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(54) METHOD AND APPARATUS FOR HEATING PARTICULATE SOLIDS

(71) I, JOHN EVINSON WHITE, a British subject, of 17½ Brambledown Road, South Croydon, Surrey, CR2 0BN, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

Particulate solids are heated for various reasons, for example, in order to effect drying, reduction or dissociation, e.g. of minerals, or incineration of combustible solids, and a wide variety of techniques has been used or proposed. In all cases, irrespective of subsidiary difficulties, a fundamental difficulty has been to achieve efficient heat transfer to the solids and any improvement in this respect is always desirable. This is true not only for endothermic processes such as calcining limestone but also for the initial stages of exothermic processes such as incineration of carbonaceous matter, e.g. dried sewage sludge. Efficiency of heat transfer to particulate solids has various aspects. First, it is desirable that as high a proportion as possible of the heat energy supplied should be utilised in heating the solids. Secondly, as part of the heat energy supplied is inevitably wasted in the first instance, it is desirable that the apparatus used should permit efficient recovery of as much of this waste heat as possible. Thirdly, the method of heating usually should ensure that not only the surface but also the interior of the particles are adequately heated. Fourthly, the method of heating should be such that all the particles are heated uniformly since, otherwise, either the product will be heterogeneous or the majority of the particles will have to be excessively heated in order to ensure that the minority are at least adequately heated. Fifthly, it is desirable that the rate of heat transfer should be high.

A method according to the invention for heating particulate solids comprises supplying combustible gas from a combustor, in which the gas is made by partial combustion of a fuel, through a nozzle into the open inlet end of a venturi, supplying to the inlet end of the venturi particulate solids entrained in a gas and burning the combustible gas in the venturi, thereby heating particulate solids drawn into the venturi. Apparatus according to the invention for heating particulate solids comprises a venturi having an open inlet end, a combustor for partial combustion of a fuel to give a combustible gas, the combustor having an outlet nozzle for supplying the combustible gas into the venturi inlet end, means for feeding particulate solids towards the venturi inlet end and means for entraining the particulate solids in gas and for supplying the entrained solids to the venturi inlet end.

As explained in more detail below the solids and gas leaving the downstream end of the venturi are normally separated and the separated gas may be used to preheat in a fluidised bed particulate solids that are to be entrained and supplied to the inlet end of the venturi.

The method and apparatus according to the invention have the advantage that heat is actually generated in the gas phase in which the particulate solids are entrained and thus very efficient heat transfer to the solids can be achieved as the rate of heat production in the venturi can be balanced with the rate of heat transfer to the solids in the venturi.

The outlet from the nozzle and the inlet end of the venturi are preferably within an entrainment chamber having an inlet for particulate solids and an inlet for entraining gas under pressure. Conveniently the entrainment of the solids in the gas is effected by supplying the gas beneath a fluidised bed base in the entrainment chamber and supplying the solids above the base, the outlet from the nozzle and the inlet end of the venturi being above the fluidised bed base. Whilst it is convenient to term the base a "fluidised bed base", the object is not to form a stable fluidised bed of the particulate solids in the entrainment gas but rather to form above the base a loose, mobile dispersion or fog of the solids in the gas, this dispersion readily being drawn into the venturi.

Instead of the arrangement described above for providing particulate solids entrained in a gas, the particulate solids may be so supplied that they become directly entrained in the flow of combustible gas leaving the nozzle. In this case a separate supply of entrainment gas is unnecessary although, in any case, it may be desirable to supply a gas in addition to the combustible gas to the venturi inlet end.

The nozzle for supplying the combustible gas is desirably the outlet from a combustor in which a fuel, e.g. a hydrocarbon fuel such as oil, a liquefied petroleoum gas or natural gas, is partially burned. Combustors are well known that are suitable for this purpose. The hot combustible gas formed in the combustor is under pressure and the nozzle results in an enormous increase in the gas velocity. The low pressure zone resulting from the high velocity stream of gas entering the venturi ensures that the gas-entrained solids are drawn into the venturi.

