PATENT SPECIFICATION

Application Date: Aug. 4, 1933. No. 21,997/33.

413,130

Complete Accepted: July 12, 1934.

COMPLETE SPECIFICATION.

Manufacture of Gas.

I, HAROLD GEORGE CRUIKSHANK FAIRWEATHER, Chartered Patent Agent, of 65—66, Chancery Lane, London, W.C. 2, of British Nationality, do hereby declare the nature of this invention (a communication from Air Reduction Company Incorporated, a corporation organized and existing under the laws of the State of New York, United States of America, of 60, East 42nd Street, City, County and State of New York, United States of America), and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to a method and apparatus for the manufacture of gas for industrial and other purposes such as heating, lighting, etc.

The use of a gaseous fuel presents many advantages over the direct combustion of solid fuel, but the use of ordinary gaseous fuels has certain disadvantages. Thus illuminating gas with a heating value of about 600 B.T.U. per cubic foot is manufactured by the destructive distillation of coal in retorts, and is too expensive to be considered as a heating agent in most industries. Producer gas, on the other hand, is made by blowing steam and air through an incandescent bed of bituminous coal. The resultant gas, however, has a very low heating value on account of the large proportion of nitrogen which it necessarily contains, and it cannot be economically distributed from a central installation but must be utilized on the premises.

What is known as blue water gas has attained a wide development as a gas having a calorific power of about 300 B.T.U. per cubic foot, but it is manufactured by a comparatively expensive and inefficient process. The operation usually consists of two periods. In the first period, termed the " blow ", air is blown through a bed of coke or coal until heated to almost a white heat. The outgoing gas during this blow period consists mainly of carbon dioxide, carbon monoxide, and nitrogen and has a low heating value. It is utilized chiefly on the premises as a fuel gas for producing the steam or for heating appliances used subsequently to enrich the blue water gas obtained. The second period of the process is known as the " run " and in this stage the incandescent fuel bed is blown with steam producing what is known as blue water gas, consisting essentially of carbon monoxide, and hydrogen with some carbon dioxide, nitrogen and undecomposed steam. Usually blue water gas thus produced is subsequently enriched by adding thereto the gas resulting from the cracking or destructive distillation of oil.

It has been proposed at various times to make the blue water gas process continuous by omitting the first period and blowing with a mixture of steam and more or less pure oxygen. When a fuel bed is blown with a mixture of the proper amounts of oxygen and steam, the temperature resulting is sufficiently low to permit the formation of carbon dioxide in substantial quantities, and this is invariably the result obtained. The carbon dioxide formed in the vicinity of the steam-oxygen jet cannot be reduced subsequently to carbon monoxide by the action of the incandescent fuel bed above to an extent sufficient to avoid the presence of a large proportion of carbon dioxide in the product. The use of oxygen in this manner is objectionable, therefore, in that the gas obtained has a high content of carbon dioxide which reduces the heating value and offsets the advantage of eliminating the initial " blow ". Consequently, the suggested modification of the water gas process by substituting oxygen for air has never attained any commercial importance.

It has also been proposed to produce gas in a continuous process by causing solid or liquid fuel to react with air and steam. Using air, however, it is practically impossible to produce a carbon dioxide-free gas, since combustion with air will not produce the necessary high temperature to permit elimination of carbon dioxide. With the object of producing conditions favourable to the production of carbon monoxide it has been proposed to react on solid fuel with oxygen to which steam is added previous to the introduction of the fuel and oxygen into the reaction chamber. With such a process temperatures cannot be attained such as are obtainable when the fuel is consumed directly with the oxygen.

The object of this invention is to provide an improved simple and practicable method and apparatus for continuously producing a gas consisting essentially of carbon monoxide and hydrogen by the reaction of a solid or liquid fuel with oxygen and steam.

When a continuous stream or jet of powdered solid or liquid fuel is combined under atomising conditions with oxygen, an exceedingly high temperature is attained as the result of the combustion of the fuel and this high temperature prevents the formation of carbon dioxide or at least reduces the quantity of carbon dioxide formed to a negligible amount. The relative quantities of fuel and oxygen added in this part of the operation are such that all the oxygen is consumed to form carbon monoxide. An excess of fuel, which may be added at the same time as the fuel which goes to form the carbon monoxide, or subsequently, in the form of a second jet impinging against the first jet, will in either case attain an exceedingly high temperature. If a jet of steam, either saturated or superheated, is caused to impinge against or mingle with the jet of high temperature gas and fuel resulting from the partial combustion of the fuel and oxygen as above described, the excess fuel will react with the steam to produce carbon monoxide and hydrogen without the formation of carbon dioxide, even though the final resulting temperature of the outgoing gases is not higher than that of well-known pre-existing methods.

