging media can be dispensed with, if the heat-absorbing medium is not gaseous but is, for example, solid. The terms "relatively thin" or "relatively high heat conductance" are again to be understood in the same sense as above, namely in comparison with the usual regenerators or recuperators of ceramic material. In contrast with the heating-up of the chamber lining, where heat is only transmitted by conduction and to a lesser extent by convection, the second stage of the heat recovery of the invention is so constructed that an optimum in respect of convective heat transmission to the heat-abosorbing medium, for example a charge, is made possible. The quantity of heat used by the waste gases in the heat recovery section of the coke oven after cooling down to approx. 400—800°C for air pre-heating can be easily replaced by increased heating of the heating flues.

To ensure this convective heat transmission, there is advantageously used as the second stage a heat exchanger which, on the waste gas side, operates with relatively high flow speed. "Relatively high" means here that the flow speed of the waste gas in comparison with that in the usual regenerators or recuperators in the second stage should, according to the method of the invention, be higher, and may amount to about 20—60 m/sec.

As the second stage use may be made for example of a heat exchanger, in which the directly heated heat-absorbing medium (charge) has a relatively large heat conductance, e.g. is preferably coal. As is known, coal has a higher heat conductance coefficient than ceramic materials, so that it is particularly suited for the charge in the second stage. At the same time this solution—charge coal—offers the possibility of combining a coke oven with a substantially lower recuperator, out of which the waste gas is taken off at a still relatively high temperature, with a coal pre-heating device which is in any case present or necessary, this coal pre-heating device is supplied with waste gas which is only partially cooled down in the recuperator for a further heat recovery. In this connection it is clear that the outlay for the further cooling down of the waste gas from about 800°C to about 200°C in the recuperator can be dispensed with, considerable capital costs thereby being saved. Additionally, the efficiency of heat recovery, both in the remaining short section of the recuperator, and in the attached pre-heating device, is substantially greater than in the usual recuperators of full length, in which the waste gases are practically completely cooled down. An improved efficiency also contributes to a saving of capital costs.

Thus as the second stage a "flying stream", a fluidized bed, or a spray-bed apparatus with fine coal as the heat-absorbing medium can be used. Such apparatuses have proved best as apparatuses with optimum utilization of convection heat transmission. Since in these the speed of the heat-absorbing medium and the heat-releasing medium relative to each other is as high as possible.

As the second stage, there can also for example be used a low-temperature coking apparatus or coal gasification device, as the "fall-off heat" of the coke oven is cheaper than heat in the form of primary energy.

If this is advantageous or necessary, the partially cooled waste gas removed from the first stage, before it is transferred to the second stage, can also be cooled down by admixture of preferably inert gases such as nitrogen, carbon dioxide, or water vapour, or mixtures of these gases, or may be supplied with heat by addition of combustion gases.

The preferred combination of a metal radiation recuperator for only partial heat recovery of the sensible waste gas heat of coke ovens in connection with a coal pre-heating device, which for example comprises a "flying stream", a fluidized bed, or a spray bed apparatus, provides optimum heat recovery in coking. From the standpoint of economy, the pre-heating apparatus represents the second part of the heat recovery with a total heat balance which remains constant. The total amount of gas to be burnt remains constant. Thus the saving in regenerator and recuperator costs "for the region below 400°C, preferably in the region below 800°C", can contribute to the capital costs of "flying stream", fluidized bed, or spray bed heating of the charge. If it is assumed that the capital costs of a corresponding coal pre-heating device are equal to the said savings, each percent of production increase by pre-heating, which, as is known, can amount to up to 60%, works out as a proportional capital cost saving in the region of 0 to 30% for the coke-producing part of the coking. A particular technical advance can also be therefore seen from the fact that the introduction of the pre-heating of coal has results not only in increased production but in particular also in broadening of the coking coal palette.

The invention will be further explained, by way of example, for the case of the combination of a recuperative coke oven with a coal pre-heating device, with reference to Figure 1 of the accompanying drawings.

Gas (2) is burnt in the heating flues of the coke oven (1) with air (4) which has been pre-heated in the metal recuperator (3) from 20°C to 900°C. The waste gases (5) enter the recuperator (3) with a waste gas temperature depending on the coking conditions which obtain in the case in question and which is between 1,450°C and 1,400°C. Cold combustion air (6) abstracts heat from the waste gases (5) and is heated from 20°C up to 900°C. The waste gases (5) are thereby cooled to waste gas temperatures of 600°C to 400°C. With these temperatures, the waste gases (7) enter the coal pre-heating device (8), in which they are again cooled down to temperatures of 250°C. With these temperatures the waste gases (9) enter the atmosphere.