To enable the combustible gas to burn in the venturi a source of oxygen is required and the way in which this is provided depends to some extent on the nature of the solids to be heated and the desired object. If, for example, the heating is to effect drying e.g. of sand or to effect dissociation e.g. of calcium carbonate to calcium oxide and carbon dioxide, oxygen-containing gas must be supplied to the inlet end of the venturi. This object can very conveniently be achieved by using an oxygen-containing gas e.g. air for the entrainment of the particulate solids. However, a feature of the method that renders it versatile is the use of the combustible gas: since the gas is combustible and poor in oxygen, it is a reducing agent and thus the method can be used where the object of the heating is to reduce the solids for example to reduce a metallic oxide e.g. ferric oxide to a lower oxide e.g. ferrous oxide or to the metal. Where the method is used to effect a reduction the necessary source of oxygen for combustion of the combustible gas can be provided by the solids themselves. In this case a supply of oxygen-containing gas is not necessary apart from during any initial heating up stage and, if desired, the entrainment gas may be oxygen-free, e.g. nitrogen.

Usually it is desirable to produce an attenuated flame throughout substantially the entire length of the venturi and this can be achieved in various ways. For a given supply of combustible gas and entrainment gas, the flame length can be controlled by recycling part of the exhaust gas with the entrainment gas thereby, assuming that the entrainment gas is oxygen-rich e.g. air, attenuating the flame. Alternatively, flame attenuation can be achieved by having an annular feed around the nozzle and supplying recycled exhaust gas or other oxygen-poor gas to this so that it emerges around the combustible gas emerging from the nozzle.

The venturi has a diffuser portion that is preferably generally frustoconical in shape, its cross-section gradually increasing away from the throat of the venturi The cross-sectional area of the combustor nozzle outlet should be smaller than that of the venturi throat and the nozzle and venturi should substantially be in alignment. A cone angle for the diffuser portion in the range of 6 to 10 degrees tends to minimise vortex formation in the diffuser portion but I have found that some vortex formation is desirable in order to achieve the most efficient heat transfer and, for this reason, I prefer that the cone angle should be from 12 to 15 degrees.

The outlet of the diffuser portion of the venturi communicates with means for separating the heated solids from the exhaust gases, conveniently a multi-cyclone or series of cyclones. The heat of the solids leaving the separating means may be used to pre-heat the supply of air or other oxygen-containing gas for the combustor, the air for example passing along a duct in contact with an outlet duct for the separated solids. Alternatively or additionally, the heat of the separated solids may be used to pre-heat the entrainment gas.

The method is applicable to situations where the object is to burn or incinerate the particulate solids. In this case, depending on the nature of the initial solids, the product solids may be only a small fraction of the weight of the initial solids especially if the latter are chiefly carbonaceous matter. For incineration it will usually be appropriate to use an oxygen-rich gas system, so as to achieve high temperatures, and pure oxygen may be used as entrainment gas or additional gas. The method is particularly suitable for the incineration of dried sewage sludge and in this case it is desirable that the entrainment gas should be air, oxygen-enriched air or even oxygen and recycling of exhaust gas is preferably avoided. Furthermore, in this case, if any additional supply of gas is fed through an annular feed around the nozzle, this gas is preferably air, oxygen-enriched air or oxygen.

The dried sewage cludge is preferably entrained in the entrainment chamber, preferably containing a fluidised bed base and operated as already described. The dried sewage sludge may be obtained in various ways but, after subjecting sewage sludge to an initial dewatering step, it is preferred to subject the sludge to flash-drying in a fluidised bed, then to disintegrate the sludge and then to dry it in a further fluidised bed or beds before feeding it to the entrainment chamber. The type of layout of fluidised beds shown in Figure 1 of Specification No. 1,490,518 is particularly suitable for the flash-drying and subsequent drying, the dewatered sludge being supplied to the uppermost fluidised bed 6 for the flash-drying, the subsequent drying being effected in fluidised beds 9, 13 and 15 and the product leaving the apparatus at 21 and then being fed to the entrainment chamber used in accordance with the present invention. The disintegration may be effected by use of a twin squirrel cage pin mill built into the apparatus between fluidised beds 6 and 9 of the apparatus just described. As described in Specification No. 1,490,518, one or more of the fluidised beds used in accordance with that application may be heated indirectly by use of heat exchange ducts in addition to any heat supplied by use of hot fluidising gas.

