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[54] UPGRADING LOW RANK COALS AS FUEL

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[58] Field of Search **44/1 R, 1 B, 1 F; 208/8**

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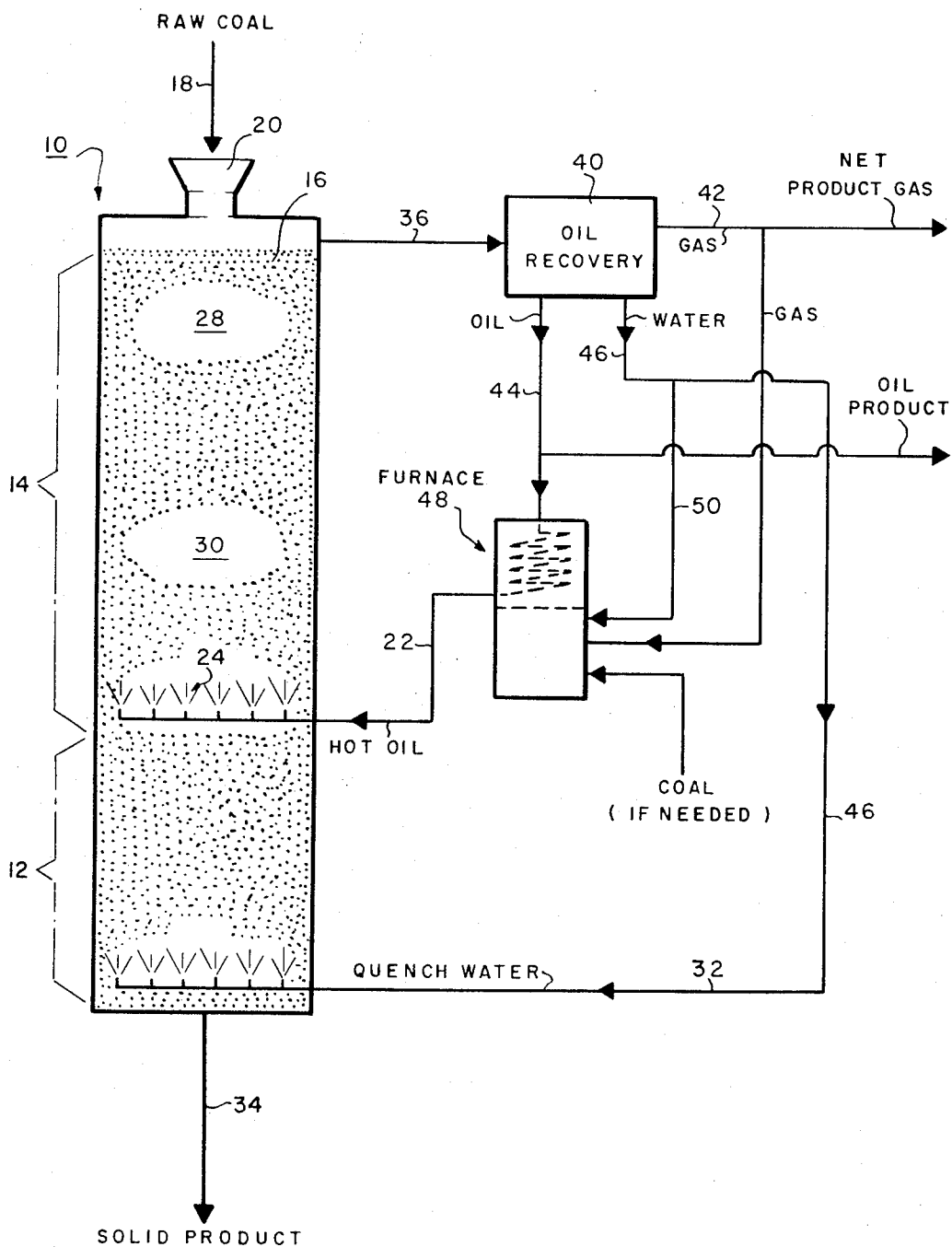
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[57] ABSTRACT

A process in which lumps of sub-bituminous or lower rank coal are heated to pyrolysis temperatures of up to about 1,000° F. by contact, preferably countercurrent, with an inert hydrogen-poor hydrocarbonaceous heat transfer fluid, preferably a coal-derived oil, thereby transforming the coal to a char product in lump form of upgraded calorific value, such product, moreover, being less pyrophoric than a char product produced by pyrolysis at the same temperatures in an inert gaseous (nitrogen) atmosphere.

