GASIFICATION OF COMBUSTIBLE MATERIALS

Filed May 12, 1949 2 Sheets-Sheet 1

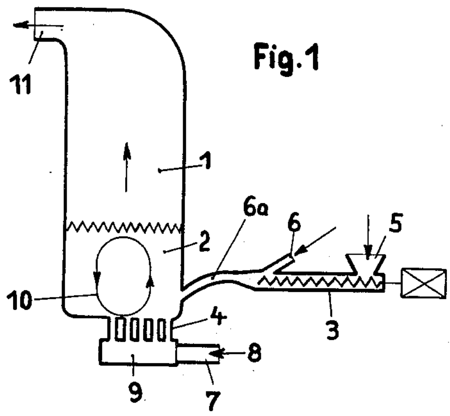

Fig.1

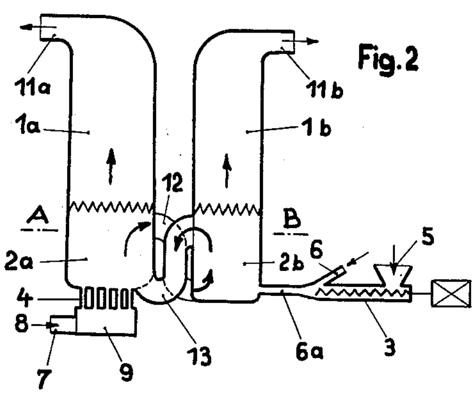

Fig.2

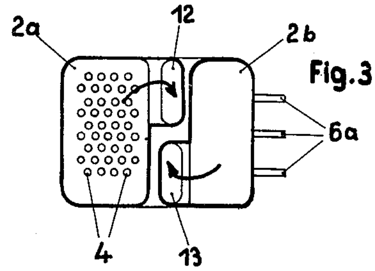

Fig.3

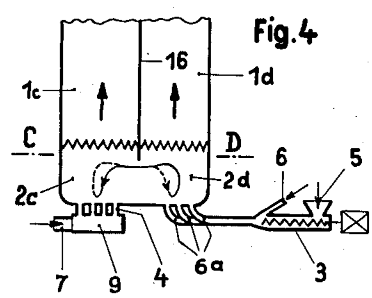

Fig.4

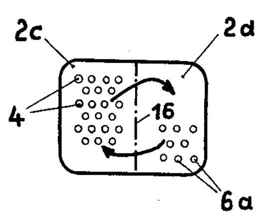

Fig. 5

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GASIFICATION OF COMBUSTIBLE MATERIALS

