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METHOD OF PRODUCING SOLID CARBON DIOXIDE

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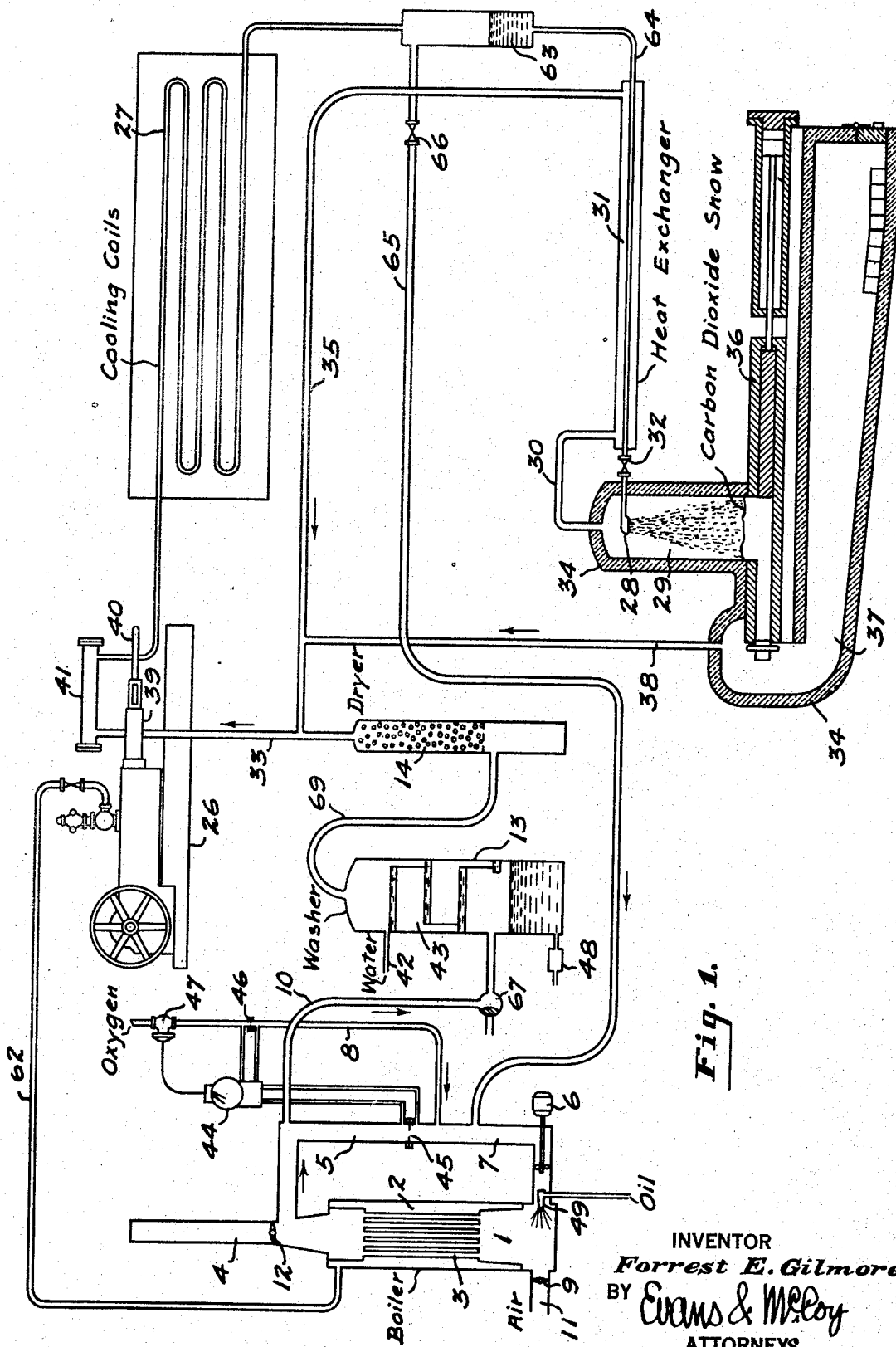


Fig. 1.

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METHOD OF PRODUCING SOLID CARBON DIOXIDE

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12 Claims. (Cl. 62—121)

This invention relates to the production of carbon dioxide in relatively pure form.

An object of the present invention is to produce carbon dioxide by direct combustion of carbonaceous materials in relatively pure form.

Another object is to produce carbon dioxide by the combustion of carbonaceous materials in an oxygen containing atmosphere in which nitrogen is excluded.