12 Claims, 1 Drawing Figure



UPGRADING LOW RANK COALS AS FUEL

BACKGROUND OF THE INVENTION

This invention relates to processes for removing water from sub-bituminous or lower rank coal.

Low sulphur coal is in high demand for use a boiler fuel in the high population density areas of the United States. Large supplies of low sulphur sub-bituminous or lower rank coals exist in low population density areas of the western United States. These coals have a relatively high water content, however, ranging from about 10 to about 30 weight percent for sub-bituminous A grade coal to about 23 to about 60 weight percent for lignite. The caloric value (BTUs per unit weight) of such coals is low because of their water content. The cost of transporting such coals to distant markets is based on weight, but the salable value of such coals as fuel is based on BTU value per unit weight. Accordingly, it is highly desirable to eliminate water from such coals both to upgrade the caloric value of the coal and to reduce the transportation costs of such coal per BTU delivered.

Of course, water can be eliminated from sub-bituminous or lower rank coal simply by heating the coal to pyrolysis temperatures. However, for economic feasibility it is necessary to transfer combustion heat to the coal with simple, low cost equipment and to obtain a high thermal efficiency in the process. Also, since valuable liquid and gaseous byproducts can be recovered, it is desirable that the byproducts emanate from the process at low temperatures, for good thermal efficiency, and that such byproducts not be contaminated with nitrogen from combustion or soot and dust, for low cost recovery. No known process suitably meets these requirements.

Also, dried coal or known low temperature (700° F. - 1,000° F.) carbonization chars are highly pyrophoric, producing severe handling problems. This pyrophoricity is caused by two basic properties of such coals or chars: (1) the hygroscopicity of the coal or char, i.e., its propensity for sorbing moisture vapor, which is attended with a rise in temperature due to release of latent heat of vaporization to the coal, and (2) the inherent chemical reactivity of the particular coal or char with oxygen, i.e., its susceptibility to self-ignition. It would be highly desirable to make a char product from a subbituminous or lower rank coal so that the product is less hygroscopic and less susceptible to self-ignition than dried coals or known char products.

Prior art considered in connection with the preparation of this application includes U. S. Pat. Nos. 1,871,862; 2,057,631; 2,131,702; 2,931,765; 3,488,278; and 3,520,067.

SUMMARY OF THE INVENTION

Briefly summarized, in this invention, sub-bituminous or lower rank coal is upgraded as fuel by contacting the coal in lump form and at its ambient temperature in a contacting zone with an inert hydrogen-poor hydrocarbonaceous heat transfer fluid having a temperature of from about 650° F. to about 1000° F., in the substantial absence of molecular hydrogen, for a period of time sufficient to gradually transform the coal to a char product in lump form which is substantially completely free of water.

Preferably, according to the invention, a sub-bituminous or lower grade coal in lump form and at its ambient temperature is continuously introduced into a contacting zone at a coal inlet point near a first end of the zone. Also continuously introduced into the contacting zone, but at a fluid inlet remote from the coal inlet and near a second end of the zone, is a stream of inert hydrogen-poor hydrocarbonaceous heat transfer fluid having a temperature of from about 650° F. to about 1000° F. The coal and the heat transfer fluid are passed in countercurrent contact through the contacting zone in the substantial absence of molecular hydrogen toward opposite ends from where they are introduced. The countercurrent contacting is effected so as both to gradually cool the heat transfer fluid until, at a point near the coal inlet, the heat transfer fluid has a predetermined temperature lower than its temperature at the fluid inlet, and also to gradually heat the coal until, at a point near the fluid inlet, the coal has become transformed into a char product in lump form which is substantially completely free of water.