Filed May 12, 1949 2 Sheets-Sheet 2

Fig.6

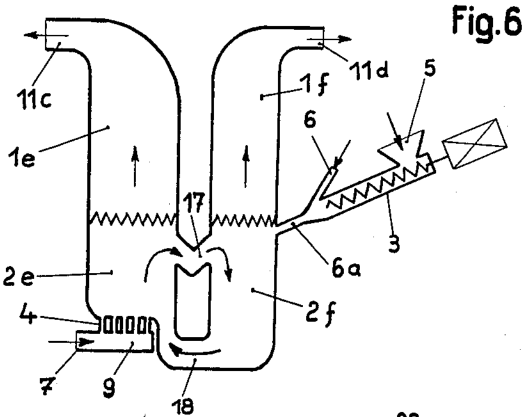


Fig.7

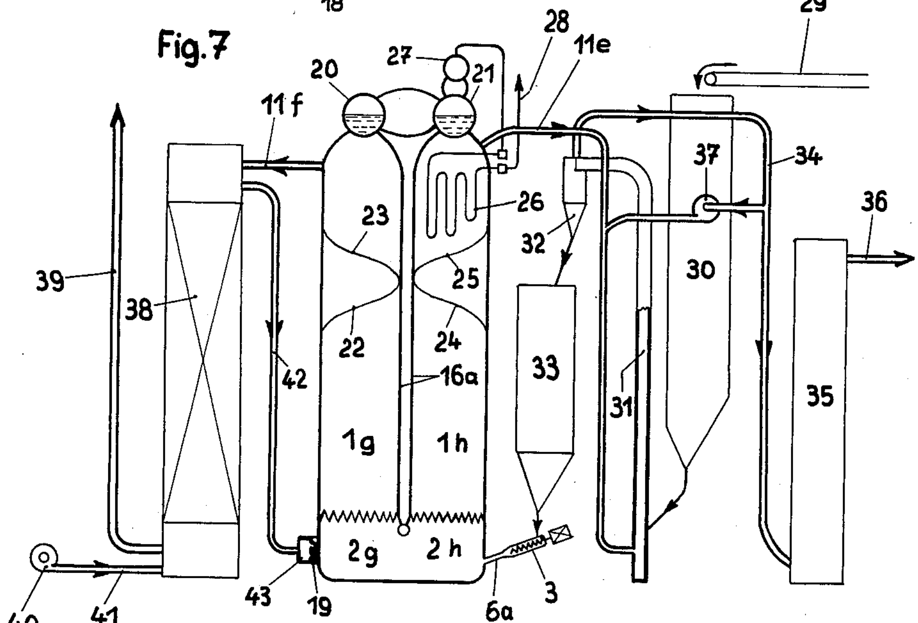


Fig.8

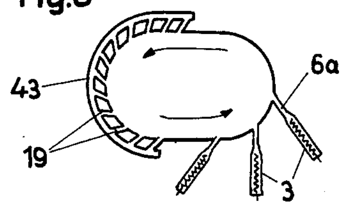


Fig.9

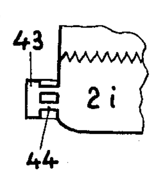
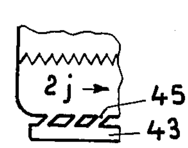


Fig.10



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GASIFICATION OF COMBUSTIBLE MATERIALS

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In Germany December 6, 1948

11 Claims. (Cl. 48—206)

1

This invention relates to new and useful improvements in the gasification of combustible materials.

The gasification of combustible materials and particularly of coal is conventionally practised for the recovery of industrially valuable combustible gases such as "producer gas," "water gas," "mixed" or "Dowson gas," etc. The formation of these gases essentially involves two types of reaction. The first is substantially endothermic in nature, and the second is substantially exothermic in nature.

In the first type of reaction the combustible material, such as coal, is brought to relatively high temperature and preferably incandescence and is then contacted with an endothermic gasification agent, i. e., an agent capable of oxidizing combustible material, such as coal, with absorption of heat. Such endothermic reactants are, for instance, water and CO_2. Water is endothermically split into hydrogen and oxygen, and thus reacts with the combustible material to furnish a mixture of carbon monoxide and hydrogen conventionally termed "water gas." CO_2 is endothermically decomposed into CO and oxygen, reacting in this manner to furnish 2CO.

In the second type of reaction a combustible material, such as coal, is contacted at relatively high temperature with a suitable exothermic, gasification agent, i. e., an agent capable of oxidizing combustible material, such as coal, with generation of heat. Such exothermic reactants are, for instance, suitable combustion supporting gases such as oxygen, air or oxygen enriched air. Depending upon the amount of combustion supporting gas used, the exothermic oxidation of combustible material, such as coal, may be guided to the formation of CO or CO_2 or variable mixtures thereof.

Gasification of combustible materials with an endothermic reactant produces a "rich" gas, i. e., a gas high in combustible or B. t. u. value. The heat loss, however, which is involved in the endothermic reaction necessitates frequent periodic re-heating of the combustible material to the required reaction temperature. One method of accomplishing this is by alternately subjecting the material to be gasified to an endothermic and exothermic gasification reaction, i. e., contacting the material alternately with an endothermic gasification reactant such as steam or CO_2, and the exothermic gasification reactant such as oxygen, air, or oxygen-enriched air. In the exothermic reaction, the temperature is then again sufficiently raised to be available for the

2

endothermic gasification step. The resultant gases can then be separately recovered. If heat is the primary consideration in the exothermic step, that reaction is usually carried to the substantially complete combustion of the combustible material to CO_2. Alternatively, if it is desired to obtain a combustible gas, the reaction is carried only to the partial combustion of the material to CO. Should non-combustible diluents be present in such gas, such as varying proportions of CO_2 or of N_2 (introduced if air was used), a so-called "lean" gas results. When continuous operations are desired, it is conventional practice to simultaneously contact the material to be gasified with the endothermic and exothermic gasification reactants. Thus, for instance, steam or carbon dioxide together with oxygen, air, or oxygen-enriched air, are passed into contact with the heated coal. From this is then recovered a so-called "mixed" gas which is higher in combustible and B. t. u. value than "lean" gas but lower in combustible and B. t. u. value than "rich" gas.