The excess fuel over and above that required to form carbon monoxide with the oxygen present may be added as a part of the initial fuel-oxygen jet, or it may be added as a separate jet, coming into contact with the initial jet of fuel and oxygen before or after the initial combustion of the fuel and oxygen present has taken place. This excess fuel may also be added with the steam of the steam jet. The results attained, however, are independent of any one of the three modes of introduction of the fuel jet.

In order to understand the novel features of this invention it is advisable to consider briefly the physico-chemical aspects of the process in order to determine whether the results we have obtained are in accordance with what chemical and physical facts are known about the reactions occurring in furnaces such as were employed in our experiments.

Consider a space occupied by a finely divided liquid or solid carbonaceous fuel undergoing combustion in an atmosphere composed essentially of oxygen with or without accompanying inert diluting gases. Let as assume that the amount of carbonaceous fuel present in the space is considerably in excess of that quantity which will react with the oxygen present in the space to form carbon monoxide. It is a well known fact, for which authority will be given presently, that under such conditions, even though as far as the whole space is concerned there is present an excess of fuel substantially in excess of that required to form carbon monoxide, there is a strong tendency for carbon dioxide to form. This fact has been recognized for many years and the explanation is undoubtedly as follows. In the immediate neighborhood of any small particle of carbon or carbonaceous fuel, there are available for combination a relatively large number of oxygen molecules, i.e., relative to the carbon atoms in the fuel particle available for union with the oxygen. This is due to the fact that oxygen molecules are mobile whereas a substantial percentage of the carbon atoms are protected from the oxygen atoms on account of the fact that they are in the interior of a fuel particle. Furthermore, the reaction

$$C + O_2 = CO_2$$

is known to be an exceedingly rapid reaction, so rapid in fact that its progress is limited not by the rate of the re-action itself, but by the rate of diffusion of oxygen molecules up to the carbon or carbonaceous particles, vide. Haslam & Russell, "Fuels and Their Combustion," page 148.

In the jet described in the present application, the rate of diffusion of oxygen up to or around a carbonaceous particle is made to be exceedingly rapid on account of the scouring action of the oxygen jet upon the solid or liquid carbonaceous particles as the latter travel in the jet. Hence, we may conclude that the above reaction will occur preferentially, unless other conditions not hitherto noted prevent the formation of carbon dioxide. In the method herein described, this initial formation of carbon dioxide is prevented, even though we assume a transient oxidizing condition in the neighborhood of any carbonaceous particle, by the extremely high temperature attained when carbon is allowed to burn adiabatically to carbon monoxide. If this temperature is not high enough to prevent the initial formation of carbon dioxide, carbon dioxide does form for the reason noted in Haslam, and subsequent reduction of the carbon dioxide to carbon monoxide by means of the reactions

$$CO_2+C=2CO$$

is relatively so slow that it could not take place to any marked extent previous to the contact and sudden cooling of the oxygen and fuel particles with the steam jet. That is to say, if the temperature resulting from the initial combustion of the carbon and oxygen is not sufficiently high, carbon dioxide will form and will not be subsequently reduced to carbon monoxide by the excess fuel present. In case the oxygen-fuel jet contained as its gaseous content only pure oxygen, the temperature resulting from the combustion of carbon to carbon monoxide is so high that no appreciable carbon dioxide can exist even under the oxidizing conditions present locally around a carbon particle.

Instead of introducing an excess of fuel with the oxygen, the amount of fuel initially supplied may be such that the carbon of the fuel is converted into substantially only carbon monoxide. An additional amount of fuel sufficient to react with the oxygen supplied by the steam may be introduced independently into the reaction chamber, for example, by a separate fuel jet or it may be brought with the steam into contact with the highly heated gases resulting from the initial reaction. This additional fuel becomes highly heated and reacts with the steam which is supplied in sufficient quantity to produce a gaseous mixture consisting substantially of only carbon monoxide and hydrogen.