The char product produced according to the process of this invention has an increased calorific value. Surprisingly, such char product is less pyrophoric (less hygroscopic and less susceptible to self-ignition) than either the dried parent coal from which it is produced (where such parent coal is dried with nitrogen to a water content of 4 weight percent), or a char produced from the parent coal by pyrolysis in nitrogen at the same (or higher) temperature as the maximum temperature within the 650° F.-1000° F. range at which the char product of the invention is produced.

In one preferred form of the invention, the char product is steam stripped, suitably by contacting the char with sufficient steam to cause such stripping. Preferably, steam stripping is accomplished in concert with cooling the char. In such case, the (hot) lump char product is passed from the aforesaid contacting zone under non-oxidizing conditions into a cooling zone, where the hot char is contacted under non-oxidizing conditions with a predetermined quantity of water effective both to reduce the temperature of the char to 300° F. or lower and to generate steam which acts as a stripping agent for the char in such cooling zone. Preferably, also, the steam generated in such cooling zone is then passed into the aforesaid contacting zone for countercurrent contact with the coal passing there-through for recapture of at least a portion of the heat in the steam.

The steam stripped char product recovered from said cooling zone has unique properties. It has been unexpectedly found that the steam stripped char product is even less susceptible to self-ignition than the char product produced by this invention at the same maximum temperature but not steam stripped.

DETAILS OF THE INVENTION

Sub-bituminous or lower rank coal and not higher rank coal is processed by this invention. Under the conditions used in the present process, sub-bituminous and lower rank coal neither melts nor significantly decrepitates during or as a result of the process treatment, unlike caking-type bituminous coals, which melt and agglomerate in the course of such treatment. The sub-bituminous or lower rank coal processed according to the invention is in lump form, and normally will be "run-of-mine" coal. It is unnecessary, and from the

standpoint of keeping the cost of the char produced by the process as low as possible, it is undesirable, to comminute the coal in order to treat it by the present process. Of course any quantity of coal will have coal solids of various sizes. Ordinarily lump "run-of-mine" coal will have some fragments in small particle sizes, even 8 mesh and smaller, but the great majority of the particles will be at least $\frac{1}{2}$ inch in longest dimension or larger.

The ambient temperature of the coal will vary according to how the coal is handled prior to use in the process. If the coal is conveyed into the contacting zone directly from the mine, without intermediate storage, the temperature of the coal will approximate the temperature of the bed from which it is produced. On the other hand, if the coal is piled for holding until it is upgraded by the present process, the ambient temperature of the coal from the pile may be much higher, because of oxidative heat generation in the pile. Preferably the temperature of the coal will be no higher than about 150° F.

The hydrocarbonaceous heat transfer fluid used in the process is inert in the sense that it will not chemically react to any material extent with the coal in the contacting zone under the conditions in such zone. The heat transfer material also is poor in hydrogen content, the hydrogen-to-carbon ratio of such hydrocarbonaceous material being at most about 1.5 suitably being within the range from about 0.5 to about 1.5, preferably from about 0.7 to about 1.4, e.g. about 0.9–1.0. Suitable hydrocarbonaceous heat transfer fluids having such hydrogen-to-carbon ratios are oils derived from coal. Petroleum oils have generally higher hydrogen-to-carbon ratios, e.g. 1.5–2.0.

Hydrogen-poor hydrocarbonaceous heat transfer fluids are employed because hydrogen-rich hydrocarbonaceous materials improve the solvency power of the heat transfer fluid to the extent that excessive quantities of high-BTU constituents are extracted from the coal, undesirably reducing the BTU content of the solid fuel char produced by the process. For the same reason, the process is conducted in the substantial absence of molecular hydrogen, so as to prevent the formation in the contacting zone of hydrogen donor compounds in the oil which might improve the solvency powers of the oil.