All of the hitherto methods and devices to carry the same into effect have in common the disadvantage that they require a combustible material, such as coal, which is relatively compact, which will not tend to lose that compactness when subjected to relatively high temperatures, which should be substantially free from small particles and fines, and which should not tend to bake together at the temperature of reaction.

Furthermore, the hitherto known procedures and devices do not lend themselves readily to the gasification of combustible materials of a bituminous nature, as, for instance, bituminous coal or brown coal, peats, bituminous shales, etc. When subjecting these bituminous substances to gasification, some of the bituminous constituents, either as such or in the form of partial decomposition products, pass into the gas to be recovered, thereby either impairing the value of such gas for many purposes or necessitating special, and at times, costly purification.

Another drawback to which most of the hitherto known gasification procedures and devices for the recovery of combustible gases are subject, is the accumulation of ashes or clinkers which necessitate discontinuance of operations for their periodic removal. This latter disadvantage, however, is avoided in a procedure which has found industrial application and in which a combustible material, such as coal, is treated with soda ash, usually with the further addition of lime to thereby convert the relatively high melting residual silica and alumina compounds into lower melting products. The latter then form a slag which is molten at the relatively high temperature of gasification, thus permitting the residues to be continuously removed from the reaction zone. Also this procedure, however, is still subject to the other disadvantages and drawbacks above mentioned, requiring relatively high grade coal compactness of the individual pieces, absence of granulars and fines, and the difficulties involved in the use of bituminous materials.

One object of the invention comprises an improved method for the gasification of combustible materials and particularly those of the coal type.

Another object of the invention comprises an improved device for the gasification of combustible materials and particularly those of the coal type.

The foregoing and still further objects of the invention may be seen from the following description read in conjunction with the drawings in which:

Fig. 1 is a diagrammatic side view representation illustrating one embodiment of the device in accordance with the invention;

Figs. 2, 4 and 6 represent respectively diagrammatic side view representations of alternative embodiments of the device in accordance with the invention;

Fig. 3 shows a diagrammatic cross-section through the construction of Fig. 2 on the plane A—B thereof;

Fig. 5 illustrates a diagrammatic cross-sectional view through the construction shown in Fig. 4 on the plane C—D thereof;

Fig. 7 illustrates a diagrammatic side view representation of a preferred embodiment of the device in accordance with the invention, and showing various ancillary structural arrangements; and

Figs. 8, 9 and 10 respectively show diagrammatic cross-sectional representations or parts thereof illustrating alternative means for the introduction of reactants into the device in accordance with the invention.

Referring to Fig. 1, a conventional tower 1 is provided at the bottom thereof with the molten slag reservoir or tub 2. Gas nozzles 4 are provided in eccentric position at the bottom of tub 2 and are supplied by a suitable exothermic reactant such as oxygen, air, or oxygen-enriched air from a source 8 through duct 7 and manifold 9. A suitably driven feeder for combustible material, such as the worm feeder 3, is provided, with its feed end 6a passing into tub 2 on one side thereof and preferably near the bottom. Feeder 3 is provided at one end with hopper opening 5 for feeding particled coal material as, for instance, brown coal, and preferably more or less granular coal, into the feeder 3. A duct 6 entering the feeder 3 at the feed end of the worm is provided for the admission of an endothermically reacting gasifying agent such as steam, CO_2, or the like.

In the practical operation of the method in accordance with the invention utilizing the arrangement shown in Fig. 1, tub 2 is filled with molten slag. A useful slag may be any slag comprising mixtures or reaction products of different oxides, the most common and important of which are silica, lime and alumina. Oxide mixtures in the slag may be present as binary or as ternary systems, as well as in the form of various eutectics between different oxides, as is well understood in the art. Slags useful in accordance with the invention may be individually produced, if desired, in accordance with practices conventional in, for instance, metallurgical processes, or, they may be conveniently obtained by way of the slags used in such processes as, for instance, in the reduction to metal of, for example, iron ore. Alternatively, the slag may be obtained, in accordance with my preferred practice, by way of the substantially non-combustible residues of coal products. In that case the slag may be obtained for instance from a coal gasification procedure conducted under conditions of slag formation with the addition of soda ash and lime (if necessary). Most conveniently, however, such slag may be individually prepared by charging the slag reservoir or tub 2 with coal, soda ash and lime in appropriate proportions, as are well understood in the art, and then subjecting the charge to gasification or combustion at high temperatures in the hitherto known manner, to form a molten slag. If the particular type of coal used already carries sufficient Ca containing constituents as, for instance, a limey shale, the addition of lime may be omitted.