The charged coal (10) abstracts the heat of the waste gases (7) and is heated to about 150°C to 250°C. This pre-heated coal (11) is charged into the coke oven. After the coking period corresponding to the selected coking conditions, the coke (12) leaves the coke oven (1).

Figure 2 diagrammatically shows a possible system of a suitable recuperator.

The waste gas from a heating flue of a coke oven enters the recuperator through the open surface (A), which forms the cross-section of the radiation chamber (C). This cross-section has an area of between 0.05 m^2 and 0.15 m^2.

The air which is to be heated for each heating flue of the coke oven enters the recuperator through the cross-section (B). This cross-section (B) can be formed of several cross-sections (B_1-B_4). The sum of the cross-sections for an individual heating flue do not exceed an area of about 0.1 m^2.

WHAT WE CLAIM IS:—

1. A method of recovering heat from a coke oven by carrying out heat transmission from the waste gas of the coking process in two stages, wherein the waste gas is cooled down in a first stage, being a heat recovery section consitituted by a recuperator or regenerator of the coke oven, only to a temperature of not less than about 400°C, preferably not less than about 800°C, a heat-absorbing fluid, preferably air, flowing at comparatively high speed in the first stage while the waste gas flows at comparatively low speed so that the waste gas gives up its heat predominantly by radiation, and wherein the waste gas is further cooled down in a second stage, being a separate heat-exchanger, preferably a directly operating

heat-exchanger, through which a heat-absorbing medium passes and in which the waste gas flows at a relatively high speed so that the waste gas gives up its heat predominantly by convection.

2. A method as claimed in claim 1, wherein, as the first stage, use is made of a recuperator, which operates on the waste gas side in a temperature range between about 1450°C and about 400°C, preferably between about 1300°C and about 800°C, and on the heat-absorbing-fluid side between about ambient temperature and about 900°C, preferably between about ambient temperature and about 700°C.

3. A method as claimed in claim 1 or 2, wherein the recuperator has waste gas channels of relatively large cross-section.

4. A method as claimed in any of claims 1 to 3, the recuperator has channels of relatively small cross-section which carry the heat-absorbing fluid.

5. A method as claimed in any of claims 1 to 4, wherein, as the first stage, use is made of a recuperator which employs relatively thin, closely arranged partitions between the heat exchanging media, waste gas and heat-absorbing fluid, of a material of high heat conductance, preferably metal.

6. A method as claimed in any of claims 1 to 5, wherein, as the second stage, use is made of a heat exchanger with relatively thin, closely arranged partitions between the heat-exchanging media, if the heat-absorbing medium is also gaseous, of a material with relatively high heat conductance, preferably metal, or entirely without partitions between the heat-exchanging media, if the heat-absorbing medium is not gaseous but for example, solid.

7. A method as claimed in any of claims 1 to 6, wherein, as the second stage, use is made of a heat-exchanger, in which the directly heated heat-absorbing medium (charge) has a relatively large heat conductance, e.g. is coal which is to be pre-heated.

8. A method as claimed in claim 7, wherein, as the second stage, use is made of a flying stream, a fluidized bed, or a spray bed apparatus with fine coal as the heat-absorbing medium.

9. A method as claimed in any of claims 1 to 6, wherein, as the second stage, use is made of a low-temperature coking device or coal gasification device.

10. A method as claimed in any of claims 1 to 9, wherein the partially cooled-down gas removed from the first stage, before the transfer into the second stage, is cooled down by admixture of preferably inert gases, such as nitrogen, carbon dioxide, or water vapour, or mixtures of these gases, or is supplied with heat by burning of combustion gases.

11. A coke oven with a heat recovery section for the performance of the method according to any of claims 1 to 10, wherein the heat recovery section is a maximum of 1/3 of the height of the oven chamber.

12. A coke oven as claimed in claim 11, including a recuperator whose waste gas channels have a cross-section of about 0.05 m^2 to about 0.15 m^2, preferably 0.1 m^2.

13. A coke oven as claimed in claim 11 or claim 12, wherein the heat-absorbing-fluid channels of the recuperator have a cross-section of about 0.01 m^2 or less.

14. A coke oven as claimed in any of claims 11 to 13, wherein the partition of the recuperator between the waste gas and the heat-absorbing fluid consists of a metal, in particular steel.

15. A method of recovering heat from a coke oven, substantially as herein described with reference to the accompanying drawings.

MARKS & CLERK.

