

[54] **PROCESS FOR GASIFYING GRANULATED CARBONACEOUS FUEL**

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[22] Filed: **May 26, 1972**

[21] Appl. No.: **257,432**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 167,686, July 30, 1971, abandoned.

[52] U.S. Cl. **48/203, 48/206, 48/210**

[51] Int. Cl. **C10j 3/46, C10j 3/54**

[58] Field of Search **48/197 R, 202, 203, 204, 48/206, 210**

[56] **References Cited**

UNITED STATES PATENTS

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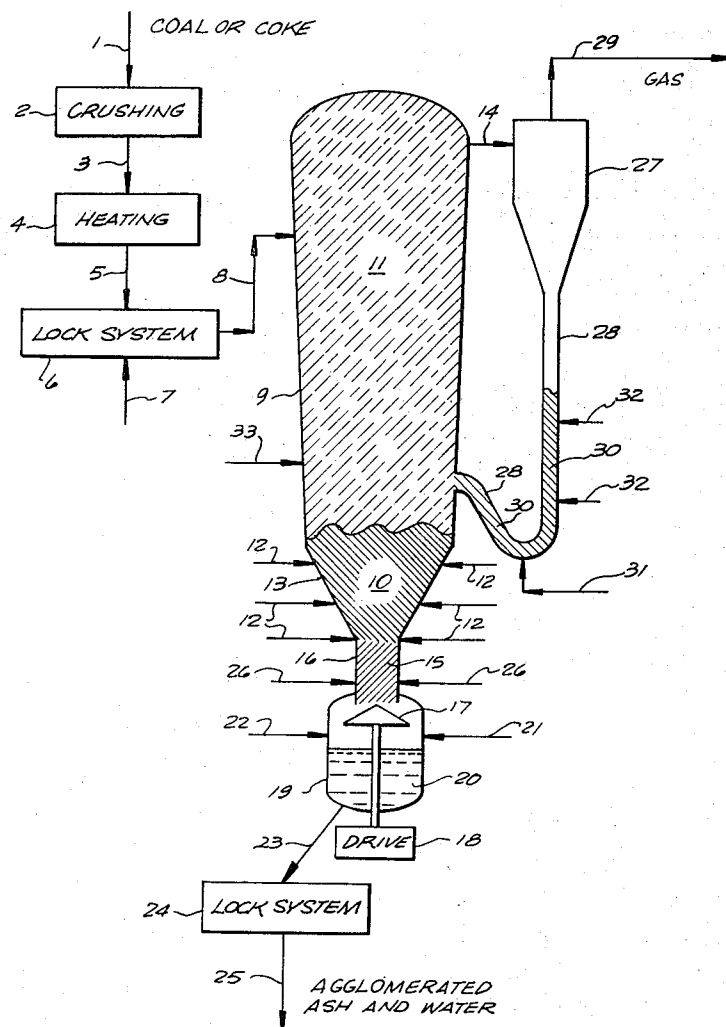
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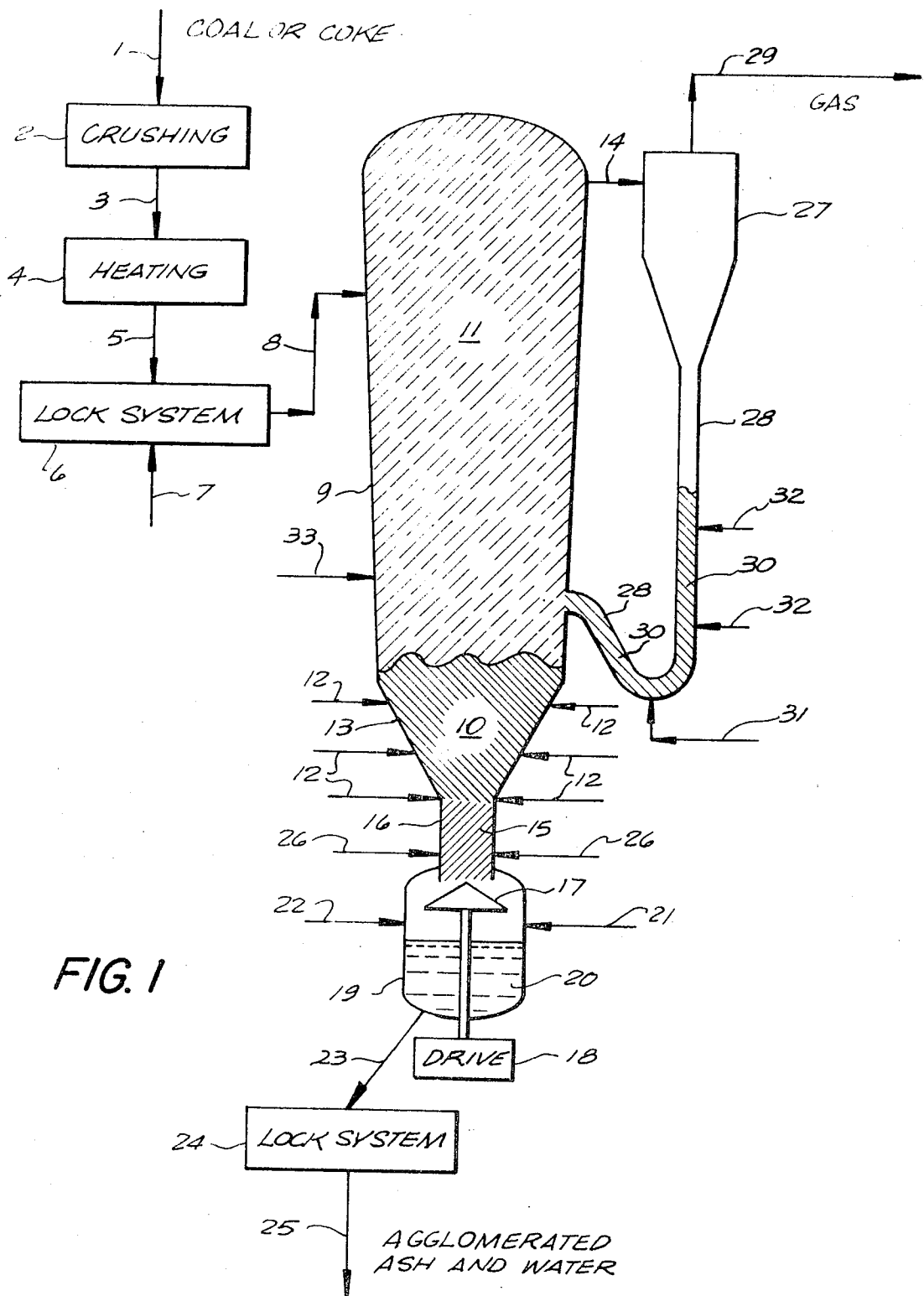
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[57] **ABSTRACT**