Granular coal, such as bituminous coal, is fed into the hopper opening 5, being thence transported by feed worm 3 into the molten slag in tub 2. A combustion supporting gas such as oxygen, air, or oxygen-enriched air, is injected with relatively high velocity through nozzles 4 into the molten slag within tub 2. The introduction of the high velocity combustion supporting gas imparts a certain turbulence to the molten slag, and the eccentric position of the nozzle with respect to the bottom of the slag tub 2 imparts at the same time to the slag a circulatory motion as, for instance, indicated by the arrows 10. An endothermic gasification reactant gas such as steam, CO_2, or the like, is introduced into the molten slag in tub 2 and preferably in a manner serving simultaneously to aid the feeding of a combustible material such as coal into the molten slag. Thus, as illustrated in Fig. 1, an endothermic gasification reactant, such as steam or CO_2, is passed through duct 6 and preferably under pressure into and through duct 6a, thence issuing into the molten slag in tub 2. As illustrated, this endothermically reacting gas enters at the feed end of worm feed 3 and aids in the further transport of the combustible material, passing the same with a certain velocity into the molten slag bath and thus also aiding the distribution of the combustible material therein. This distribution is further supported by the turbulent motion imparted to the molten slag by the injection effect of the combustion supporting gas issuing from nozzles 4.

Within the preferred procedure, the combustible material as, for instance, coal, is converted to more or less granular form by the use of, for instance, suitable spiked rollers (not shown), and may be introduced through the hopper opening 5 without preliminary drying, i. e., with a moisture content as it is obtained from the mines. The moisture content of the coal thus introduces in a convenient manner one of the endothermic reactants. The coal may be subjected, if desired, to a preliminary drying operation.

As the moist coal enters the molten slag bath, the water content thereof is almost explosively gasified, thus furnishing and finely distributing steam for participation in the endothermic gasification reaction. At the same time, the explosive force of the gasification of water upon entry into the molten slag further aids the distribution of the particles of combustible material, such as coal, in the molten slag. If desired, it is possible to use the moisture content of the coal as the sole source for the endothermic gasification reactant, in which case additional endothermic reactant gas need not be introduced through duct 6. However, it is preferred to introduce some gaseous agent through duct 6 to aid the feeding of the combustible material into the slag bath and when it is desired to solely rely upon the moisture content of the combustible material as the source for the endothermic gasification reaction, the gas supplied through duct 6 may then be any other suitable gas, including, if desired, a combustion supporting gas or an inert gas. It is, of course, understood to avoid in such case any gas that might interfere with the desired gasification of the combustible material or may cause the presence of undesirable constituents in the gas mixture passing off through duct 11.

As the molten slag circulates by the impelling force of the high velocity combustion supporting gas issuing through nozzles 4 and as schematically indicated by arrows 10, the finely distributed carbon particles are thus brought into constant recurrent intimate contact with both the endothermic and the exothermic reactants. The exothermic reactant introduced through nozzles 4, such as oxygen, air, or oxygen-enriched air, causes a combustion with the liberation of heat. The endothermic reactant as, for instance, water vapor, introduced for example by way of the moisture content of the combustible material, reacts to form with the combustible material CO and H_2, consuming heat in the reaction. If CO_2 were to be introduced as endothermic gasification reactant, further amounts of CO would be produced. It is possible to so adjust the amount of combustion supporting gas through nozzles 4 that the heat liberated in the exothermic reaction will substantially balance the heat consumed in the endothermic reaction, so that the bath of molten slag within tub 2 remains at a substantially uniformly constant temperature.

Thus, within the broad concept of the invention, gasification of combustible materials, such as coal, is obtained by substantially continuously distributing a normally solid combustible material such as coal in substantially particled and preferably granular form in a molten slag, and substantially continuously intimately contacting said combustible material while so distributed with a combustion supporting gas and with an endothermic gasification reactant, and recovering a combustible gas mixture therefrom.