A further object is the production of carbon dioxide of substantial purity without the necessity of absorbing such carbon dioxide from a dilute mixture thereof and regenerating from the absorbent.

Another object is the combustion of such carbonaceous materials in an atmosphere containing oxygen mixed with carbon dioxide.

Carbon dioxide may be produced by the combustion of carbonaceous materials, which yields the carbon dioxide mixed with a very large amount of nitrogen and some oxygen. This necessitates absorbing the carbon dioxide in some way, usually by means of alkaline carbonate solution and subsequently regenerating it from this solution. This or other methods of purification are costly and relatively difficult.

It is quite impossible to obtain economically liquid carbon dioxide by direct compression of a flue gas resulting from the burning of a carbonaceous fuel with air. With the liquid receiver operating at a pressure of 4000 pounds to the square inch, no condensation of carbon dioxide will occur with ordinary cooling water temperatures. With pressure of 2000 pounds and independent refrigeration of the liquid receiver to a temperature of minus 40 F. only about two-thirds of the carbon dioxide is liquefied and the whole body of material must be brought to this high pressure and low temperature, the power requirement being prohibitive from an economical point of view. Even if by a design of the apparatus the power requirements could be lessened, it would still be impossible to recover the unliquefied third of the carbon dioxide by any subsequent procedure that did not entail absorption.

It is impracticable to burn carbonaceous materials with pure oxygen on account of the very high temperatures that are reached by combustion under such circumstances and the consequent serious effect on the apparatus used. In particular, it is not feasible to use this method in the burning of a carbonaceous fuel in an internal combustion engine both because of the explosive nature of the reaction and because a body of indifferent gas is necessary in order to develop the

mechanical energy for operating the engine from the combustion.

I accordingly provide an artificial atmosphere consisting of a mixture of pure oxygen and carbon dioxide and by the use of this atmosphere I am able to secure a combustion of the carbonaceous fuel either in a furnace or in an internal combustion engine without producing unmanageably high temperatures and am able in this way to obtain gases of combustion which are substantially entirely carbon dioxide mixed with water vapor.

The carbonaceous materials used may be either coal, coke, or fuel oil, or combustible gas such as natural gas. In the case of the two latter materials, combustion may be carried out either in a furnace or in a Diesel or other type of internal combustion engine. In either case, the fuel is burned in an atmosphere consisting substantially of carbon dioxide to which has been added the desired amount of pure oxygen, the latter being obtained from any desired source.

However, the combustion of the carbonaceous fuel is carried out, it will be desirable to obtain as far as possible the available mechanical energy from it in order to drive the necessary apparatus. In the case of combustion in a furnace, it will be desirable that the furnace heat a boiler both to obtain steam to drive the necessary apparatus and to cool the gases of combustion. In the case of an internal combustion engine, the mechanical energy will, of course, be obtained directly.

Referring now to the drawings in which like numerals refer to like parts:

Figure 1 shows apparatus for the production of carbon dioxide in solid form using a furnace and boiler; and

Fig. 2 shows diagrammatically a similar apparatus in which an internal combustion engine is used for combustion.

Referring to Fig. 1, a suitable furnace is shown, consisting of a fire pit 1, boiler 2, fire tubes 3 and stack 4. A flue 5 connects with the stack 4 above the furnace to receive and return a portion of the gases of combustion to the fire pit 1, there being provided a blower 6 to cause recirculation of the flue gases in this way. Above the connection between the flue 5 and the stack 4 is provided a valve or damper means 12 which, when closed, will prevent gases from going up the stack and cause them to be entirely diverted to the flue 5.

The fire pit 1 is provided with the oil burner 49 in this embodiment, although if solid fuel is used a grate may be substituted, preferably with me-

chanical stoking which will be substantially gas tight. The fire pit is provided with the air port 11 in which is the gas tight valve 9, for purposes of starting. In the course of the return flue 5 is an orifice 45, the flue on either side of this orifice being connected with the ratio controlled device 44 by piping transmitting the pressure on either side to the differential mechanism thereof.

Communicating with the portion 7 of the flue 5 between the ratio controller orifice 45 and the fire pit 1, is a pipe 8 supplying pure oxygen. In the pipe 8 is the orifice 46, pressure connection being made from either side of the orifice 46 to the ratio controller 44. The ratio controller 44 controls the valve 47 in line 8, and in this way any predetermined addition of oxygen can be made to the flue gases passing through the return flue 5 to secure the desired conditions for combustion as regards excess or deficiency of oxygen, depending on the use to which the carbon dioxide is to be put. A pipe 10, to which is attached the venting valve 67, leads from the flue 5 to carry away the carbon dioxide produced, and communicates with the water cooler 13, provided with water inlet 42 and outlet with trap 48, a pipe 69 connecting this with the chemical dryer 14. The dryer 14 communicates by the pipe 33 with the cylinder 39 of the compressor 26.