Granulated coals or cokes derived from coal or petroleum, in sizes up to about three-fourths inch, are fed to a "slow, stationary" fluidized bed maintained at 1,900°F to 2,100°F and supplied with gasification medium, e.g., oxygen or air and steam. There is superposed a contiguous "fast" bed of coke fines fluidized by gases rising from the "slow" bed. Both beds operate at superficial fluidizing-gas velocities greater than about 4 feet per second. Gasification products and coke fines are withdrawn from the fast bed and separated in a cyclone separator. Gasification products are discharged. Coke fines from the cyclone separator pass to a standpipe leading to a region in which the fines are fluidized by steam. They return from this region to the fast bed at a rate sufficient to maintain the fast fluidized state therein. When coals or cokes derived from coal are gasified, roughly spherical ash agglomerates form in the "slow" bed and are withdrawn from the bottom of this bed.

10 Claims, 3 Drawing Figures





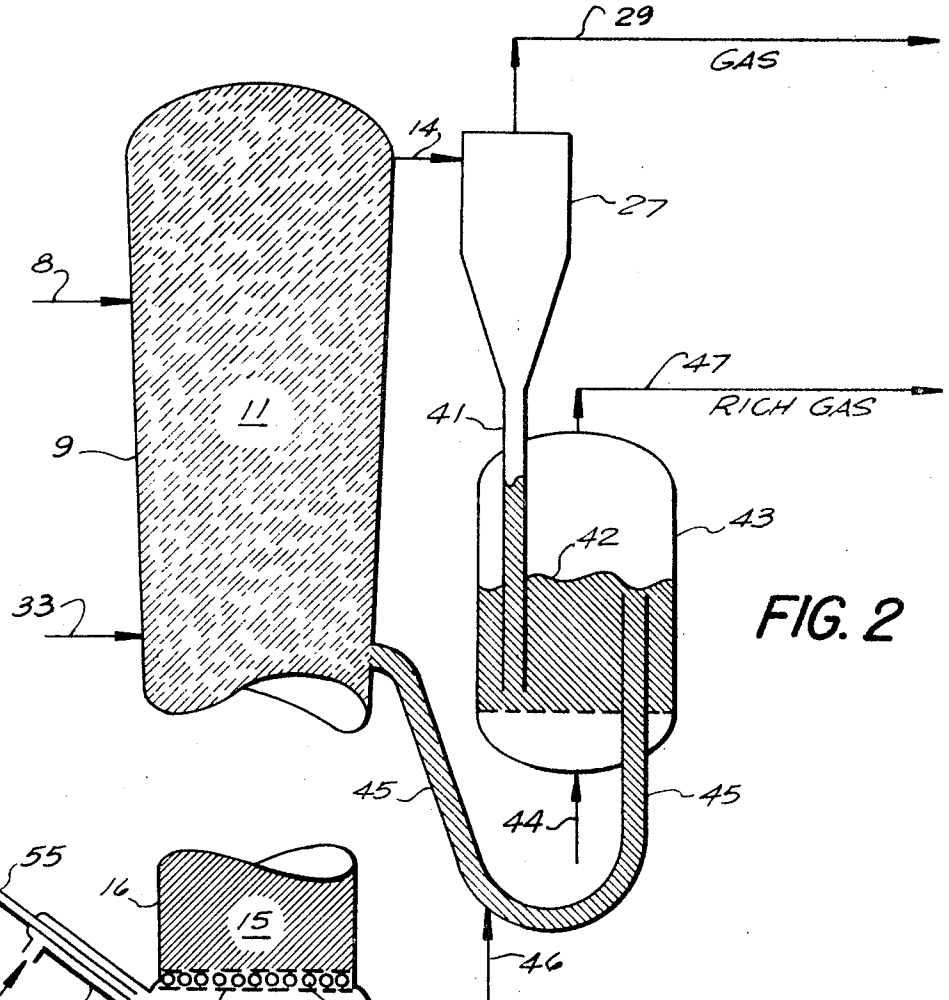


FIG. 2

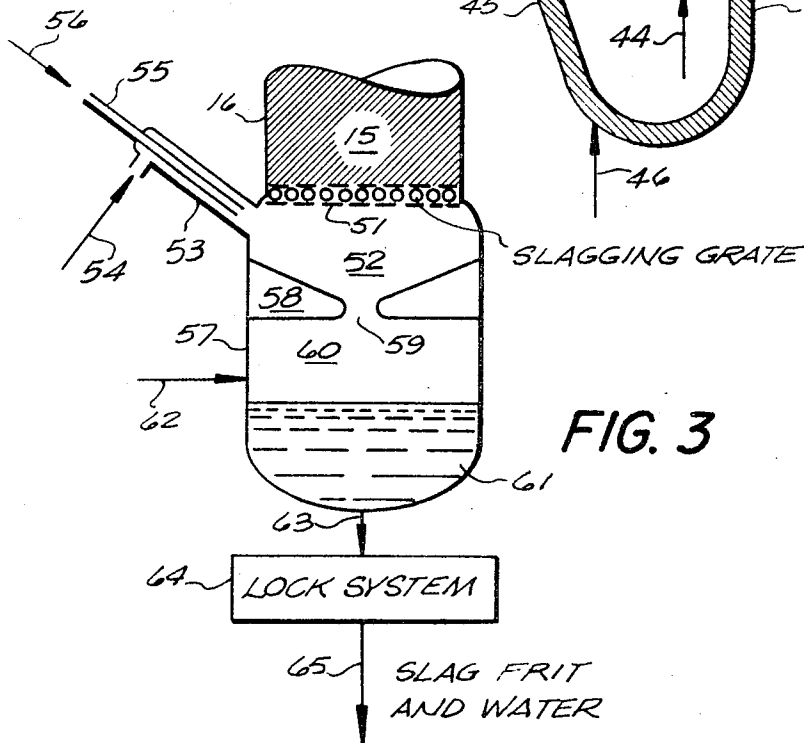


FIG. 3

PROCESS FOR GASIFYING GRANULATED CARBONACEOUS FUEL

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of my co-pending application Ser. No. 167,686, filed July 30, 1971, now abandoned.

It is well known to gasify a granulated carbonaceous fuel by supplying gasification medium, oxygen and steam for example, to a fluidized bed of the fuel; indeed, the first patent disclosing a fluidized bed was for a process to gasify solid fuel (U.S. Pat. No. 1,687,118, Oct. 9, 1928). Dent (*Transactions of the Institution of Chemical Engineers*, vol. 39, 1961, page 22) reported data indicating that a fluidized bed of coke, heated externally to a temperature above about 1,900°F, has the power to convert steam into a fuel gas in which the species H_2 , CO, and H_2O are present at concentrations which are substantially in equilibrium with carbon according to its reaction with steam. In the case of a coke derived from coal and of relatively small particle size, a fluidized bed operating at 1,900°F and at relatively low superficial fluidizing-gas velocities, below about 2 feet per second, is in peril of defluidization by virtue of formation of agglomerates of coal ash which grow in size essentially without limit and ultimately block the flow of fluidizing gas and ruin the bed's performance. Godel (U.S. Pat. No. 2,866,696, Dec. 30, 1958; *Revue generale de thermique*, vol. 5, 1966, pages 349 through 359) discovered that a bed of large coke particles fluidized at velocities approaching 10 feet per second can operate at temperatures above 1,900°F without danger. At such higher velocities, ash matter, released from the coke particles as they undergo gasification, sticks to itself to form roughly spherical agglomerated particles incorporating little carbon. He found the roughly spherical ash agglomerates to grow in size independently of one another; they do not coalesce into a large irregular agglomerated mass such as might block the flow of fluidizing gas. Godel rested his fluidized bed upon