Among the advantages enjoyed by the procedure in accordance with the invention are the fact that the same lends itself satisfactorily to the use of bituminous materials. The combustible material such as coal, whether bituminous or any other type, does not require any particular degree of firmness or compactness, need not be free from fines, and need not possess non-sintering or non-baking characteristics. If a bituminous material, such as soft or brown coal, peat, shale, or the like, is used, the procedure in accordance with the invention permits the gasification reaction to proceed in such manner that a minimum of distillation products, traceable to the bituminous constituents of the material, is found in the recovered combustible gas. Thus, the gasification of bituminous materials can proceed to the recovery of a combustible gas directly usable for most industrial purposes without the necessity of special scrubbing or purifying treatments.

The preferred embodiment of the invention, as exemplified by a number of variations, is shown in Figs. 2 et seq. It is essentially concerned, in the application of the broad principle of the invention, with the separation of the gases resulting respectively from the endothermic and exothermic reaction phases.

As for instance illustrated in Fig. 2, there are provided two separate towers 1*a* and 1*b* having the gas lead-offs 11*a* and 11*b* respectively. A slag reservoir or tub is provided having the sub-portions 2*a* and 2*b* respectively. Ducts 12 and 13 interconnect sub-portions 2*a* and 2*b* and are preferably so arranged that duct 12 leads from a point just below the surface of the molten slag in the tub at 2*a* to a point adjacent the bottom of the tub at 2*b*, and duct 13 leads from a point just below the surface of the molten slag in tub at 2*b* to a point adjacent the bottom of the tub at 2*a*. The bottom of the slag tub portion 2*a* carries nozzles 4 (see Fig. 3) issuing from manifold 9, fed by duct 7. A multiple number of inlets for the combustible material such as coal, and for the gaseous endothermic reactant of the type and arrangement shown and described in connection with Fig. 1 are provided, passing these materials through the ducts 6*a* into the molten slag within the tub portion 2*b* and preferably at a point adjacent the bottom thereof.

The introduction of materials into the structure illustrated in Fig. 2 proceeds essentially in the same manner as above illustrated in connection with the device exemplified by Fig. 1. In this case, however, the combustion supporting gas issuing with a relatively high velocity from nozzles 4 into the molten slag in tub portion 2*a* imparts turbulent agitation to the bath and at the same time a motion in the direction of the arrow, thereby forcing a molten slag current flow into and through duct 12, thence as indicated by the arrows into and through slag tub portion 2*b*, and thence into and through duct 13 back into slag tub portion 2*a*. As combustible material such as coal enters through ducts 6*a* into the slag in tub portion 2*b*, it is distributed therein and picked up by the circulating slag and thusly carried through duct 13 into the molten slag within tub portion 2*a*. The gaseous endothermic reactant, such as water, introduced for instance by way of the moisture content of the combustible material or separately introduced in the form of steam, passes through the slag, being intimately contacted therein in tub portion 2*b* with the well distributed combustible material as it is circulated and agitated by the slag current which is set up by the impeller effect of the high velocity combustion supporting gas issuing through the nozzles 4 into tub portion 2*a*. The gaseous endothermic material reacts endothermically with the combustible material in the tub portion 2*b* and the gases resulting from that reaction as, for instance, a high grade "water gas," are recovered in the tower 1*b* by way of the lead-off 11*b*. The non-gasified portion of the combustible material, such as coal, is carried by the slag current into the tub portion 2*a* and is there exothermically reacted with the combustion supporting gas such as oxygen, air or oxygen-enriched air issuing through nozzles 4, thereby replenishing the heat loss incurred by the endothermic reaction within tub portion 2*b*. The thusly reheated slag (and the balance, if any, of non-gasified combustible material) is recycled through duct 12 back into tub portion 2b, to be there again charged with combustible material for the endothermic reaction between the combustible matter and the gaseous endothermic agent. The reaction gas produced in tub portion 2a is then recovered from the tower 1a by way of the lead-off 11a. Usually the volume of the combustion supporting gas introduced through nozzles 4 is such that combustion proceeds to a large extent to CO_2. In that case, particularly when air was used (introducing diluent N_2), the gas mixture issuing from tower 1a is too lean in combustible components to be useful for most purposes except for the utilization of its heat. It is however possible to so adjust the reaction conditions, including the volume of combustion supporting gas, that a relatively large component of CO is obtained in the gas mix passing from tower 1a, so that a gas of sufficient combustion value is obtained to make its recovery practical for certain limited purposes.

There is thus broadly defined within the preferred embodiment of the invention the substantially continuous circulation of molten slag through a first and second reaction zone, substantially continuously introducing particled combustible material of the coal type in said slag in said first reaction zone, substantially continuously introducing an endothermic gasification reactant for said material into said slag in said first zone, substantially continuously introducing a combustion supporting gas into said slag in said second zone, and substantially continuously separately recovering the gaseous products of reaction from at least said first zone.