The method, therefore, consists in introducing the fuel, either solid or liquid, in a finely divided condition, with oxygen substantially free from nitrogen and from steam into a combustion chamber wherein the initial combustion occurs. The amount of oxygen is limited so that the carbon of a portion of the fuel reacts therewith to produce in an initial reaction substantially only carbon monoxide. The reaction results in an extremely high temperature in the gaseous products, and the excess fuel initially supplied or additional fuel introduced to the reaction chamber is raised to a high temperature. While the mixture of combustion gases and fuel particles are at the high temperature resulting from the reaction, steam is separately introduced either saturated or superheated in limited amount to react in a second reaction with the remainder of the fuel. Thus the steam is introduced in the proportion required to react with the highly heated fuel in accordance with the reaction

$$C+H_2O=CO+H_2$$

This reaction is strongly endothermic, and heat is absorbed rapidly from the initial combustion gases. The temperature of the products is accordingly reduced and may be lower than the temperature of the outgoing gases in the ordinary water gas method.

The reactions

$$2CO=CO_2+C \text{ and}$$
$$CO+H_2O=CO_2+H_2$$

do not occur to any substantial extent and the product is practically free from carbon dioxide. This may be accounted for by the fact that the reactions last mentioned are relatively much slower than the reverse reactions and the combustion products which are initially at a temperature which precludes the formation of carbon dioxide cool too rapidly to afford any opportunity for the production of carbon dioxide in the latter stage of the procedure. This might be expressed by saying that the gases are "frozen" in their primary composition before any substantial amount of carbon dioxide can be formed. Consequently it is possible to produce a gas which consists almost wholly of carbon monoxide and hydrogen. Carbon dioxide is excluded by the temperature attained during the initial combustion and by the rapid cooling when steam comes into contact with the initial combustion products. The presence of nitrogen is avoided by utilizing oxygen instead of air, the oxygen having the further function of affording the initial high temperature which is essential to the method.

The fuel employed in the method may be pulverized solid fuel such as the various grades of coal, or it may be a liquid fuel of petroleum or other origin which can be atomized and introduced thus to the combustion chamber. We have found pulverized solid fuel very satisfactory. It can be introduced continuously by any suitable mechanism which is capable of feeding it uniformly at a predetermined rate.

It is preferable to employ relatively pure oxygen from any source such as the usual air liquefaction plant. Although oxygen may be obtained with a purity of better than 99%, it is not essential that the oxygen be free from impurities although obviously the usual impurity, nitrogen should be excluded so far as it is commercially practicable, because it is inert and merely dilutes the resulting products. Oxygen containing 10% or even more nitrogen can be used in carrying out the method, although the quality of the resulting gas will be poorer because the gaseous product will be diluted with nitrogen, and its heating value will be reduced correspondingly.

The amount of carbon which will be consumed by a given quantity of oxygen is easily determined. The total amount supplied either initially or by introduction of additional fuel should be considerably in excess of that required to react with the oxygen and sufficient to react with the steam which can be converted thereby into hydrogen and carbon monoxide by utilizing the heat produced by the initial reaction. Any further excess of carbon would be useless as it could not react and would merely be carried along with the gases. Likewise an excess of steam would serve no purpose.

The oxygen and steam should be introduced under sufficient pressure to effect the necessary commingling thereof with the fuel to effect the desired purpose. Excess pressure would serve no useful purpose. The reactions are substantially instantaneous and the resulting gaseous product may be withdrawn continuously at a comparatively low temperature. The product may be conducted through a dust separator to remove the ash, and thence through a gas washer to remove soluble impurities and into a holder of the usual type.

In carrying out the invention, any suitable apparatus may be used, but in the accompanying drawing an apparatus suitable for the practice of the method is illustrated diagrammatically.

Referring to the drawing, 5 indicates a combustion chamber of any suitable refractory material capable of withstanding the relatively high temperature of the initial reaction. A fuel pipe 6 extends through one end of the chamber and is connected to a hopper 7 to receive pulverized solid fuel, for example. A screw 8 is arranged in the fuel pipe and is driven by a source of power such as an electric motor 9. The powdered fuel is thus fed continuously and uniformly into the combustion chamber. If liquid fuel is used, the screw and hopper are omitted and the liquid is fed under pressure through the pipe to a suitable atomizing nozzle (not shown).