The exhaust gases leaving the cyclone or other separating means are hot and it is advantageous to use this heat to pre-heat the particulate solids before they are supplied, entrained in gas, to the venturi. Conveniently, this is achieved by using the hot exhaust gases to heat and maintain one or more fluidised beds of the particulate solids, the particulate solids leaving this fluidised bed or the last of these fluidised beds then being supplied, for instance, above the fluidised bed base in the entrainment chamber. Alternatively, or additionally the hot exhaust gas may be used to run a boiler.

The invention is further described with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of apparatus embodying the invention;

Figure 2 is a longitudinal section through the apparatus according to the invention;

Figure 3 is a cross-section at A—A of Figure 2;

Figure 4 is a plan section of part of a modified form of the apparatus of Figures 2 and 3.

Figure 5 is a cross-section at B—B of Figure 4;

Figure 7 is a view at X of Figure 4 and

Figure 7 is an enlargement of part of the section shown in Figure 4.

Referring to Figure 1, combustor 1 has hydrocarbon fuel and air supply means 2 and 3 respectively, and the fuel and air supplies are so adjusted that only partial combustion of the fuel occurs, the product thus still being a combustible gas. Hot combustible gas formed by the combustor emerges through nozzle 4 into the inlet end of venturi 5, the venturi being aligned with the nozzle and having a bell-shaped inlet 6, a throat 7, and a diffuser portion 8. An open-ended annular space around the end of the nozzle is defined by wall 19 and, at the upstream end of this space, is a chamber 10 which may be supplied with gas through duct 11.

The outlet from the nozzle 4 and the inlet end of the venturi are within entrainment chamber 12 which is supplied with entrainment gas, e.g. air, through duct 13. Beneath the nozzle outlet and venturi inlet but above the inlet for the entrainment gas is fluidised bed base 14. Particulate solids are supplied to the entrainment chamber through chute 15 and the flow of entrainment gas is so adjusted that the particulate solids are entrained in the entrainment gas to form a mobile dispersion rather than a stable fluidised bed and this dispersion is sucked into the inlet of the venturi by virtue of the low pressure zone created by the combustible gas emerging from the nozzle. The combustible gas is burnt in the venturi and the entrained particulate solids thereby heated in the venturi.

The heated solids entrained in hot exhaust gas pass from the outlet from the venturi to a multi-cyclone 16 where the solids are separated from the gas. The hot, separated solids leave the multi-cyclone by a broad, shallow duct 17 underneath which is a duct 18, also broad and shallow, for the supply of combustion air via fan 19 and the duct 3 to the combustor 1.

The exhaust gases leave the multi-cyclone 16 via duct 20, emerge beneath a fluidised bed base 21 and serve to fluidise and heat particulate solids on this base. The solids leave the fluidised bed over weir 22 and thus pass into the chute 15 for supplying the solids to the entrainment chamber 12. The solids are supplied to fluidised bed base 21 via a chute 23 into which solids from an upper fluidised bed over fluidised bed base 24 pass over a weight 25. The particulate solids are supplied to fluidised bed base 24 from a hopper 26 via a chute 27 and the gas leaving the lower fluidised bed serves to heat and fluidise the particulate solids of the upper fluidised bed.

In the upper part of the fluidised bed there may be a tubular heat exchanger, having hot and cold headers Hh and Hc. The heat recovered by the heat exchanger may be used to pre-heat the entrainment gas or the air supplied to the combsutor. The use of such a heat exchanger is practicable because in a fluidised bed the gas/solid system reaches an isothermal state very near the base of the bed and negligible useful heat transfer to the solids occurs higher in the bed.

Gas leaving the upper fluidised bed passes through duct 28 to multi-cyclone 29 where particulate solids entrained in the gas are separated. The gas then passes via duct 30 to fan 31, beyond which some of the gas may be recycled via duct 32, optionally with the assistance of a further fan 33, to the chamber 10. Some or all the gas leaving the fan 31 passes through heat exchanger 34 where it pre-heats air subsequently fed via duct 35 and fan 36 to the entrainment chamber 12.

The apparatus described above is especially suitable for calcining limestone or other mineral forms of calcium carbonate to give calcium oxide and carbon dioxide.

In a simplified system of the type described above there is no annular space around the nozzle 4, nor is there a chamber 10 nor is there a duct 11. In this case the recycling duct 32 joins duct 35.