Figs. 4 and 5 diagrammatically illustrate a variation of the device shown in Figs. 2 and 3. As there exemplified, the slag tub comprises the lower portion of a tower carrying the partition 16 extending to just below the liquid level for the molten slag in the slag tub, and separating the tower into the educt portion 1c above reaction zone 2c and the educt portion 1d above the reaction zone 2d. A multiple number of combustible material and endothermic reactant feed units 3 are provided, the ducts 6a of which enter the bottom of the reaction zone 2d at one side thereof. The nozzles 4 for the combustible gas supplied by way of duct 7 and manifold 9 are arranged at the bottom of the reaction zone 2c at one side thereof and in a position generally about diagonal with respect to the position of the entrance openings of the ducts 6a. The impelling action of the high velocity combustion supporting gas issuing from nozzles 4 will cause molten slag to flow upwards in zone 2c over to and downwards in zone 2d. The introduction of gaseous endothermic reactant, and particularly when accentuated by the introduction under pressure of a gaseous agent by way of duct 6, will cause an upward current of slag in zone 2d over to and downward in zone 2c. In view of the fact that the direction of the current essentially controlled by nozzles 4 and that of the current essentially controlled by the end openings of ducts 6a are not in direct juxtaposition, the injection openings of nozzles 4 and of ducts 6a operate in a manner to form a substantially recycling current, substantially as illustrated by the arrows within the slag tub and shown in Figs. 4 and 5.

A still further variant in accordance with the preferred embodiment of the invention is for instance illustrated in Fig. 6. As there shown, a more or less U-shaped tower is used, having legs 1e and 1f and gas-lead-offs 11e and 11f respectively. A partition is provided in the lower portion of the U, separating the same into the reaction zones 2e and 2f, and defining the ducts 17 and 18 respectively between these two zones. The liquid level for the molten slag is provided so as to extend into the respective portions 1e and 1f. The duct 7, manifold 9, and nozzle arrangement 4 (for the combustible gas) are mounted below the reaction zone 2e in a position somewhat higher than the bottom of the U, to provide for a nozzle discharge level above the horizontal portion of the duct 18. Feeding duct 6a (for combustible material and gaseous endothermic reactant) is arranged to pass into the reaction zone 2f at a point below the surface of the molten slag, at which point it will be seized and carried away by the downwardly directed current. The impelling force of the high velocity combustion supporting gas issuing from nozzles 4 causes the slag to circulate in the direction of the arrows from zone 2e to and through duct 17, thence to and through zone 2f, thence to and through duct 18 and back into zone 2e. Whereas thus in the previously described embodiments exemplifying devices in accordance with the invention, the endothermic reaction is carried out in an upwardly directed stream, Fig. 6 illustrates an embodiment where such reaction is accomplished while the combustible material is passed through the endothermic reaction zone in a downwardly directed stream.

The device shown in Figs. 7 and 8 exemplifies a further preferred practice and structure in accordance with the invention effectively utilizing the heat of the produced gases for the pre-heating of the gasifying agents, generation of steam, and pre-drying of combustible material. There is also illustrated in Fig. 7 a still further variant with respect to the circulation arrangement for the molten slag bath in that, in this case, the combustion supporting gas nozzles and entry ducts for the combustible material and endothermic reactant are so arranged that a substantially horizontal circulatory motion of the molten slag is obtained.

A tower is separated by the partition 16a into the portions 1g and 1h. A slag tub is arranged at the bottom of the tower, and the partition 16a extending to below the level of the molten slag within the tub, defines the reaction zones 2g and 2h. Combustible material such as coal is fed into reaction zone 2h by way of the worm feed 3. Combustion supporting gas is blown into the molten slag in zone 2g by way of the nozzles 19 connected to manifold 43 supplied by duct 42. Nozzles 19 and the feed ducts 6a of worm feeds 3 enter their respective reaction zones in a downwardly inclined position, being at the same time inclined sidewise with respect to the movement of the molten slag as indicated by the arrows in Fig. 8. In this manner, a very effective intimate mixture of combustible material, slag, and gasification agents, is at all times assured. Tower 1h carries within the walls thereof suitable cooling means such as water pipes (not shown), which end in water drum-tanks 20 and 21. Cooling racks having water cooling pipes are diagonally secured in the upper tower portions. These are, for instance, diagrammatically indicated by the racks 22 and 23 in the tower portion 1g, and the racks 24 and 25 in the tower portion 1h. These cooling racks serve the purpose of liquefying or solidifying portions of slag that may be propelled upwardly along with the reaction gases.