The pipe 6 is surrounded by an oxygen conduit 10 which is supplied from any suitable source through an inlet 11 with oxygen of the desired purity under pressure sufficient to ensure commingling of the oxygen and fuel in the proper proportions. The resulting combustion when the fuel is ignited results in the production of combustion gases consisting substantially of carbon monoxide carrying fuel particles at very high temperature, usually above 2000° C., and generally nearer 3000° C.

A plurality of nozzles 12 are directed through the walls into the combustion chamber, preferably perpendicular to the flow of gases and steam, either saturated or superheated, and with or without additional fuel, is introduced through the nozzles under a pressure sufficient to cause commingling with the gases, with the result that the secondary reaction is completed with the highly heated carbon or carbonaceous particles to produce the gaseous product. As hereinbefore indicated, additional fuel can be introduced with the steam. The temperature is reduced rapidly by the secondary reaction.

The gaseous products consisting principally of carbon monoxide and hydrogen escape through the throat 13 of the combustion chamber into a dust separator 14 of any usual form. The ash is separated and may be removed through a door 15 at the bottom. The gas escapes through an off-take 16 to a gas washer 17 of any usual type and is delivered by a pipe 18 to a gas holder 19.

As an example of the practical application of the process in an apparatus such as that described, 12 pounds per minute of pulverized coal with 8.4 pounds per minute of 99% oxygen for the initial reaction, and 6.5 pounds per minute of steam at the same pressure as the oxygen were delivered to the reaction chamber, the oxygen being under a pressure of about 5 pounds per sq. in. The method produced continuously a gaseous product consisting substantially of carbon monoxide and hydrogen with a heat value well over 300 B.T.U.

Since substantially all of the carbon or carbonaceous material is converted into carbon monoxide and a large part of the heat is employed in effecting the decomposition of steam, it is apparent that the method as described is very efficient and effects important economies in the quantities of fuel and steam required per unit volume of gas produced. The simplicity and ease of operation of the apparatus is also an important factor in the economic value of the invention.

The term "carbonaceous fuel" in the accompanying claims includes both solid and liquid fuels, and the term "oxygen" includes not only substantially pure oxygen but mixtures thereof with other gases which can be utilized to burn the fuel and attain the temperature which is required to prevent substantial formation of carbon dioxide. The term "steam" includes either saturated or superheated steam.

Various changes can be made in the details of operation and in the apparatus employed without departing from the invention or sacrificing any of the advantages thereof.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. The method of continuously producing gas for industrial and other purposes in which a carbonaceous fuel and oxygen substantially free from nitrogen and from steam are supplied continuously to an internally heated reaction chamber, the amount of oxygen being limited so that the carbon of a portion of the fuel reacts therewith to produce in an initial reaction substantially only carbon monoxide, and a separate supply of steam is led continuously to the reaction chamber in limited amount to react in a second reaction with the remainder of the fuel previously highly heated by the initial reaction to produce substantially only carbon monoxide and hydrogen.

2. The method as in claim 1 in which the temperature attained by the gaseous products of the initial reaction of the fuel with oxygen substantially precludes the formation of carbon dioxide.

3. The method as in claim 1 in which the highly heated products of the initial reaction of fuel with oxygen are cooled so rapidly by the endothermic reaction with steam that the formation of carbon dioxide is substantially prevented.

4. The method as in the preceding claims in which the total amount of fuel is supplied with the oxygen or a portion of the fuel is introduced with the oxygen and an additional quantity of fuel is supplied with the steam.

5. The method as described for the purpose set forth.

Dated this 4th day of August, 1933.

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Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1934.