It is preferred that the heat transfer material be a coal-derived oil which has not been hydrotreated to upgrade its content of donatable hydrogen. Such an oil may be a creosote oil suitably used as an inventory oil to start up the process, but which, on attainment of process equilibrium for a given oil introduction temperature, has become augmented and in the main consists essentially of oils derived directly from the coal being processed. Typically such an oil will have light ends which boil about 450°–500° F. and heavier ends which distill about 1000°–1200° F., a typical 50 percent off point being about 700°–750° F. Coal-derived oils which have not been hydrotreated are rich in aromatic structures such as benzenes, indene, naphthalenes, acenaphthenes, fluorenes, anthracenes, pyrenes, chrysenes, and dibenzofurans, and contain only insignificant amounts, if any, of hydroaromatic structures and phenolic structures containing donatable hydrogen atoms. Thus, the coal-derived oil will contain little, if any, octahydronaphthene, indane, tetralins, dihydronaphthaene, tetrahydroacenaphthene, hexahydrofluorene, octahy-

droanthracenes, decahydropyrenes, tetrahydroanthracenes, hexahydropyrenes, or dihydropyrenes. Small amounts of such persaturate structures as perhydroindane, decalins, perhydroacenaphthenes, perhydroanthracenes, and perhydropyrenes can be tolerated.

The heat transfer fluid, preferably a coal-derived oil, is introduced into the fluid inlet in the contacting zone at a temperature from about 650° F. to about 1000° F., suitably in the vapor, liquid, or mixed phase, preferably the mixed phase (partially liquid). At equilibrium composition, a coal-derived oil normally will have substantial quantities thereof in the vapor phase when the oil is introduced into the contacting zone at the fluid inlet at the higher temperatures within the aforesaid 650° F.–1000° F. range.

At equilibrium conditions, and especially at oil temperatures of from about 750° F. – 900° F., when the oil is injected into the contacting zone, sufficient quantities of oil are derived from the coal treated by the process that the coal-derived oil can be recycled to the fluid inlet of the contacting zone without having to add more hydrocarbonaceous heat transfer fluid to maintain the process in fluid balance. At the temperatures at which the hydrocarbonaceous heat transfer fluid is introduced into the contacting zone, no advantage is obtained by using a petroleum oil as an inventory oil to start up the process or as a diluent or makeup oil, for petroleum oils are less refractory than the coal derived oils, and consequently, undergo cracking, being converted to light ends, gas and coke (which deposits on the char product). Use of petroleum oil as a heat transfer agent, therefore, requires makeup oil to maintain fluid balance, unlike the use of coal-derived oil, as aforesaid.

The feed rate at which the heat transfer fluid is introduced into the contacting zone is sufficient to provide from about 1 to about 10 lbs. of such fluid per lb. of coal introduced into the contacting zone. Residence time of the coal in the contacting zone suitably is within the range from about 1 to about 120 minutes, preferably, from about 5 to about 30 minutes.

The contacting zone into which the lump coal and the inert heat transfer fluid are introduced preferably is operated at substantially atmospheric pressure, although slight sub-atmospheric or relatively low super-atmospheric pressures, e.g. about 25–50 psig suitably may be employed if desired. The coal and the heat transfer fluid are preferably countercurrently contacted in the contacting zone, suitably by passing the coal downwardly through a rising stream of the fluid, but alternatively the coal may be passed upwardly, as by elevators, through a downflowing stream of the heat transfer fluid, using countercurrent contacting devices familiar to those in the art.

The invention will be further understood from the following description of a preferred mode of conducting the process, taken with the examples which follow such description.

DESCRIPTION OF THE DRAWING

The sole FIGURE is a schematic flow path illustrating a preferred mode of practicing the invention, wherein the contacting and cooling zones are included in one vessel.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the FIGURE, an atmospheric pressure reactor 10 is illustrated which has a lower cooling zone 12 and an upper contacting zone 14 that is sized to be in flooded condition with a pool 16 of a preferred heat transfer fluid of a coal-derived recycle oil.

Run-of-mine sub-bituminous or lower rank coal 18 in lump form is continuously introduced into contacting zone 14 and into pool 16 through a coal inlet 20. A stream of hot coal-derived recycle oil from line 22 at least partially in liquid phase is injected into a lower portion of pool 16 through an oil inlet 24 which is remote from coal inlet 20, and which suitably takes the form of an oil distributor device located near the centerline of reactor 10. The hot oil has a temperature within the range from about 650° F. to about 1,000° F., preferably from about 750° F. to about 900° F., having been preheated to such temperature in furnace 48. The hot oil provides the heat for raising the temperature of the coal.