Figures 2 and 3 show in detail the structure of a suitable combustor, entrainment chamber and venturi for use in the simplified system just mentioned. Corresponding parts are given numbers corresponding to those in Figure 1. The fluidised bed base 14 has holes in which loosely fit hollow stemmed, hollow capped valves 37. In the absence of an adequate pressure of entrainment gas these valves remain closed, the caps resting on the upper surface of the fluidised bed base 14 and preventing the downward escape of particulate solids through the holes. With an adequate pressure of entrainment gas the valves lift and allow the entrainment gas to pass upwards and the pressure at which this occurs is such that there is virtually no tendency for particulate solids to fall downward through the holes. Valves of this type are described in more detail in my British Patent Specification No. 1,488,347.

Figure 4 shows in detail part of a combustor and venturi system suitable for use in the apparatus of Figure 1. Corresponding parts are given the same numbers as in Figure 1. In this case, as in Figure 1, there is an annular space (not shown) around the nozzle, defined by the wall 9, and a chamber 10. Figures 5, 6 and 7 are self-explanatory.

WHAT I CLAIM IS:—

1. A method for heating particulate solids comprising supplying combustible gas from a combustor, in which the gas is made by partial combustion of a fuel, through a nozzle into the open inlet end of a venturi, supplying to the inlet end of the venturi particulate solids entrained in a gas and burning the combustible gas in the venturi, thereby heating particulate solids drawn into the venturi.

2. A method according to claim 1 in which the venturi has a diffuser portion that is frusto-conical in shape.

3. A method according to claim 1 in which the cone angle of the diffuser portion is 12 to 15°.

4. A method according to any preceding claim in which the entrainment of the particulate solids in the gas is effected in an entrainment chamber having a fluidised bed base, below the nozzle and venturi inlet end, entrainment gas being supplied beneath the base and the solids to be entrained being supplied above the base.

5. A method according to any preceding claim in which at least part of the gas in which the particulate solids are entrained is exhaust gas which has left the downstream end of the venturi.

6. A method according to any preceding claim in which exhaust gas which has left the downstream end of the venturi is supplied into the open inlet end of the venturi through an annular feed around the nozzle.

7. A method according to any of claims 1 to 4 in which the gas in which the particulate solids are entrained is air, oxygen-enriched air or oxygen.

8. A method according to any of claims 1 to 4 and 7 in which air, oxygen-enriched air or oxygen is supplied into the open inlet end of the venturi through an annular feed around the nozzle.

9. A method according to any preceding claim in which the solids and gas leaving the downstream end of the venturi are separated, and the separated gas is used to preheat in a fluidised bed particulate solids that are to be entrained and supplied to the inlet end of the venturi.

10. A method according to claim 1 in which the particulate solid is calcium carbonate which is calcined in the method to give calcium oxide and carbon dioxide.

11. A method according to claim 1 in which the particulate solid is dried sewage sludge which is incinerated in the method.

12. A method according to claim 1 substantially as hereinbefore described and with reference to the accompanying drawings.

13. Apparatus for heating particulate solids comprising a venturi having an open inlet end, a combustor for partial combustion of a fuel to give a combustible gas, the combustor having an outlet nozzle for supplying the combustible gas into the venturi inlet end, means for feeding particulate solids towards the venturi inlet end and means for entraining the particulate solids in gas and for supplying the entrained solids to the venturi inlet end.

14. Apparatus according to claim 13 in which the nozzle and the venturi inlet end are within an entrainment chamber having an inlet for the particulate solids to be entrained and an inlet for an entrainment gas under pressure.

15. Apparatus according to claim 14 in which there is a fluidised bed base in the entrainment chamber, the inlet for the particulate solids being above the base and the

inlet for the entrainment gas being below the base, and the nozzle and the inlet end of the venturi are above the base.

16. Apparatus according to any of claims 13 to 15 in which there is an annular feed around the nozzle for supplying gas into the open inlet end of the venturi.

17. Apparatus according to any of claims 13 to 16 in which the venturi has a diffuser portion that is generally frustoconical in shape and has a cone angle of 12 to 15°.

18. Apparatus according to any of claims 13 to 18 including a cyclone for separating the gas and solids leaving the downstream end of the venturi, and a fluidised bed in which particulate solids that are to be entrained may be preheated by the separated gas.