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1596488 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

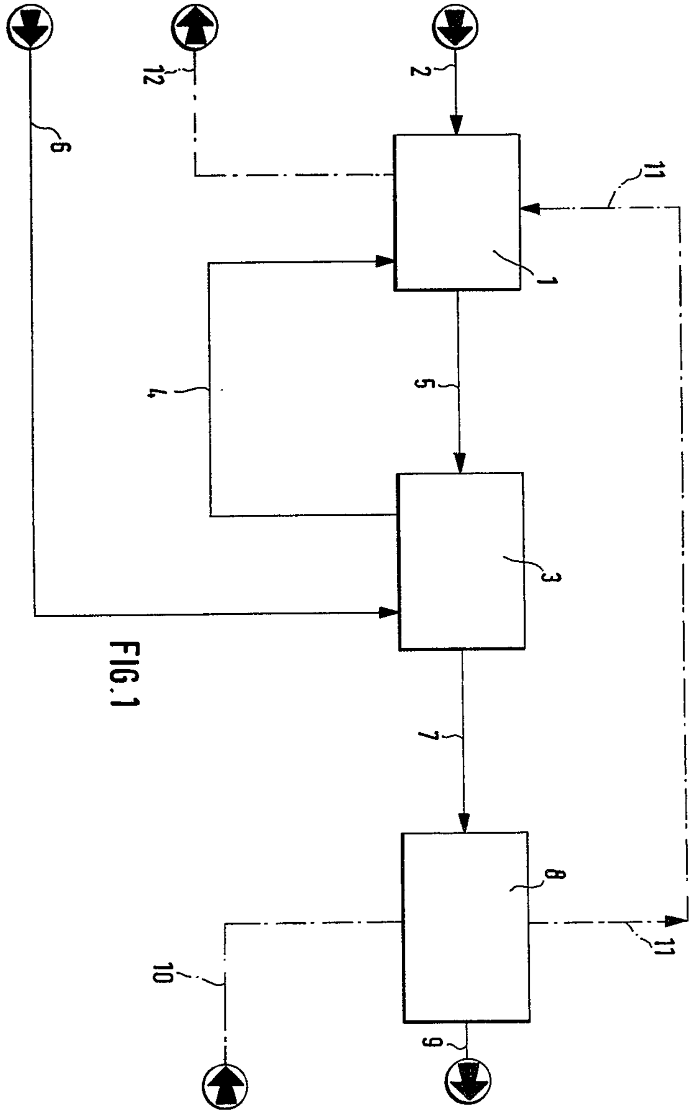

FIG.1

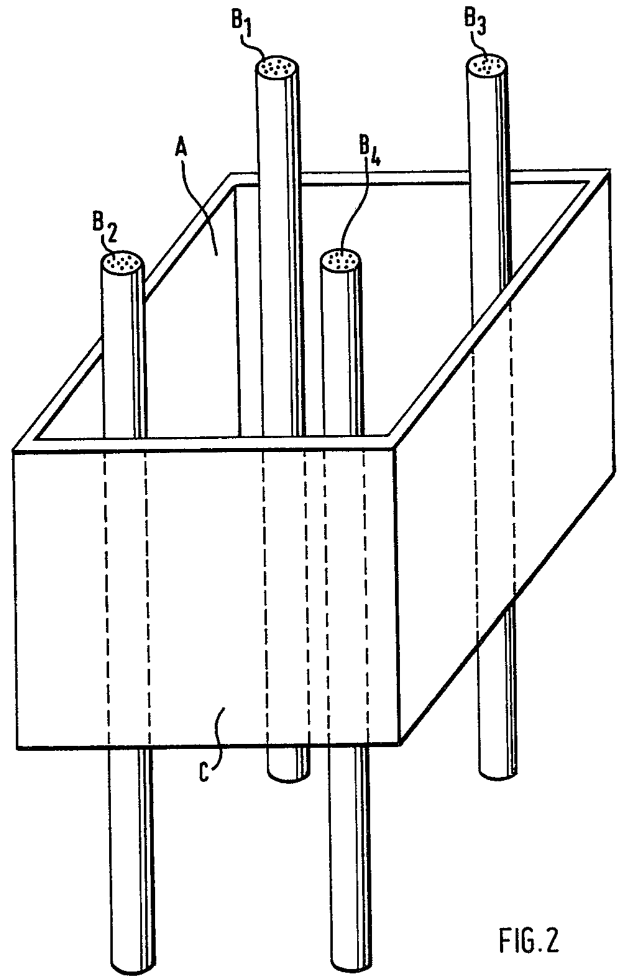

FIG. 2