an inclined travelling grate which emerged from the upper surface of the bed. After a given ash agglomerate has grown to a size so large that it does not remain fluidized, the agglomerate sinks to the grate, which removes agglomerated ashes to an ash pit. Godel's important discovery teaches a method for removing substantially carbon-free ashes from a fluidized bed rich in carbon undergoing gasification. His apparatus is not well suited for operation at elevated pressure, desirable if gasification products are to be used or further treated at high pressure. Trouble has been experienced in gasifying highly caking bituminous coals in Godel's equipment on account of blockage of the bed by large masses of agglomerated coke. Godel's apparatus is not well suited for gasification of fine particles of coal or coke, which simply blow out of the fluidized bed of large particles.

An old idea is to circulate a hot solid into a bed of coke fluidized by steam in order to sustain the endothermicity of the reaction of carbon with steam, to provide a gas comprising mainly H_2 and CO without use of oxygen in the gasification process. In general, embodiments of this idea employ a combustion of coke with air to raise the temperature of the hot solid appreciably above that of the fluidized bed, the combustion being complete, yielding a gas containing carbon dioxide.

Raynor (*Journal of the Institute of Fuel*, vol. 25, March 1952, pages 50 through 59) described a version of this idea in which the hot solid comprised coke particles, withdrawn from the fluidized bed itself, which had been heated by combustion of the particles with air in a dilute phase riser. In another version (U.S. Pat. No. 3,171,369, Mar. 2, 1965), the hot solid comprised coal ash agglomerates formed in a fluidized combustion bed. The fluidized bed in U.S. Pat. No. 3,171,369 is lean in carbon, in contrast to the carbon-rich bed of Godel.

SUMMARY OF THE INVENTION

The invention relates to an improved method for gasifying granulated coal or coke, the coke being derived from either coal or petroleum.

An object of the invention is to provide an improved process for converting coals or cokes into gaseous fuels or gases rich in hydrogen and carbon monoxide and suitable for conversion into hydrogen or for use in a variety of syntheses.

Another object is to provide an improved process for converting coals or cokes into a gas rich in hydrogen and carbon monoxide, containing substantially no nitrogen, without use of oxygen.

Another object is to provide a process for converting cokes into carbon monoxide containing substantially no nitrogen, without use of oxygen.

Another object is to provide a process for gasifying coals or cokes derived from coal with the capability of utilizing substantially all carbon in the fuel and of discharging agglomerated ashes containing little carbon.

Another object is to provide a process for gasifying coals or cokes and providing a gasification product which contains H_2 , CO, and H_2O in concentrations standing substantially in equilibrium relationship for the reaction of carbon with steam.