In contacting zone 14, the coal lumps move downwardly from an upper portion 28 of the contacting zone in countercurrent contact with rising streams of the hot oil, hot oil vapors, steam and noncondensable coal gases. In such upper portion 28, the temperature of the coal progressively increases with absorption of heat from the rising streams of heat transfer fluids until water in the coal begins to evaporate. The rise in temperature of the coal slows as heat transferred to the coal is consumed as heat of vaporization. Some noncondensable gases are released from the coal in this portion of the contacting zone. Temperatures in the upper portion 28 of the contacting zone are within the range from about 100° F. at the top thereof to about 400° F., preferably about 212° F. to 300° F. at the bottom thereof.

As substantially most of the water evaporates from the coal, the temperature rise of the coal speeds up, progressively increasing as the downwardly moving coal particles pass into a lower portion 30 of contacting zone 10. In such lower portion 30, some liquid and gaseous materials are liquefied and pyrolyzed from the coal, augmenting the coal-derived oil and producing some noncondensable and condensable gases.

Temperatures in the lower portion 30 range from at least about 212° F. in the portion adjacent to upper portion 28 to the hottest temperatures commensurate with the temperature of the introduced oil, which occur at the level of oil inlet 24. The temperature of the coal progressively increases as it travels through the lower portion 30 of contacting zone 10. The passage of the coal solids is controlled such that the coal solids suitably attain a terminal temperature in contact zone lower portion 30 which approaches and preferably is substantially the same as the temperature of the hot recycle oil at the point of injection into contacting zone 10.

In the lower portion 30 of contacting zone 10, the coal has been transformed to a char in lump form which is substantially completely free of water. Its content of liquefiable tar materials and water will decrease according to the maximum temperature it attains in such lower portion 30 of the contacting zone.

From contacting zone 10, the char solids pass downwardly into cooling zone 12, where the hot char solids

are cooled by transfer of heat to a rising stream of steam. The steam is generated by contact of the hot char solids with a predetermined quantity of water in cooling zone 12 effective to reduce the temperature of the char solids to no greater than about 300° F. The quench water is introduced near the bottom of reactor 10 by line 32. The stream generated by contact of the hot char solids and the water rises through the char solids to provide essentially a simple, gas-to-solids heat exchange. The rising stream of steam also serves to strip any liquefied coal and recycle oil adhering to the char solids.

The steam from the cooling zone 12 passes upwardly into the contacting zone supplementing the hot oil, any hot oil vapors, and the liquid and gaseous materials released from the coal which are rising in the contacting zone in countercurrent contact with the descending coal solids and being cooled by the entering coal. Thus, contacting zone 12 and particularly upper portion 28 serves as a byproduct cooling zone as well as a coal heating zone.

The lump char product is removed by line 34 from the bottom of reactor 10, suitably at a temperature within the range from about 200° F. to about 300° F.

Although in the embodiment illustrated, quench water is injected directly into reactor 10, alternatively, the unquenched, hot char solids may first be transferred under non-oxidizing conditions through a flow control valve into another vessel, such as onto a screen in a rotating drum, and there contacted with the quench water under non-oxidizing conditions, stripped oils passing through the screen and being cycled for heating in furnace 48 for recycle to fluid inlet 24. The steam generated by contact with the hot char may be recovered and introduced into contacting zone 14, either in the lower portion 30 or upper portion 28 thereof, for recovery of heat in the steam.

At the top of reactor 10, the cooled vaporous and liquid effluent streams are removed by line 36. Suitably, the temperature of such streams is within the range from about 100° F. to about 400° F., e.g. from about 200° F. to 300° F. The liquid stream includes the coal-derived oil introduced through inlet 24, liquefied oil from coal 18, and water. The gaseous stream includes noncondensable gases emitted from the coal, oil vapors from the coal-derived oil recycle stream, vaporous oils from the coal, steam, and entrained water and oil. The effluent streams are passed by line 36 to oil recovery zone 40, where noncondensable gases are separated from the other effluent materials and removed by way of line 42.