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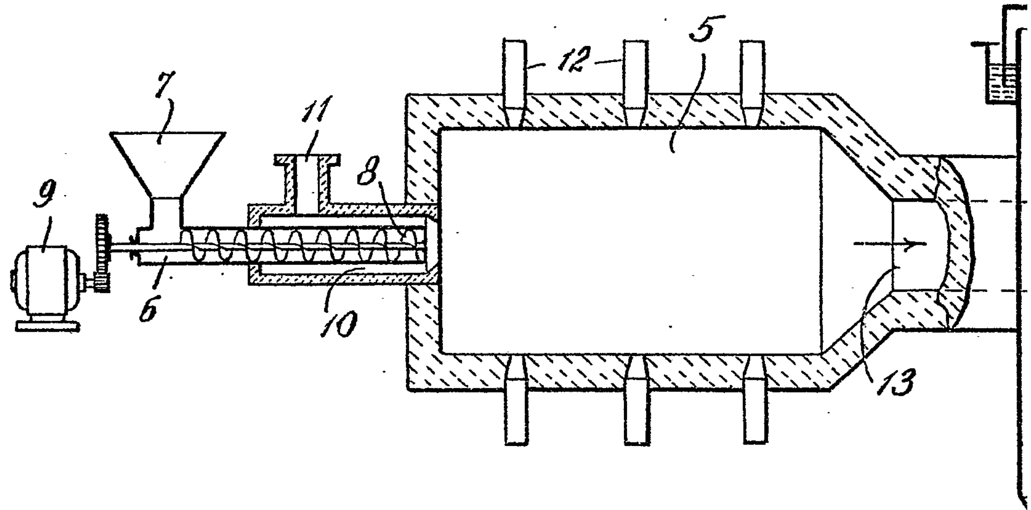