According to the invention, there is provided a process for gasifying a granulated carbonaceous fuel, preferably crushed to sizes smaller than about three-fourths inch. The fuel is supplied to a vessel housing contiguous upper and lower fluidized bed zones which are at a temperature between about 1,900° and 2,100°F. The upper zone comprises a fast fluidized bed of fine particles arising both directly from the coking of fine particles present in the original fuel and from the wastage of larger particles in the fuel as they gasify. The lower zone comprises a slow fluidized bed of large particles arising from the coking of large particles present in the original fuel and also, in the case of a fuel derived from a coal, ash agglomerates. A gasification medium, such as air and steam, air and carbon dioxide, air alone, oxygen and steam, oxygen and carbon dioxide, or other suitable mixture containing O_2 and H_2O or CO_2 , is supplied to the lower zone. Products of gasification of the fuel together with fine particles are withdrawn from substantially the top of the upper zone. The products of gasification are separated from the fine particles in a cyclone separator, and products of gasification are discharged. The separated fine particles are caused to flow from the cyclone separator into a standpipe, which conducts the fine particles into a region in which they are maintained in the slow fluidized state. The fine particles are caused to flow from this region into substantially the bottom of the upper zone at a rate of flow sufficient to maintain the fast fluidized state in the upper

zone. The fine particles are brought intermittently into contact with a gas rich in steam or carbon dioxide and containing substantially no hydrogen or carbon monoxide.

Anthracites, subanthracites, bituminous coals, subbituminous coals, lignites, and cokes made from these fuels are suitable for practice of the invention. Cokes made from petroleum, coal tars, pitches, bitumens, carbonaceous matter from tar sands or oil shales, Gilsonite, kerogens, and the like are also suitable.

I will now explain the distinction between the "slow," "stationary" fluidized bed of the kind usual in normal fluidization art and the "fast fluidized bed" specified for the upper zone of the instant invention.

In a slow fluidized bed, the fluidized solid remains in place, the bed displays a distinct upper surface, and the bed is characterized by a relatively continuous solid "phase" and a relatively discontinuous gas "phase." The solid mainly occupies the so-called "dense phase," and the gas passes through the bed primarily in form of "bubbles." For a fine solid, having a mean particle size between about 50 and 100 microns, the fluidization velocity appropriate for slow fluidization is generally below about 2 feet per second.

If the fluidization velocity to a slow fluidized bed is gradually increased, the density of the fluidized bed decreases, but the rate of decrease in density with increase in velocity is not marked. Ultimately, however, a critical velocity is abruptly reached at which the density of the bed drops sharply; the bed appears suddenly to "thin out." Unless the space containing the bed is extremely tall, the gas will convey most of the bed overhead and away from the space. This critical velocity may be termed the "dilute phase transition velocity for zero transport."

If now the space be supplied at the bottom with gas at a velocity somewhat greater than this transition velocity, and if particulate solid be supplied to the bottom of the vessel at a definite rate, the solid will in general be conveyed upward through the vessel and out at the top in dilute phase transport. However, if the rate of supply of particulate solid be gradually increased, at a critical rate of supply the inventory of solid in the space will sharply increase. Dense phase regions appear, the solid in these regions tending to stream downward at a high velocity.

If the gas velocity is further increased, a critical velocity is again reached at which the inventory of solid drops, and the solid supplied to the space is again conveyed upward in dilute phase transport. This critical velocity may be termed the "dilute phase transition velocity for transport" at the rate of supply of solid to the space.

For a given rate of supply of solid to the bottom of a space, the "fast fluidized state" is a convenient term to denote the condition in the space when the prevailing gas velocity is greater than the dilute phase transition velocity for zero transport and less than the dilute phase transition velocity for transport at the given rate of supply.

The "fast fluidized bed" is in commercial use for the calcining of aluminum hydroxide to produce cell-grate alumina (see L. Reh, "Fluidized Bed Processing," *Chemical Engineering Progress*, vol. 68, February 1971, pages 58 through 63; see also U.S. Pat. No. 3,565,408, June 3, 1968). An inventory of 5 to 10 pounds of solid per cubic foot of reaction space can be achieved for

alumina of 50 to 100 microns fluidized at about 10 feet per second.

No scientific study of the fast fluidized bed is yet available, but some facts already appear clear. In contrast to the slow fluidized bed, the fast bed exhibits no upper surface but substantially fills the space available. There is a marked gradient in solid density between the bottom and top of the space, the density being greater at the bottom. The aforementioned inventory of 5 to 10 pounds per cubic foot is an average. The solid phase in the fast fluidized bed appears on the whole to be the discontinuous phase, and the gas phase appears on the whole continuous. The solid phase appears generally to take the form of falling streamers and ribbons, while the gas appears to flow upward inbetween. The gas conveys solid upward, and much "refluxing" of the solid occurs in the fast fluidized bed.

The fluidized beds of the instant invention should operate at superficial fluidizing-gas velocities greater than about 4 feet per second, preferably greater than about 7 feet per second. The large particles of the lower zone should be sufficiently large that the slow fluidized state is maintained therein; in general, the coke particles in this zone will range up to about one-fourth to one-half inch in size, if the coal or coke feed to the process contains particles of such a size, while ash agglomerates in the lower zone, if present, may range up to about one inch. The particles of the upper zone will in general range below about 100 microns in size.

The slow fluidized bed of the aforementioned lower zone operates substantially in the manner disclosed by Godel if a coal or a coke derived from coal is treated. The lower zone is preferably in form of a frusto-conical segment with the smaller cross section at the bottom and having an included angle of 60°. Gasification medium is preferably introduced into the lower zone by means of pipes penetrating the walls of the frusto-conical segment. At the above-specified superficial fluidizing-gas velocities, roughly spherical ash agglomerates grow independently of one another and without risk of massive agglomeration such as would cause blockage of flow of fluidizing gas. The ash agglomerates may be withdrawn from the bottom of the lower zone via a gravitating bed resting upon a mechanical grate. An alternative method for withdrawing ash agglomerates is via a gravitating bed resting upon a "slagging grate" of the general type disclosed by Secord (U.S. Pat. No. 3,253,906, May 31, 1966).

These arrangements are better suited for operation at elevated pressure than the arrangement of Godel employing a travelling grate.

Presence of the contiguous superposed fast fluidized bed of fine carbon particles above the slow, ash agglomerating fluidized bed allows for good utilization of fine carbon particles.