The compressor 26 may be conveniently driven by steam, steam being provided by the boiler 2 through the pipe 62. The gas from the low pressure cylinder 39 passes to the low pressure intercooler 41 and high pressure cylinder 40. The highly compressed hot gas passes from the high pressure cylinder 40 to the cooling coils 27 where it is substantially liquefied, except for the excess oxygen gas. It now passes to the liquid receiver 63 from the bottom of which a pipe 64 leads the liquefied carbon dioxide to the heat exchanger 31. Here it is further cooled, and then passes through the expansion valve 32 to the nozzle 28 inside of the freezing chamber 29. The freezing chamber is heavily insulated with the insulation 34. Passing from the top of the freezing chamber 29 is the return duct 30 leading to the other side of the heat exchanger 31 and from this the gas which has been warmed up practically to room temperature is lead by the pipe 35 to join the pipe 33 leading to the inlet of the compressor 26. The gas accumulating in the top of the liquid receiver 63 is lead off by the pipe 65 in which is the throttling valve 66. As this gas under high pressure is reduced by this valve 66 practically to normal pressure some refrigerating effect is secured and this effect may be conveniently used to cool the liquid in receiver 63, although not so shown. By the pipe 65, this gas, which is in part carbon dioxide and in part oxygen, is returned to the portion 7 of return flue 5. By proper adjustment of the pressure on receiver 63 with respect to the percentage of excess oxygen in the compressed gas, the issuing gas from pipe 65 may be made to have the desired proportion between oxygen and carbon dioxide. For example, if there is three percent of excess oxygen by volume in the gas to be compressed, and the gas is compressed to a pressure which is once and a quarter that of the vapor pressure of carbon dioxide at the temperature at which the receiver 63 is maintained, the gas passing from the top of the receiver will be 20% by volume oxygen.

Any fuel desired is burned in the fire pit 1, either on a grate in the case of solid fuel or by means of the burner 49 if fluid fuels are used.

Combustion being started with the air port 11, damper 12, and venting valve 67 being open, the blower 6 is started and pure oxygen is supplied through the pipe 8. The air port 11 and the damper 12 are now closed.

At this moment the gas issuing from the venting valve 67 is an ordinary flue gas consisting largely of nitrogen. Since, however, no nitrogen is added to the system, the gas passing from venting valve 67 becomes poorer and poorer in nitrogen and it finally becomes practically pure carbon dioxide containing a little excess oxygen and water vapor. If the proportion of carbon to hydrogen is high in the type of fuel used there will be produced nearly a volume of new carbon dioxide for every volume of oxygen that is supplied from the pipe 8. Venting valve 67 is now closed, the compressor 26 is started and the gas flowing in pipe 10 passes through the water cooler and chemical dryer 13 and 14. Here the water vapor is substantially removed. The carbon dioxide gas containing a little excess oxygen is then compressed in the compressor 26.

It passes first to the low pressure cylinder 39 of the compressor 26, is cooled by the intercooler 41 and is then further compressed in the high pressure cylinder 40 of the compressor 26. It is then cooled substantially to room temperature in the cooling coils 27.

The largest portion of the carbon dioxide is liquefied, the amount unliquefied depending upon the amount of excess oxygen and the ratio of the pressure in the receiver 63 to the vapor pressure of carbon dioxide at the temperature of the receiver as above noted.

The liquid carbon dioxide now passes through the heat exchanger 31 where it is cooled by the cool carbon dioxide returning from the freezing chamber 29 and then passes through the expansion valve 32 and the spray nozzle 28 into the freezing chamber 29. This chamber is maintained substantially at atmospheric pressure in order to produce solid carbon dioxide at a temperature at which its evaporation pressure is not greater than that of the atmosphere. The liquid carbon dioxide passing into this chamber is partially frozen and partially vaporized. The vaporized carbon dioxide is returned by the pipe 35 to the inlet of the compressor 26, first, however, passing through the heat exchanger 31 where it is brought practically to room temperature, and in so doing cools the liquid carbon dioxide passing to the freezing chamber.