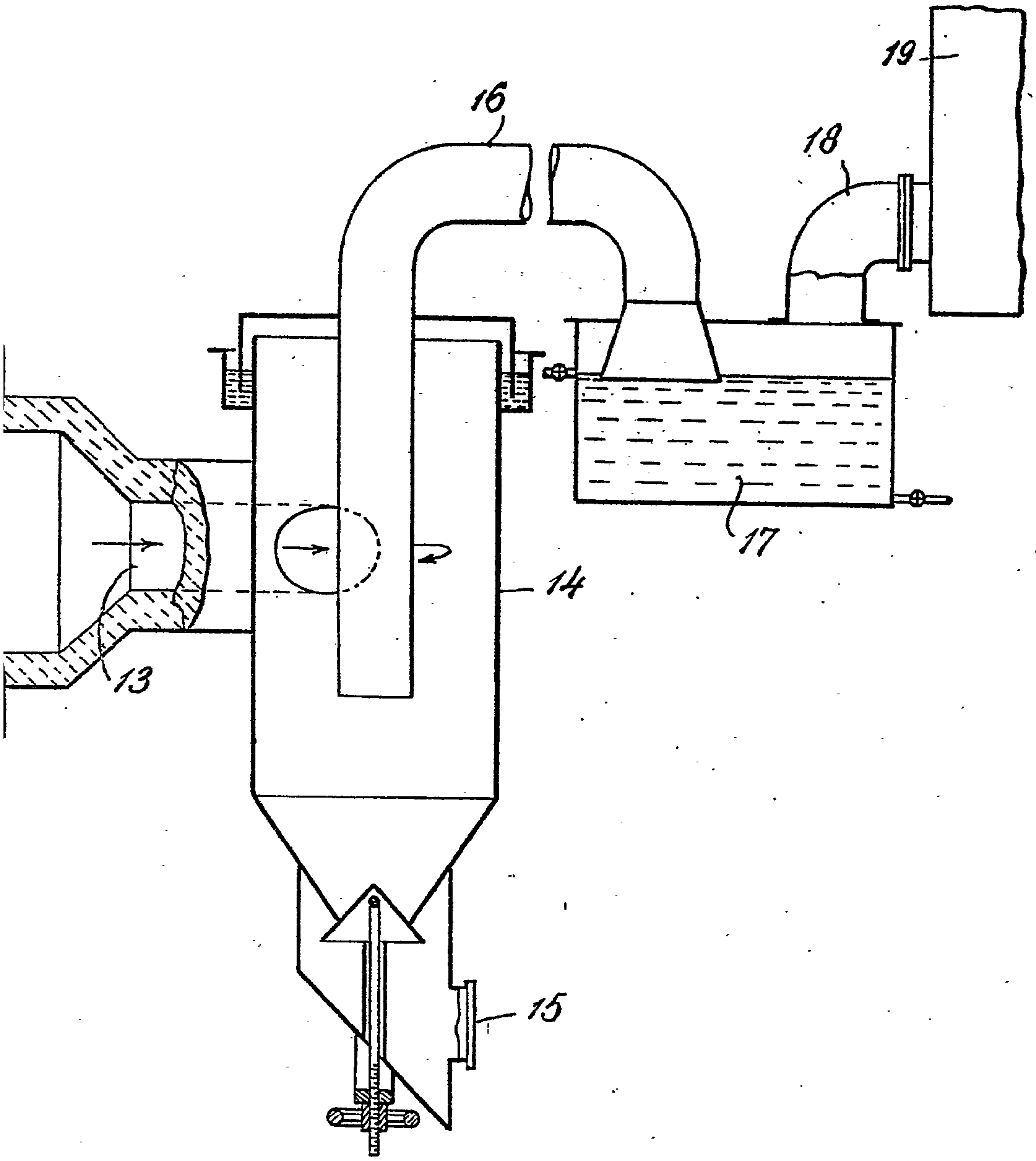

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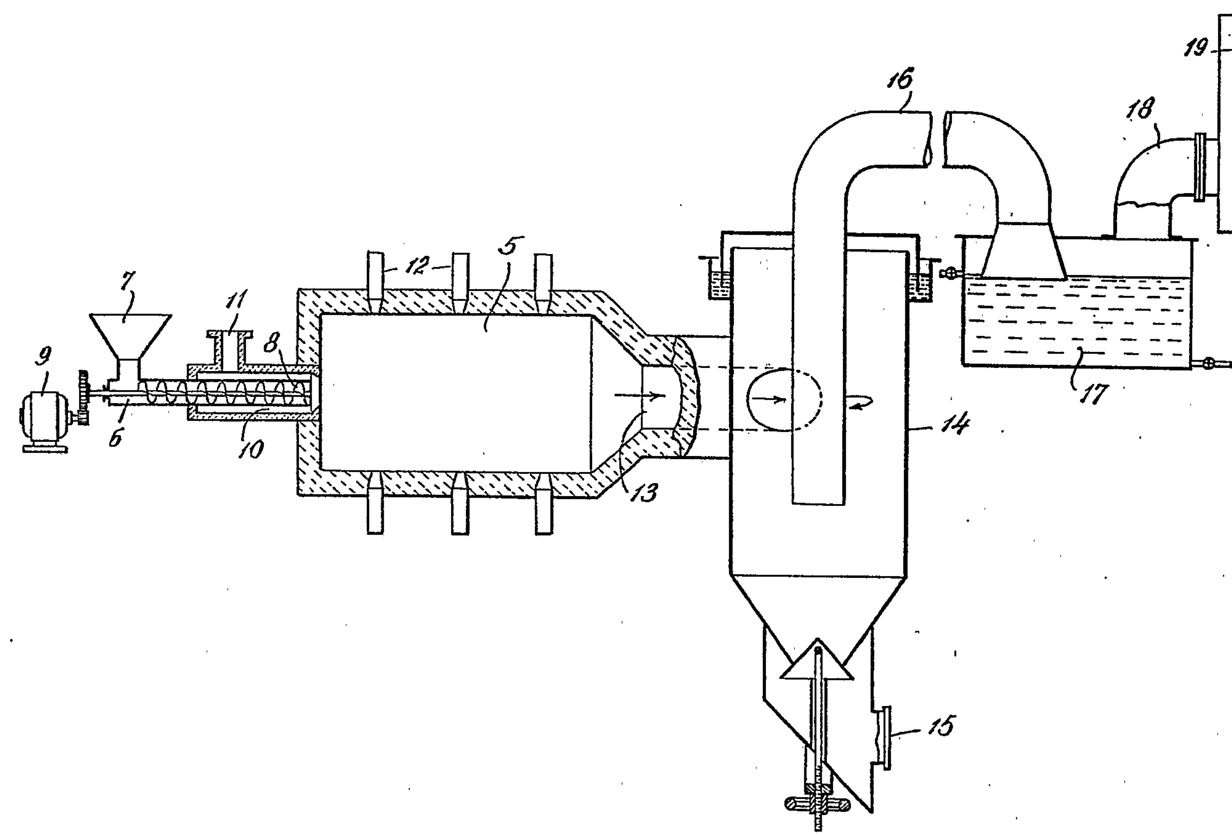

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