One end of the cooling pipes for each pair of racks **22**—**23** and **24**—**25** is attached to a source of water supply and preferably to the water tank drums **20** and **21** comprising pre-heated water resulting from the cooling pipe system built into the walls of the tower portions **1***g* and **1***h*. The other end of the cooling pipes of the set **24**—**25** feeds into the super-heater **26**. The effect of the hot gases passing the cooling racks is to convert the water therein into steam, which passes into the super-heater **26**, in which it is super-heated by the passage of the hot reaction gases in tower portion **1***h*. Super-heater **26** is connected with the steam reservoir **27** and has the steam draw-off duct **28**, whence super-heated steam may be passed off to any industrial usage.

Suitably broken coal, such as brown coal, as for instance by the use of a conventional spiked roller arrangement (not shown), is continuously carried by the endless band **29** into silo **30** whence it passes into the drying duct **31**. The pre-cooled but still hot reaction gases, drawn off the top of tower portion **1***h* by way of duct **11***e*, pass into the bottom of the drying column **31** in which they carry the particled coal upwardly in a stream or current of gas, at the same time drying the same to a predetermined moisture content. The gas and particled coal pass into the duct separator **32** in which the gas is freed of coal dust, being thereafter passed through duct **34** into and through washer **35** and thence out through duct **36**, being now ready for industrial use. Blower **37** is provided to draw any portion of the cooled gas passing through duct **34** into the hot gas passing through duct **11***e* to the bottom of drying column **31**. In this manner, the temperature of the gas for drying and transporting the particled coal upwardly in drying column **31** can be adjusted to obtain for the coal the desired predetermined moisture content. The coal is then passed from separator **32** into the hopper **33** whence it is fed by way of the worm feeds **3** into the reaction zone **2***h*.

The reaction gases, cooled by the cooling racks **22**, **23**, are passed from tower **1***g* by way of duct **11***f* into a suitable heat exchanger **38**. Such heat exchanger may be conventionally provided, for instance, with a multiple series of cooling racks and are usually arranged in pairs so that one of the heat exchangers can receive the hot gas to be cooled (hot blowing), while the other, having previously received such hot gas, now receives a cooled gas (cold blowing) to impart thereto, by heat exchange, the temperature of the racks. In the illustration of Fig. 7 only one of such pair of heat exchangers is illustrated. Assuming that the racks of heat exchanger **38** have been hot blown and the reaction gases passing out through duct **11***f* are now being cooled in heat exchange relation in a second re-generator (not shown), the air pump **40** blows air through duct **41** into the heat exchanger **38**, thereby preheating the same in heat exchange relation with the previously hot blown (from the reaction gases of tower portion **1***g*) racks of the exchanger. This preheated air is then passed through duct **42** into manifold **43** and by way of the nozzles **19** into the reaction zone **2***g*.

The gas issuing from duct **36** is substantially free from undesirable impurities, it is free of steam and coal dust, and can be passed off directly to the intended industrial use. In the particular embodiment shown in Fig. 7, the amount of air introduced by way of nozzles **19** is preferably such that the combustible material circulated within the molten slag in reaction zone **2***g* is substantially completely combusted, and the gas passed off through heat exchanger is passed out of the exchanger by way of duct **39** leading to chimney elimination.

As will be apparent from the foregoing, the novel device in accordance with the invention for the improved gasification of combustible materials with gaseous endothermic and exothermic reactants to recover thereby industrially valuable combustible gases within the broad concept thereof, essentially comprises means defining a molten slag reservoir, nozzle means for introducing high velocity combustion supporting gas into said reservoir, said nozzle means being positioned and arranged to impart to molten slag in said reservoir a cycling motion, means for introducing substantially solid gasifiable combustible material such as coal into said reservoir, means for introducing into said reservoir simultaneously with said combustible material a gaseous endothermic gasification reactant therefor, and means for recovering gaseous reaction products from said reservoir.