In oil recovery zone 40, vaporous oil materials are condensed into liquid form, and oil is separated from the water and recovery by way of line 44. The oil in line 44 is conveyed through heating coils in furnace 48, in which some or all of the noncondensable gases recovered from oil recovery zone 40 are combusted to provide the heat for increasing the temperature of the oil, with supplemental coal or other fuel being fired to the furnace as necessary.

Water from oil recovery zone 40 is removed by line 46 for recycle to line 32 in sufficient quantities as the quench water for the process. Any excess water from line 46 not needed for quench is passed by line 50 to furnace 48 to burn phenols dissolved in the water. Sufficient oil is recovered from oil recovery zone 44 for preheating in furnace 48 and recycle to contacting

zone 14 to maintain pool 16 in fluid balance so that no make-up oil is necessary. At oil injection temperatures from about 750° F. to about 900° F., preferably about 800° F., sufficient oil is recovered from contacting zone 14 for recycle in fluid balance that a surplus of oil product is produced. Preferably, the net oil produced is only the lightest oil obtained from the last stages of partial condensation in oil recovery zone 40 and boils from about C₅ to about 430° F.

The following examples will further illustrate the process of this invention.

EXAMPLE 1

In order to eliminate the process described above, a relatively large quantity of coal was processed with a small quantity of recycled oil, using a reactor connected to a condenser product receiver system combined to an oil feed line so that the recovered feed and product could be recycled. Water was separated from the oil product by a reboiler-reflux system, and gaseous effluent was measured through a dry test meter. The entire system was operated at essentially atmospheric pressure. Batches (750 to 950 gm) of wet $\frac{3}{4}$ by $\frac{1}{2}$ inch lumps of Wyodak coal were charged to the reactor and the reactor was plunged in a sand bath at 800° F. and immediately connected to the other parts of the system. One thousand grams of raw creosote oil was introduced into the reactor at nominally 1.5 wt oil/wt. wet coal/hr. to heat up the coal. The coal normally required about 15 minutes to reach an operating temperature of 800° F. The oil feed was held constant an additional 15 minutes after reaching operating temperature, and the feed was then terminated and a small nitrogen flow introduced for about 10 minutes to purge oil from the lines and the reactor. Then the reactor was removed from the sand bath, and a fresh reactor charged with a bath of coal was introduced to repeat the cycle. The original oil charged to the system contained about 20 percent toluene to aid in oil-water separation. After about 28 batches of coal had been treated, the oil appeared to have equilibrated and remained essentially constant in composition for the next 24 batches. However, the toluene in the original charge essentially disappeared, indicating that the condensation and recovery of light liquids in the effluent gas was imperfect and explaining the fact that the material balance runs usually achieved only about 98 percent recovery on oil charged. In the course of treating 52 batches, 94 lbs. of coal were processed with a system oil inventory of 2.3 lbs. It was never necessary to add make-up oil even though minor leaks and spills did occur.

The experimental results for the foregoing runs are summarized in Table I below.

TABLE I

Yield as Wt. % of Wet Wyodak Coal Charged

Batch Numbers	Char	Water	Gas	Oil	Total
1-10	54.4	30.0	-a	-b, d	-
11-18	55.3	36.0	-a	-b, d	-
19-28	54.9	36.1	5.2 ^f	1.8 ^e	98.0
29-39	56.2	34.8	4.8 ^f	0.7 ^e	96.5
40-44	55.0	33.0	4.9 ^f	-d	-
45-52	55.3	35.2	4.7 ^f	2.1 ^e	97.3
Average	55.2	34.9	4.9 ^f	-	-
Fischer Assay	55.4	32.9	4.9	6.8	100.0

^aNot measured.

^bNot determined because oil/water separation after batch 10 was imperfect.

^cSafety valve popped, oil loss estimated as 0.1% on coal.

^dGasket on oil feed reboiler leaked.

^eIncludes 0.2% oil caught on paper towel under packing gland leak in feed pump circulation system.

^fBased on average gas gravity from spot samples of 1.1 × air.