I have found, however, that the described combination of slow and fast fluidized beds is generally not capable of converting steam into a fuel gas in which the species H_2 , CO, and H_2O are present at concentrations which are substantially in equilibrium with carbon according to its reaction with steam. This is in contrast to Dent's experience, cited earlier, for a fluidized bed operating at the specified temperatures. I have found that the difficulty may be overcome, and equilibrium substantially achieved, by means of intermittent contacting of the fine coke particles of the upper zone with a gas rich in steam and substantially free of hydrogen or car-

bon monoxide. Dent believed the good kinetic performance of a fluidized bed for gasification of carbon at temperatures beyond about 1,900°F to be related to the fact that each particle of solid in a fluidized bed is brought intermittently into contact with gas entering the bed, i.e., gas rich in steam and containing no hydrogen. Be that as it may, intermittent contacting of the fine particles of the upper zone of the instant invention with such gas serves to maintain their reactivity, not only improving the approach to steam-carbon equilibrium but also promoting the production of methane.

Carbon reactivity may also be promoted by the intermittent contacting of the fine particles with a gas rich in carbon dioxide and substantially free of hydrogen or carbon monoxide.

A preferred method for bringing the fine particles into intermittent contact with a gas rich in steam or carbon dioxide is to use steam, carbon dioxide, or a gas rich in these species to aerate the region in which the fine particles are maintained in the slow fluidized state. Another method is to introduce such a gas into the upper fluidized bed zone to create a pocket of the gas in this zone.

Gas leaving the slow fluidized region, under the preferred alternative, is a gas rich in hydrogen or carbon monoxide, and can be supplied substantially free of nitrogen if the gas used to aerate the region contains no nitrogen. It may sometimes be desired to discharge this gas separately from the products of gasification discharged from the cyclone separator. The latter products could be a lean fuel gas containing nitrogen, for example, if air is used in the gasification medium, while the gas discharged from the slow fluidized region could be a rich mixture of hydrogen and carbon monoxide, if steam is used to aerate this region. Another possibility would be to make a rich fuel gas in the primary gasification step, using steam and oxygen as gasification medium, while discharging substantially pure carbon monoxide from the slow fluidized region, if carbon dioxide is used to fluidize the region.

It will be clear to those skilled in the art that the instant invention offers considerable flexibility in respect to the composition of two gas products, one discharged from the cyclone separator and a second from the slow fluidized region. Both gases contain fuel species, in distinction from the proposals of Raynor and U.S. Pat. No. 3,171,369, cited earlier. For example, a lean fuel gas from the cyclone separator could fire a gas turbine while a rich gas from the slow fluidized region could be converted to hydrogen. The hydrogen could advantageously be used to hydrolyze hydrocarbonaceous fuel according to the process of my aforementioned copending application Ser. No. 167,686, while the coke pellets made by this process could advantageously provide the feed fuel to the process of the instant invention.

The presence of the fast fluidized zone not only allows for better utilization of fine carbon particles than does Godel's arrangement, but also facilitates the feeding of a highly caking bituminous coal to the lower zone. Such coal should be fed at an elevation intermediate between bottom and top of the upper, fast fluidized zone. Fine particles coke promptly and join the particles of the upper zone. Large particles of coal undergo rapid heating as they fall through the fast fluidized upper zone, so that an outer skin of the particles is thoroughly coked by the time the particles reach the

lower zone. The height of the point of entry of coal above the lower zone should be such to allow at least about 1 second time of fall of the largest particles before they reach the lower zone. Heat exchange from the turbulent particle mass of the fast fluidized bed zone to the falling coal particles is far more effective than heat exchange from the gas flowing upward from the fluidized bed of Godel's apparatus, this dilute phase gas being relatively free of particles by comparison with the fast fluidized bed zone. Presence of a coked skin on the particles when they reach the lower zone prevents the formation of a massive agglomerate of coke therein.

There are substantial advantages in operating the process of the instant invention at elevated pressure. Availability of gaseous products at high pressure is advantageous for many uses to which they might be put — e.g., firing gas turbines, processing to provide hydrogen for the aforementioned hydrolysis, providing carbon monoxide for treatment of organic wastes at high pressure, etc. An elevated pressure promotes the formation of methane, advantageous in reducing oxygen requirements if fuel is gasified with steam and oxygen. Equipment for the process is smaller at elevated pressure and cheaper to provide. Pressures for stationary gas turbines are today generally in the vicinity of about 10 atmospheres. Gas-turbine inlet temperatures continue to rise steadily, and pressures between about 15 and 20 atmospheres are anticipated for the machines to be built within a few years for operation at temperatures beyond 2,000°F. In general, a pressure above 10 atmospheres will be preferred for the process of the instant invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention including various novel features will be more fully understood by reference to the accompanying drawings and the following description of the operation of the alternatives illustrated therein:

FIG. 1 is a schematic diagram of an embodiment of the invention for treating coal or coke produced from coal.

FIG. 2 is a schematic diagram of an alternative embodiment capable of producing both a lean fuel gas and a rich gas made without use of oxygen in the gasification medium.

FIG. 3 is a schematic diagram of an alternative arrangement for discharging ash matter from the coal gasification process.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference is now made to the schematic diagram of FIG. 1. Crushing means 2 crushes anthracite, subanthracite, bituminous, or subbituminous coal or lignite from line 1 to a size preferably smaller than about three-fourths inch. Line 3 conveys the crushed solid to drying-and-heating means 4. Line 5 carries dried and heated coal to lock system 6, which is supplied with a gas from line 7. Lock system 6 preferably has the form disclosed in my copending application Ser. No. 167,687, filed July 30, 1971, now U.S. Pat. No. 3,719,192 issued Mar. 6, 1973. Coal passes from lock system 6 into vessel 9 via line 8. In a unit of large throughput, a multiplicity of lines 8 is advantageously provided, but for simplicity of the drawing, only one line 8 is shown. Vessel 9 houses slow fluidized bed 10, comprising coke particles of larger sizes undergoing

gasification, and a contiguous superposed fast fluidized bed 11, comprising coke particles of smaller sizes undergoing gasification. Larger particles present in the coal feed fall from line 8 into bed 10 and are coked with release of volatile matter. Smaller particles present in the coal feed join the fine coke of bed 11 and are also coked with release of volatile matter.