A preferred device in accordance with the invention essentially comprises means defining a first slag reservoir reaction zone and a second slag reservoir reaction zone, nozzle means for introducing high velocity combustion supporting gas into one of said reaction zones, said nozzle means being positioned and arranged to impart to molten slag in said first reaction zone a circulating motion over to, through, and back from the other reaction zone, means for introducing combustible material into said other reaction zone, means for introducing simultaneously with said combustible material a gaseous gasification reactant therefor into said other reaction zone, and means for separately recovering the reaction gases produced in each of said zones.

It will be generally understood that it is desirable that the path of travel for the gasification reactants through the molten slag, whether in the endothermic or exothermic phase, is preferably so dimensioned and the introduction of combustible material so related thereto, that the gasification reactions between the combustible material and the gasification agents are essentially completed at the end of about one cycle along the path of travel of the combustible agent. It is however well within the skill of any competent engineer to appropriately correlate to this end the velocity of the gasification agents entering the molten slag bath, the height and/or volume of the slag bath, as well as its horizontal dimensions.

Further variations in combustion supporting gas nozzle arrangements are, for instance, illustrated in Figs. 9 and 10. As shown for example in Fig. 9, the nozzles **44** supplied by the manifold **43** are substantially horizontally disposed to propel high velocity combustion supporting gas in a substantially horizontal direction into the slag reservoir or tub **2***i*. The horizontal angular disposition of these nozzles **44**, however, is substantially similar to that of the nozzles **19** illustrated in Fig. 8 to thereby set up a substantially horizontal circulatory movement of the slag within the reservoir **2***i*, and continue the impelling of the circulatory slag current thereby created. The nozzles **45** of Fig. 10 supplied by manifold **43** are arranged at the bottom of the molten slag tub **2***j* and are mounted to issue the high velocity combustion supporting gas at an angle to the vertical, to thereby impart current movement to the slag bath substantially in the direction of the arrow.

It is understood that when proceeding in accordance with the invention, additional molten slag is continuously formed as part of the gasification reaction of the introduced combustible material. There should, therefore, be preferably provided either conventional overflow arrangements for the purpose of continuously withdrawing excess molten slag, or, alternatively, conventional means should be provided for a periodic withdrawal of such excess slag. The excess slag itself, with or without additives, may be used for the information, such as by casting or molding, of building blocks or similar materials. It may also be desirable from time to time, or, continuously (as conditions may require) to add suitable slagging additives for appropriate slag conversion of the alumina and silica constituents continuously introduced by the combustible material.

I claim:

1. In the gasification of combustible material of the coal type, the improvement comprising substantially continuously introducing such a material in substantially particled form into a molten slag below the surface thereof, substantially continuously contacting said material in said slag with a combustion supporting gas and with an endothermic gasification reactant for said material, and recovering a combustible gas mixture therefrom.

2. Improvement according to claim 1 in which said slag is substantially continuously moved in a substantially cyclic current.

3. Improvement according to claim 1 in which said combustion supporting gas is substantially continuously introduced into said slag in a direction and with a velocity sufficient to thereby cause said slag to move in a substantially cyclic current.

4. Improvement according to claim 3 in which at least a portion of said endothermic reactant is H_2O introduced by way of moisture content of said combustible material.

5. Improvement according to claim 1 in which said slag is substantially continuously moved in a substantially cyclic current, in which said combustible material and said endothermic reactant are substantially continuously endothermically reacted in a first portion of said slag current defining a first reaction zone, in which said combustion supporting gas is substantially continuously exothermically reacted with remaining combustible material in a subsequent portion of said slag current defining a second reaction zone, and in which there is separately recovered a combustible gas mix from said first zone.

6. Improvement according to claim 5 in which said combustion supporting gas is substantially continuously introduced into said slag in a direction and with a velocity sufficient to thereby cause said slag to move in a substantially cyclic current.

7. Improvement according to claim 6 in which at least a portion of said endothermic reactant is H_2O introduced by way of moisture content of said combustible material.

8. Improvement according to claim 6 in which at least a portion of said endothermic reactant is substantially continuously introduced as a gas into said slag in a direction and with a velocity sufficient to co-act with said combustion supporting gas in substantially maintaining such cyclic current.

9. Improvement according to claim 8 in which said combustible material is introduced substantially in and with said endothermic reactant gas.

10. Improvement according to claim 8 in which a portion of said endothermic reactant is introduced as a gas into said slag in said direction and with said velocity, and in which the remainder of said endothermic reactant is H_2O introduced by way of moisture content of said combustible material.

11. Improvement according to claim 10 in which said combustible material is introduced substantially in and with said endothermic reactant gas.

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