As shown by Table I, the average char yield is consistently close to about 55 percent, which is coincidentally the same as that obtained on Fischer Assay of a typical sample of the wet Wyodak coal. Gas make is consistently close to the 4.9 grand average and is equal to the Fischer Assay gas make. The grand average water yield of 34.9 percent is higher than a Fischer Assay yield of 32.9 percent. This is consistent, however, with a lower oxygen content found to be in the oil product compared by those from Fischer Assays, and set out below in Table II, and may be the result of the oil treatment. Because of the relatively small quantities involved and the possibility of leaks and poor gas clean up, the small shortages in coal material balance show up in the oil yield. By difference, it averages 5.0 percent versus 6.8 percent for Fischer Assay. The oil, however, was a much lighter, lower oxygen content material. The oxygen content of the oil from this process is compared to that of Fischer Assay tar below:

TABLE II

Oxygen Content of Raw Oil Product	Wt. % Oxygen in Tar
This process	5.3
Fischer Assay	7.9

EXAMPLE 2

The effect of conducting the process at the different temperatures of 700°, 800°, 900°, and 1000° F. was determined using the process procedure set out above in Example 1. The results are set out below in Table III.

TABLE III

Temp., °F.	700	800	900	1000
Yields, Wt. %				
Wet Feed				
Char	63.8	56.1	51.5	49.8
Water	32.9	35.1	40.1	40.7
Oil	-2	2.1	1.4	0.7
Gas	-	5.1	6.1	-
Total	-	98.4	99.1	-

As shown in Table III, the char yield decreases and the water and gas yields increase consistently with increasing temperature. Apparently with Wyodak coal in the equipment utilized, there is a maximum of oil production in the vicinity of 800° F. It is believed that this maximum results from the interplay of the two competing reactions involving a primary production of oil from coal in the liquefaction process and a cracking and oxygen elimination occurring when the oil is heated for use as a heat transfer agent. The temperature at which maximum oil production occurs will probably differ from various reactor configurations and for different coals.

The char quality, as measured by Btu content, obtained on treating the coals at the different temperatures was found to be high and to increase as temperature was increased, as illustrated in Table IV.

TABLE IV

	Btu/lb.
Raw Coal (31% H ₂ O)	8,147
Dried Coal (4% H ₂ O)	11,412*
Bone Dry Coal	11,887*
700° F. Char	-
800° F. Char	12,594
900° F. Char	12,812

1000° F. Char

*Based on coal dried in a nitrogen atmosphere, coal dried commercially in an atmosphere containing some oxygen could be lower.

EXAMPLE 3

This example shows that a char product of the present process is less pyrophoric than char products produced by pyrolysis at the same (or higher) temperatures immersed in an inert nonhydrocarbon gaseous (nitrogen) atmosphere.

Reduced hygroscopicity. When subjected to an atmosphere containing water vapor, chars made by the present process absorb less water than the parent coal dried to 4 percent water content or chars made by pyrolysis in an inert nitrogen atmosphere. Data showing moisture absorption levels for samples equilibrated in atmospheres controlled at several humidities are shown below in Table V. Chars A and B in Table V were prepared by the present process as described in Examples 1 and 2.

TABLE V

Sample	Moisture retained after equilibrium at humidities shown expressed as pct. of dry charge				
	97%	88%	73%	43%	7.5%
dried sub-bit. coal	30.2	18.7	14.8	10.5	3.8
char, made in N ₂ at 900° F.	21.2	11.9	9.9	8.4	3.3
Char A made at 750° F.	20.8	10.5	8.1	5.2	2.7
char B made at 900° F.	18.8	10.7	9.3	6.2	3.0

Reduced reactivity. When tested in an adiabatic calorimeter which maintains an environment around the sample at the same temperature as the sample which is heating spontaneously due to reaction with air or oxygen being passed through it, chars produced by the present process exhibit a lower rate of reactivity with oxygen than either the parent coal dried to 4 percent water content or chars made by pyrolysis of the parent coal in an inert nitrogen atmosphere at a like elevated temperature as that employed in the process. This is particularly true for chars produced at elevated temperatures within the 650° F. to 1000° F. range. Steam stripped chars of this process produced at lower temperatures within such range are especially less reactive. This is shown by the data below in Table VI. In Table VI, the measure of reactivity used is the rate of temperature increase in degrees fahrenheit at a temperature of 235° F., using oxygen as the oxidant.