Gasification medium is introduced into bed 10 from a multiplicity of substantially horizontal inlet pipes 12 penetrating frusto-conical segment 13 of the walls of vessel 9. The included angle of segment 13 is preferably about 60°. The gasification medium may be oxygen and steam, if a gas comprising primarily hydrogen and carbon monoxide is desired. The gasification medium may be air and steam, or air and combustion products containing carbon dioxide, if a fuel gas of low heating value is desired. Sometimes, especially for coals of low rank, the gasification medium may comprise simply air. The temperature and composition of the gasification medium are preferably adjusted so that the temperature of beds 10 and 11 is between about 1,900° and 2,100°F. The superficial fluidizing-gas velocity in beds 10 and 11 should be greater than the minimum fluidizing velocity of a bed of coal particles of substantially the largest size present in the coal feed. In general, the velocity should be greater than about 4 feet per second, and is preferably greater than about 7 feet per second.

The pressure in vessel 9 is in general preferably super-atmospheric. If, however, vessel 9 operates at substantially atmospheric pressure, lock system 6 may be omitted.

When a strongly caking bituminous coal is treated, line 8 should enter vessel 9 at an elevation between the upper surface of bed 10 and outlet line 14; the height of bed 11 and location of line 8 should be such to allow preferably at least about 1 second residence time for fine particles in the coal in bed 11 before such particles are blown out of bed 11 via line 14, this residence time being reckoned on basis of the superficial gas velocity in bed 11 and the difference in elevation of lines 8 and 12; also, the height of bed 11 and location of line 8 should be such to allow preferably at least about 1 second residence time within bed 11 for the largest coal particles as they fall toward bed 10, this time being reckoned on basis of the free fall velocity of such particles and the difference in elevation of the upper surface of bed 10 and line 8.

Under the conditions specified for beds 10 and 11, both volatile matter and coke react with gasification medium to form a mixture of CH_4 , H_2 , CO , H_2O , and CO_2 (together with N_2 if the gasification medium includes air). Gases leaving bed 11 via line 14 contain negligible amounts of tar and small amounts of hydrocarbons higher than methane.

As coke is consumed in bed 10 by gasification reactions, the larger coke particles comprising bed 10 waste away, and as a consequence, ash matter is released and coke dust is formed. The coke dust enters bed 11. At the temperatures specified for bed 10, the ash matter of substantially all coals is sticky. Ash sticks to ash, not to coke; and, as ash matter is released, ash agglomerates form. At the fluidizing-gas velocities specified for bed 10, ash agglomerates grow in roughly spherical form, and individual ash agglomerates do not coalesce to irregular masses of agglomerated ash of such large size as to block the flow of gas in bed 10.

When an ash agglomerate grows too large to remain fluidized at the velocity prevailing in bed 10, the agglomerate sinks to the bottom of bed 10 and enters zone 15 in section 16 of vessel 9. Section 16 has a substantially vertical wall, or zone 15 may sometimes advantageously be somewhat larger in horizontal cross section at bottom than at top. Zone 15 is occupied by a gravitating bed of ash agglomerates, the discharge of agglomerates from zone 15 being governed by rotating grate 17, which is provided with a suitable drive 18. Ash agglomerates drop into water pool 20 housed in chamber 19. Water is furnished to pool 20 from line 21. The cooling of the ash agglomerates in pool 20 produces steam, which enters zone 15 and flows upward therein countercurrent to the downward movement of ash agglomerates. If desired, gasification medium containing oxygen or air may be introduced into chamber 19 from line 22 in order to promote gasification of the last traces of carbon present in the ash agglomerates descending through zone 15.

Agglomerated ash and water are let down to the atmosphere through line 23, lock system 24, and line 25.

If desired, ash agglomerates may be fluidized in a portion of zone 15 by introducing additional gasification medium via several optional lines 26 at a rate to maintain an appreciably higher fluidizing-gas velocity in zone 15 than in bed 10.

Fast fluidized bed 11 is established by the circulation of coke dust through line 14 into cyclone gas-solid separator 27, and thence via standpipe-and-U-tube 28 back into bed 11 near its bottom elevation. If desired, a valve (not shown in FIG. 1) may be supplied in tube 28 to assist in control of the circulation of coke dust.

Gas product from the gasification process of FIG. 1 is discharged from cyclone separator 27 via line 29 to purification or further processing steps, for example, for removal of sulfur or conversion of carbon monoxide to hydrogen followed by removal of carbon dioxide.

Line 31 provides aeration gas to fluidized coke dust in standpipe-and-U-tube 28 with the formation in tube 28 of region 30 in which fine coke particles are maintained in the slow fluidized state.

To maintain good carbon reactivity in bed 11, it is necessary to bring the fine particles of bed 11 intermittently into contact with a gas rich in steam or carbon dioxide and containing little or preferably no hydrogen or carbon monoxide. Such intermittent contact promotes a closer approach to equilibrium for the steam-carbon reaction among the relevant gaseous species present in line 29, viz., H_2 , CO , and H_2O . The contact also promotes greater formation of methane in bed 11.

A preferred procedure for causing such intermittent contact is to provide steam to line 31 furnishing aeration gas to region 30. A gas rich in carbon dioxide may sometimes be preferred as aeration gas in line 31.

Another technique is to supply additional gasification medium, or steam or carbon dioxide, through a multiplicity of optional lines 33 near the bottom of bed 11, thereby creating pockets of such gas in bed 11 near the points of entry of lines 33 into bed 11, the pockets being lean in hydrogen and carbon monoxide.

Make-gas from line 29 may conveniently be used to supply gas to line 7.

Chars or cokes made from any of the coal types enumerated above may also be treated by the process depicted schematically in FIG. 1.