The carbon dioxide snow falls to the bottom of the spray chamber where it is compressed by the snow press 36 to form blocks, which are collected in the storage chamber 37. This storage chamber 37 and the freezing chamber 29 are heavily insulated, and the storage chamber 37 is also kept relatively gas-tight so that the evaporated carbon dioxide can be returned through pipe 38 back into the system. In this way waste of carbon dioxide through evaporation in the storage chamber is avoided. While not so shown, an air lock may be provided at the door of this chamber to prevent contamination of the atmosphere within the chamber with atmospheric air while the carbon dioxide blocks are being removed.

Referring now to Fig. 2, there is shown diagrammatically the method of burning a fluid fuel in an internal combustion engine, preferably of the Diesel type. In this figure, 15 is the cylinder of an internal combustion engine 51 having the inlet ports 16, outlet ports 17, these ports being

suitably provided with valves, not shown. There is supplied to the inlet ports 16 through the pipes 18 and 19 a mixture of carbon dioxide and oxygen. Pipe 18 has in it the three-way valve 70, whereby either air or the mixed oxygen and carbon dioxide can be supplied to the cylinder 15. The mixture is suitably proportioned by the ratio controller 56, with orifice 57 in pipe 18, orifice 58 in oxygen pipe 19 and control valve 59 in the latter. This mixture is highly compressed in the cylinder 15 and fuel oil is supplied by the pipe 20 to the injecting mechanism 21 and by this to the cylinder. The fuel is thereby burned in the usual Diesel cycle and the engine is thereby driven, serving to drive the compressor 55. The exhaust gas passes from the port 17 by pipe 69 to the cooler 22, where the gas is cooled and then passes through the pipe 68 in which is the venting valve 67, to the water scrubber 23 provided with water inlet 61 and outlet trap 60. Here the water vapor is largely removed. The gas then passes by the pipe 71 to the chemical drier 24 where it is practically wholly dried. This connects by the pipe 25 with the low pressure cylinder 52 of the compressor 55. From here it passes to the inter-cooler 53 and then to the high pressure cylinder 54. The latter connects with the cooling coils 27 and from there on the apparatus is similar to that in Fig. 1, and carries like reference numerals. The return pipe 35, however, for the excess carbon dioxide in this case joins the pipe 25 leading to the inlet of the compressor 55 instead of pipe 33, as in Fig. 1, and the pipe 65 connects with the pipe 18.

Operation is essentially similar in principle to the operation in the case of the apparatus shown in Fig. 1. With the valve 70 turned to supply air to the cylinder 15, with the valve 67 in the pipe 68 open, with the valve 73 in pipe 69 open, and with the clutch 72 between the Diesel engine 51 and the compressor 55 open the engine 51 is started. When running smoothly, the three-way valve 70 is turned so that the cylinder 15 will take its supply of gas from the pipe 18, and the valve 73 in the pipe 69 is closed, the valve 67 still remaining open. Circulation commences in pipe 18 and oxygen is supplied from pipe 19, the excess volume being vented at 67. The issuing gas soon becomes, as before, practically pure carbon dioxide. The clutch 72 is now thrown in, starting the compressor 55 and the venting valve 67 is closed. The gas, as before, is liquefied and accumulates in the receiver 63, the excess oxygen and a certain amount of unliquefied carbon dioxide passing back to the pipe 18, and then to the cylinder 15 where it is used in the combustion of more fuel. The liquefied carbon dioxide is expanded in the freezing chamber 29, a portion being solidified and a portion returning by the pipe 35 again to the compressor 55, to again pass through the liquefying cycle.

It will thus be seen that I have devised a method for the direct production, by combustion, of carbon dioxide gas of relatively high purity, the purity being so high that it can be used directly for liquefaction or solidification without further treatment.

It will also be seen that I have devised a method in which substantially all of the carbon dioxide produced is eventually recovered. It will also be seen that I have devised a method whereby the power obtained in the burning of a carbonaceous fuel will be sufficient to obtain the carbon dioxide resulting from that fuel in the form of solid carbon dioxide, and it will be observed that this con-

stitutes a very economical process for the production of solid carbon dioxide.

Furthermore, it is to be understood that the particular form of apparatus shown and described, and the particular procedure set forth, are presented for purposes of explanation and illustration and that various modifications of said apparatus and procedure can be made without departing from my invention as defined in the appended claims.

What I claim is:

1. The process of producing carbon dioxide gas, which consists in preparing a mixture of substantially pure carbon dioxide and substantially pure oxygen, burning a fluid carbonaceous fuel in such artificial atmosphere in the combustion chamber of an internal combustion engine removing the water vapor from the exhaust gases and recovering carbon dioxide from said exhaust gases.