TABLE VI

Sample	Reactivity temp. increase (°F/Hr) at 235° F.
Dried sub-bit. coal	466
Char made in N ₂ at 900° F.	447
Char A made at 750° F.	406
Char C made at 750° F., steam stripped	225
Char B made at 900° F.	273

From both Table V and Table VI, it is seen that char A made at 750° F. is less pyrophoric than the dried parent coal and a char made by pyrolysis of such coal under nitrogen at 900° F. because char A is less hydroscopic and less reactive to oxygen than either the dried

parent coal or the char made in nitrogen at 900° F. The same is true for char B, but to a much greater extent. Steam stripping of char A to make char C reduced the reactivity of char A to below that of char B.

Having now described in detail our invention, various changes and alterations in the process may be made by those skilled in the art within the spirit of the process described to accomplish the same end result. Such changes and modifications are deemed within the scope of the invention if fairly comprehended in our invention as claimed.

We claim:

1. A process for upgrading subbituminous or lower rank coal as fuel, which comprises:

introducing said coal in lump form and at ambient temperature and a hydrogen-poor coal-derived oil having a temperature of from about 650° F. to about 1000° F. into a contacting zone, contacting said coal with said oil in said contacting zone in the substantial absence of molecular hydrogen for a period of time sufficient to gradually transform the coal to a char product in lump form which is substantially completely free of water, and separately withdrawing coal-derived oil and char product in lump form from said compacting zone.

2. The process of claim 1 in which said coal-derived oil has a hydrogen to carbon ratio of less than about 1.5.

3. The process of claim 1 further comprising: removing a fluid effluent including coal-derived oil and vaporized water from said contacting zone, recovering said coal-derived oil from the remainder of said fluid effluent in sufficient quantity for recycle to said contacting zone in oil balance, and introducing said coal-derived oil into said contacting zone at said temperature.

4. The process of claim 1 further comprising contacting said char product with steam so as to steam strip such char product.

5. A process for upgrading subbituminous or lower rank coal as fuel, which comprises:

continuously introducing said coal in lump form and at ambient temperature into a contacting zone at a coal inlet point near a first end of said zone, continuously introducing a stream of inert hydrogen-poor hydrocarbonaceous heat transfer fluid at least partially in liquid phase into said contacting zone at a fluid inlet point remote from said coal inlet and near a second end of said zone, said hot heat transfer fluid having a temperature of from about 650° F. to about 1000° F., passing said coal and said heat transfer fluid in countercurrent contact through said contacting zone in the substantial absence of molecular hydrogen both to progressively cool said heat transfer fluid, until such fluid near said coal inlet has a predetermined temperature lower than its temperature at said fluid inlet, and to progressively heat said coal, until such coal, near said fluid inlet, has been transformed to a char product in lump form which is substantially free of water, continuously withdrawing heat transfer fluid from said contacting zone near said first end, and continuously withdrawing char product in lump form from said contacting zone near said second end of said contacting zone.

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6. The process of claim 5 wherein said hydrocarbonaceous heat transfer fluid has a hydrogen to carbon ratio of from about 0.5 to about 1.5.

7. The process of claim 5 wherein said contacting zone is operated at substantially atmospheric pressure. 5

8. The process of claim 7 wherein said hydrocarbonaceous heat transfer fluid is a coal-derived oil having a hydrogen to carbon ratio of from about 0.7 to about 1.4.

9. The process of claim 8, further comprising recovering said oil from said first end of said contacting zone in sufficient quantity for recycle in fluid balance to said second end of said contacting zone. 10

10. The process of claim 9, wherein said oil introduced into second end of said contacting zone has a temperature within the range from about 750° F. to about 900° F. 15

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11. The process of claim 7 further comprising: passing said hot char from said contacting zone, into a cooling zone under non-oxidizing conditions, and,

contacting said hot char in said cooling zone under non-oxidizing conditions with a predetermined quantity of water effective to reduce the temperature of said char to no greater than about 300° F. and to generate steam as a stripping agent for said char in said cooling zone.

12. The process of claim 11 further comprising passing said steam from said cooling zone into said contacting zone for countercurrent contact with said coal passing therethrough effective to transfer at least a portion of the heat of said steam to said coal.

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