Petroleum cokes may also be treated. If a petroleum coke is used, ash agglomerates will not form in bed 10. Accordingly, equipment items 15 through 26 may be omitted in such an application of FIG. 1. Specification of a fluidizing-gas velocity in bed 10 greater than 4 feet per second is not required in order to promote regular formation of substantially spherical ash agglomerates, as in the case of a feed derived from coal. Specification of such a velocity is desirable, however, when a petroleum coke of large particle size is to be dealt with, for a higher velocity not only affords a greater capacity per unit of cross-sectional area of bed 10 but also allows feed of coke particles of larger size, reducing the crushing requirements.

For a feed derived from coal, the velocity in bed 10 should be greater than about 4 feet per second even if the feed is available only in fine particle sizes, such that no particles in the feed are sufficiently large to form a slow fluidized bed at 4 feet per second. In such a circumstance, slow fluidized bed 10 will comprise roughly spherical agglomerates of coal ash containing relatively minor amounts of incorporated carbon. In this case, the intermittent contacting of fine coke particles in bed 11 with a gas rich in steam or carbon dioxide and lean in hydrogen and carbon monoxide is automatically fulfilled by virtue of the fact that little gasification occurs in bed 10, so that such gas enters bed 11 from bed 10.

The coke pellets produced by the processes of my U.S. Pat. Nos. 3,347,561, 3,481,834, and 3,597,327, or by the process of my aforementioned copending application Ser. No. 167,686 may advantageously be gasified by the process of FIG. 1. In such an application, crushing means 2 may be omitted, and also sometimes heating means 4 or lock system 6 if the coke pellets have not been cooled or depressured respectively subsequent to their formation.

EXAMPLE

I give now an example of the invention based upon FIG. 1. Bituminous coal is supplied through line 1 in an amount comprising 87,000 pounds per hour of moisture-free coal having the following analysis (expressed in weight per cent):

69.7	carbon
5.3	hydrogen
3.8	sulfur
9.9	oxygen
1.3	nitrogen
10.0	ash

The higher heating value of the coal is 12,700 British thermal units per pound (dry basis). The coal is dried to an intrinsic moisture content of 3 weight per cent and is heated to 300°F in means 4. Make-gas from line 29 is used in line 7. Gasification medium supplied to lines 12 comprises 1,140.8 pound-moles per hour (m./hr.) of steam and 1,666.3 m./hr. of gas containing 98.0 mole per cent oxygen, 1.0 percent nitrogen, and 1.0 percent argon. The gasification medium is supplied at 1,000°F. Aeration gas from line 31 comprises 100.0 m./hr. of steam at 1,000°F. Ash agglomerates amount to 8,700 pounds per hour. Beds 10 and 11 operate at 2,000°F and 40 atmospheres. Make-gas in line 29

amounts to 8,093.5 m./hr. and has the following composition (expressed in mole per cent):

55.2	CO
32.1	H ₂
4.3	CH ₄
2.8	CO ₂
3.4	H ₂ O
1.3	H ₂ S
0.7	N ₂
0.2	A
100.0	

Turning now to FIG. 2, I describe an alternative embodiment which may sometimes be preferred. Items 8, 9, 11, 14, 27, 29, and 33 in FIG. 2 function in substantially the same manner as that already described for these items in FIG. 1. Coke fines from cyclone separator 27 pass via standpipe 41 into slow fluidized bed 42 housed in vessel 43 and fluidized with gas from line 44. Coke fines flow from bed 42 to bed 11 via standpipe-and-U-tube 45, which is aerated with gas from line 46. Gas from bed 42 leaves vessel 43 via line 47.

The slow fluidized bed 42 of FIG. 2 can be made appreciably larger in volume than the slow fluidized region 30 of FIG. 1. Accordingly, the time of residence of coke fines in bed 42 of FIG. 2 can be appreciably longer than the time of residence of coke fines in region 30 of FIG. 1. The longer residence time afforded by FIG. 2 may be preferred, for example, if it is desired to convert a coke into a fuel gas containing as little hydrogen and steam as possible. This objective might be desired if the fuel gas is to be burned ahead of a magneto-hydrodynamic electricity generator, which functions best in absence of steam. For this objective, aeration gas 44 is preferably rich in carbon dioxide and preferably contains little steam. The gas in line 47 may advantageously be joined with the gas from line 29 in this application.

Another application of FIG. 2 would use steam as the aerating gas in line 44 while using air or a mixture of air and steam as the gasification medium supplied to lines 12 of vessel 9. In this application, gas in line 29 would be a lean fuel gas containing nitrogen, while gas in line 47 would be a rich gas, substantially free in nitrogen, and suitable for further processing to provide a gas rich in hydrogen.

In another alternative using carbon dioxide as the aerating gas in line 44, a gas rich in carbon monoxide would be withdrawn via line 47. In still other alternatives, the aeration gas in line 44 would be various mixtures of carbon dioxide and steam chosen to provide a range of relative amounts of carbon monoxide and hydrogen in gas withdrawn via line 47.

Turning now to FIG. 3, I describe an alternative arrangement for withdrawing ash from gravitating-bed 15 housed in section 16 of vessel 9. In FIG. 3, bed 15 is supported by slagging grate 51, comprising closely spaced parallel stainless-steel tubes, of 5/16 inch outside diameter, say, cooled by water flowing inside the tubes (the water being supplied to the tubes and withdrawn therefrom through pipes not shown in FIG. 3). A gasification medium is supplied to space 52 below grate 51 via pipe 53 from supply 54, and fuel is supplied to space 52 via pipe 55 from supply 56. Space 52 constitutes a "forehearth" serving primarily to supply heat to the underneath sides of grate-tubes 51, and also sometimes advantageously serving as a combustion or gasification zone to consume fine sizes of coal or coke

introduced from supply 56 via pipe 55. A liquid or gaseous fuel may also be supplied from 56. The rate of fuel supply to pipe 55 and the rate of flow of gasification medium to pipe 53 are adjusted to maintain a slagging temperature in forehearth 52. Gases rising from forehearth 52 across slagging grate 51 create a zone of high temperature directly above the slagging grate, causing ash agglomerates to melt. Molten slag flows downward across slagging grate 51 and falls upon the upper, sloping surface of partition 58 dividing chamber 57 into the upper forehearth region 52 and the lower region 60. The slag flows across the upper surface of partition 58 and downward through taphole 59 in the center of partition 58, falling across space 60 into water pool 61. Notice that most of the surface or gas space "seen" by grate-tubes 51 is maintained at a high temperature, so that little radiative cooling of these tubes can occur. The sudden cooling of slag in pool 61 causes it to break apart into a frit. Water is supplied to pool 61 from line 62. Slag frit and water are removed from pool 61 via line 63, and let down to the atmosphere by means of lock system 64 and line 65.