19. Apparatus according to claim 13 substantially as hereinbefore described and with reference to the accompanying drawings.

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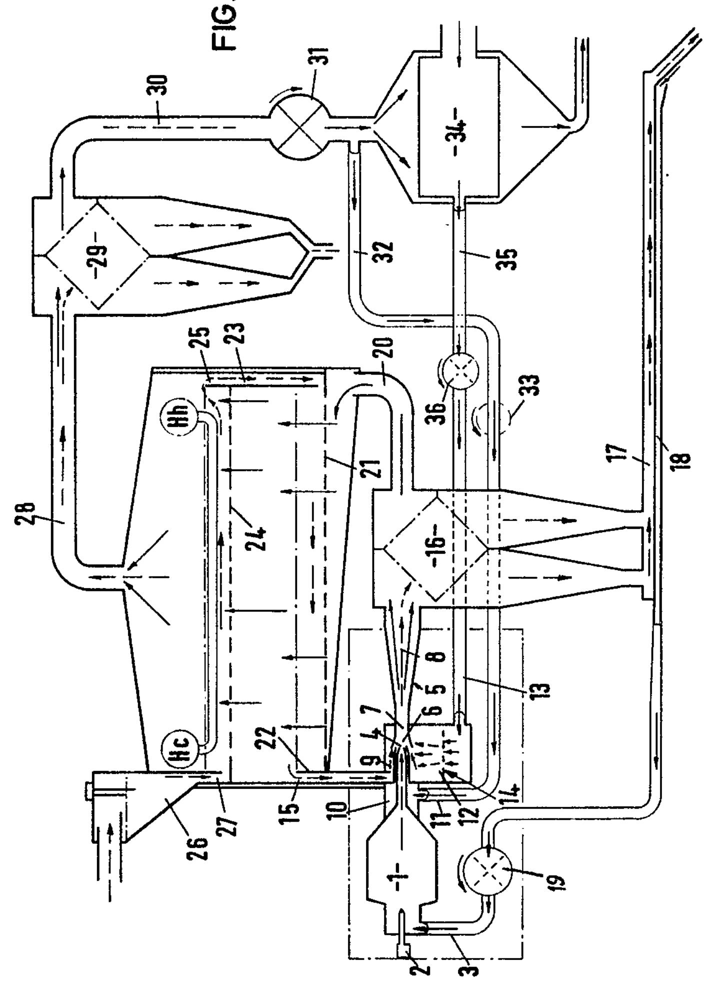
1570276 COMPLETE SPECIFICATION

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

Sheet 1

FIG.1.



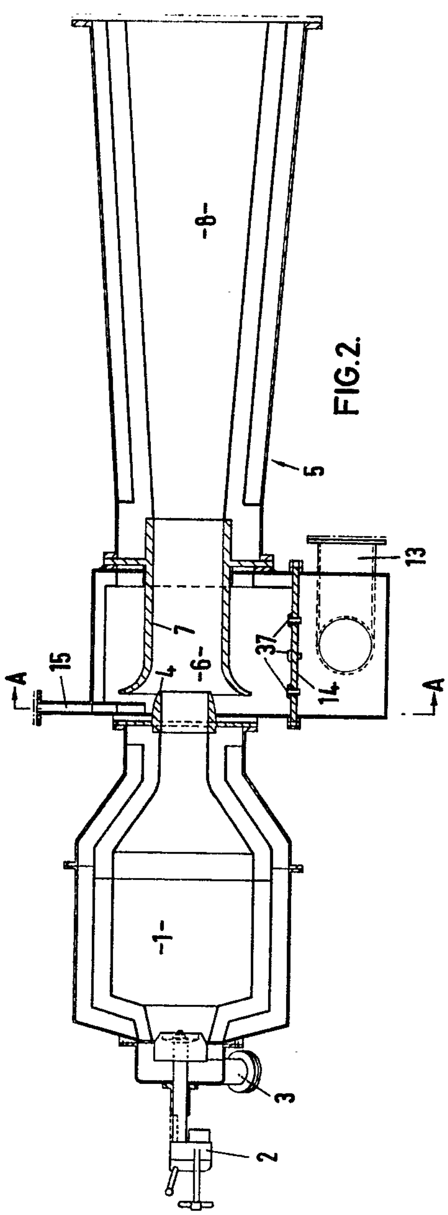


FIG.2.