2. The process of producing carbon dioxide, which consists in preparing an artificial atmosphere composed of substantially pure carbon dioxide and substantially pure oxygen, mixing such an atmosphere with a fluid carbonaceous fuel in suitable proportions for combustion, introducing such mixture into the combustion chamber of an internal combustion engine, burning the mixture removing the water vapor from the exhaust gases and recovering carbon dioxide therefrom.

3. The process of producing carbon dioxide, which consists in preparing an artificial atmosphere comprising substantially pure carbon dioxide and substantially pure oxygen, introducing such mixture into the combustion chamber of an internal combustion engine, highly compressing said mixture, introducing a liquid carbonaceous fuel into said combustion chamber, burning the same and recovering carbon dioxide from the products of combustion.

4. In an apparatus for the production of carbon dioxide, a combustion chamber enclosing a combustion zone, means for supplying carbonaceous fuel to said combustion chamber, means for mixing a portion of the gases of combustion with oxygen, and means for supplying said mixture to said combustion zone in said combustion chamber.

5. In an apparatus for the production of relatively pure carbon dioxide, a combustion chamber enclosing a combustion zone, means for supplying carbonaceous fuel to said combustion chamber, means for supplying a mixture of carbon dioxide and oxygen to said combustion zone in said combustion chamber, means for removing water vapor from the combustion gases thereof, means for compressing the dried gases, means for cooling and condensing a portion of said uncompressed gases, and means for returning the uncondensed gases to said combustion zone.

6. In an apparatus for the production of relatively pure carbon dioxide, in combination, a combustion chamber, a boiler heated by said combustion chamber, a compressor, a steam engine receiving steam from said boiler for driving such compressor and receiving steam from the boiler, a source of substantially pure oxygen gas, pipe connection between said source of oxygen and said combustion chamber, a return flue carrying gases of combustion back to the combustion chamber, means for proportionately mixing said oxygen and said combustion gases, a washing scrubber for said combustion gases, a dryer for said combustion gases, means for carrying a portion of the combustion gases from said dryer to said compressor, cooling means

for the compressed gases, whereby partial liquefaction of carbon dioxide occurs, a receiver receiving the liquid carbon dioxide and the unliquefied gases and means connected to the top of said receiver for conveying said unliquefied gases to said combustion chamber.

7. The process of producing solid carbon dioxide gas, which comprises, burning a carbonaceous fuel in an atmosphere composed essentially of carbon dioxide and pure oxygen in the combustion chamber of an internal combustion engine, the oxygen being in excess, removing the water vapor from the exhaust gases from said engine, highly compressing said gases, cooling said gases whereby liquefaction of most of the carbon dioxide occurs, passing said mixed liquid and unliquefied gases to a liquid receiver, removing the liquid from said receiver, bringing said liquid substantially to atmospheric pressure whereby a portion thereof is frozen and a portion is vaporized, returning the unliquefied gases from the liquid receiver to the cylinder of the internal combustion engine to assist in further combustion and returning the vaporized liquid carbon dioxide to the cylinders of the compressor.

8. The process of producing relatively pure carbon dioxide, which consists in preparing an atmosphere consisting substantially of oxygen and carbon dioxide, burning a carbonaceous fuel containing hydrogen in said atmosphere, removing the water vapor from the product of combustion, compressing and cooling the resulting gas whereby the carbon dioxide is largely lique-

fied, and returning the unliquefied gas to assist in burning more carbonaceous fuel.

9. The process of producing relatively pure carbon dioxide, which consists in preparing an atmosphere composed substantially of oxygen and carbon dioxide, burning a carbonaceous fuel in said atmosphere the oxygen being present in excess, compressing and cooling the resulting gas whereby the carbon dioxide is largely liquefied, returning the unliquefied portion comprising the excess oxygen and some unliquefied carbon dioxide to assist in supporting further combustion.

10. The process of producing carbon dioxide gas which consists in preparing a mixture of substantially pure carbon dioxide and substantially pure oxygen, burning a fluid carbonaceous fuel in such artificial atmosphere in the combustion chamber of an internal combustion engine and recovering carbon dioxide from the exhaust gases.

11. The process of producing carbon dioxide gas which comprises preparing an atmosphere composed substantially of oxygen and carbon dioxide and burning a carbonaceous material in said atmosphere.

12. The process of producing carbon dioxide gas having as its principal gaseous impurity, oxygen, which comprises preparing an atmosphere composed substantially of oxygen and carbon dioxide, burning a carbonaceous material containing hydrogen in said atmosphere and removing water vapor from the products of combustion.

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