I do not wish my invention to be limited to the particular embodiments illustrated in the drawings and described above in detail. If the quantity of rich gas made according to the embodiment depicted in FIG. 2 is large, a fast fluidized bed might advantageously be superposed above the slow fluidized bed 42 by extending the height of vessel 43, supplying additional steam via substantially horizontal pipes penetrating the walls of vessel 43, and furnishing a cyclone gas-solid separator with standpipe to return coke fines to bed 42. Other arrangements will be recognized by those skilled in the art, as well as other purposes which the invention can advantageously serve.

I claim:

1. A process for gasifying a granulated carbonaceous fuel, comprising:

- a. supplying a granulated carbonaceous fuel to a vessel housing contiguous upper and lower fluidized bed zones which are at a temperature between about 1,900° and 2,100°F, said upper zone comprising a fast fluidized bed of fine particles and said lower zone comprising a slow fluidized bed of large particles,
- b. supplying a gasification medium as fluidizing gas to said lower zone, said gasification medium being selected from the group of gas mixtures comprising oxygen and steam, air and steam, air and combustion products containing carbon dioxide, and air,
- c. withdrawing products of the gasification of said fuel together with said fine particles from substantially the top of said upper zone, separating said products of gasification from said fine particles in a cyclone separator, discharging said separated products of gasification, causing said separated fine particles to flow from said cyclone separator into a standpipe, said standpipe conducting said fine particles into a region in which said fine particles are maintained in a slow fluidized state, and causing said fine particles to flow from said region into substantially the bottom of said upper zone at a rate sufficient to maintain a fast fluidized state in said upper zone, and
- d. bringing said fine particles intermittently into contact with a gas rich in steam or carbon dioxide

and containing substantially no hydrogen or carbon monoxide.

2. The process of claim 1 in which step (d) is accomplished by supplying said gas as fluidizing-gas to said region maintained in a slow fluidized state.

3. The process of claim 2 in which said fluidizing gas to said region is selected from the group consisting of steam and carbon dioxide; and including the step of discharging gas from said region separately from said products of gasification discharged in step (c).

4. The process of claim 1 in which said granulated carbonaceous fuel is selected from the group consisting of anthracites, subanthracites, bituminous coals, subbituminous coals, lignites, and cokes prepared from anthracites, subanthracites, bituminous coals, subbituminous coals, and lignites; in which said lower zone is fluidized at a superficial fluidizing-gas velocity greater than about 4 feet per second; in which said large particles include roughly spherical particles of agglomerated ash matter; and including the step of withdrawing agglomerated ash matter from the bottom of said lower zone.

5. The process of claim 4 in which said granulated carbonaceous fuel is selected from the group consisting of caking bituminous coals, and in which said fuel is supplied to said vessel at an elevation intermediate between said top and said bottom of said upper zone.

6. The process of claim 1 in which said fluidized bed zones are at a pressure greater than 10 atmospheres.

7. A process for gasifying a granulated carbonaceous fuel, comprising:

- a. supplying a granulated carbonaceous fuel selected from the group consisting of anthracites, subanthracites, bituminous coals, subbituminous coals, lignites, and cokes prepared from anthracites, subanthracites, bituminous coals, subbituminous coals, and lignites to a vessel housing contiguous upper and lower fluidized bed zones which are at a temperature between about 1,900° and 2,100°F, said upper zone comprising a fast fluidized bed of fine particles and said lower zone comprising a slow fluidized bed of large particles, said lower zone being fluidized at a superficial fluidizing-gas velocity greater than about 4 feet per second, said large particles including roughly spherical particles of agglomerated ash matter,
- b. supplying a gasification medium as fluidizing-gas to said lower zone, said gasification medium being selected from the group of gas mixtures comprising oxygen and steam, air and steam, air and combustion products containing carbon dioxide, and air,
- c. withdrawing products of the gasification of said fuel together with said fine particles from substantially the top of said upper zone, separating said products of gasification from said fine particles in a cyclone separator, discharging said separated products of gasification, causing said separated fine particles to flow from said cyclone separator into a standpipe, said standpipe conducting said fine particles into a region in which said fine particles are maintained in a slow fluidized state, and causing said fine particles to flow from said region into substantially the bottom of said upper zone at a rate sufficient to maintain a fast fluidized state in said upper zone,
- d. supplying a gas rich in steam or carbon dioxide and containing substantially no hydrogen or carbon

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monoxide as fluidizing-gas to said region maintained in a slow fluidized state, and bringing said fine particles intermittently into contact with said gas, and

e. withdrawing agglomerated ash matter from the bottom of said lower zone.

8. The process of claim 7 in which said granulated carbonaceous fuel is selected from the group consisting of caking bituminous coals, and in which said fuel is supplied to said vessel at an elevation intermediate be-

tween said top and said bottom of said upper zone.

9. The process of claim 7 in which said fluidizing-gas in step (d) is selected from the group consisting of steam and carbon dioxide; and including the step of discharging gas from said region separately from said products of gasification in step (c).

10. The process of claim 7 in which said fluidized bed zones are at a pressure greater than 10 atmospheres.

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