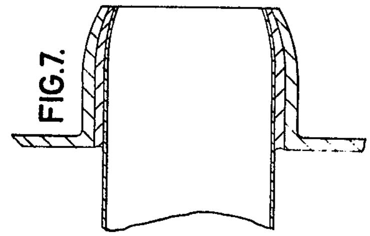


FIG.7.

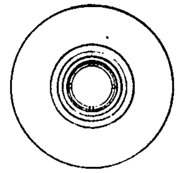


FIG.6

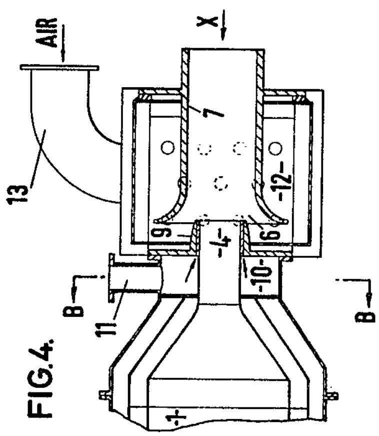


FIG.4.

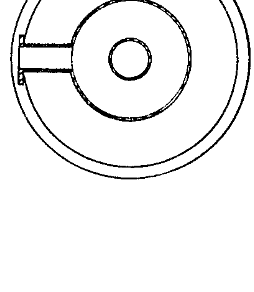


FIG5.

1570276 COMPLETE SPECIFICATION

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

Sheet 3

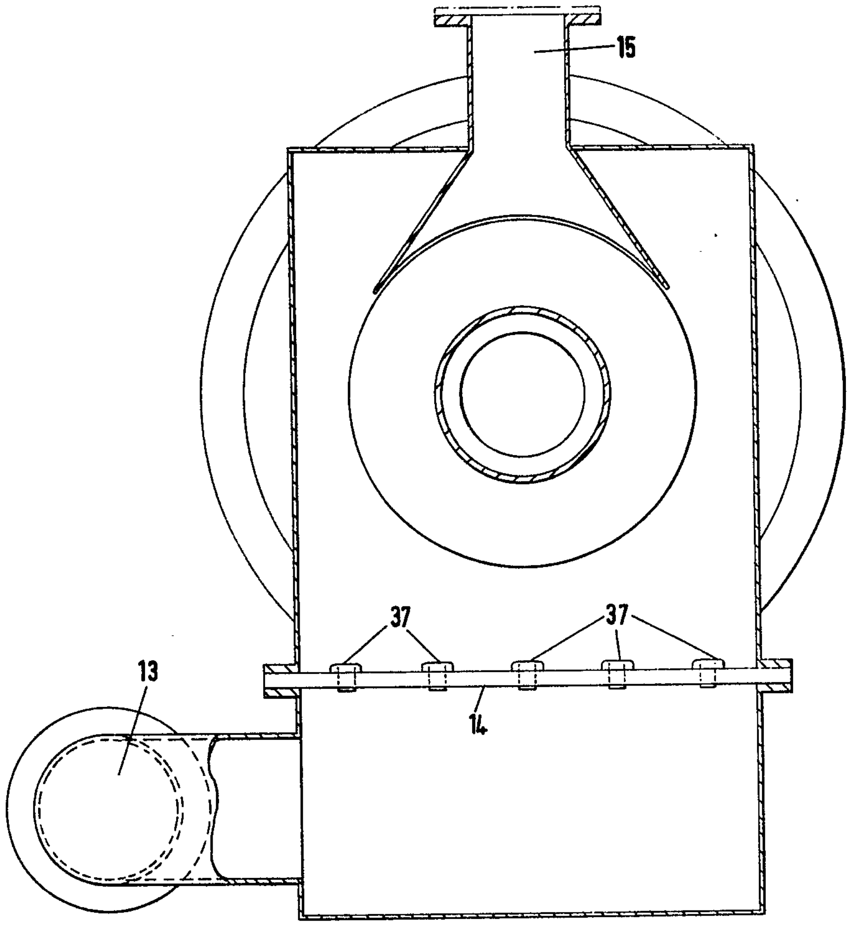


FIG. 3.