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3,520,067

COAL DRYING

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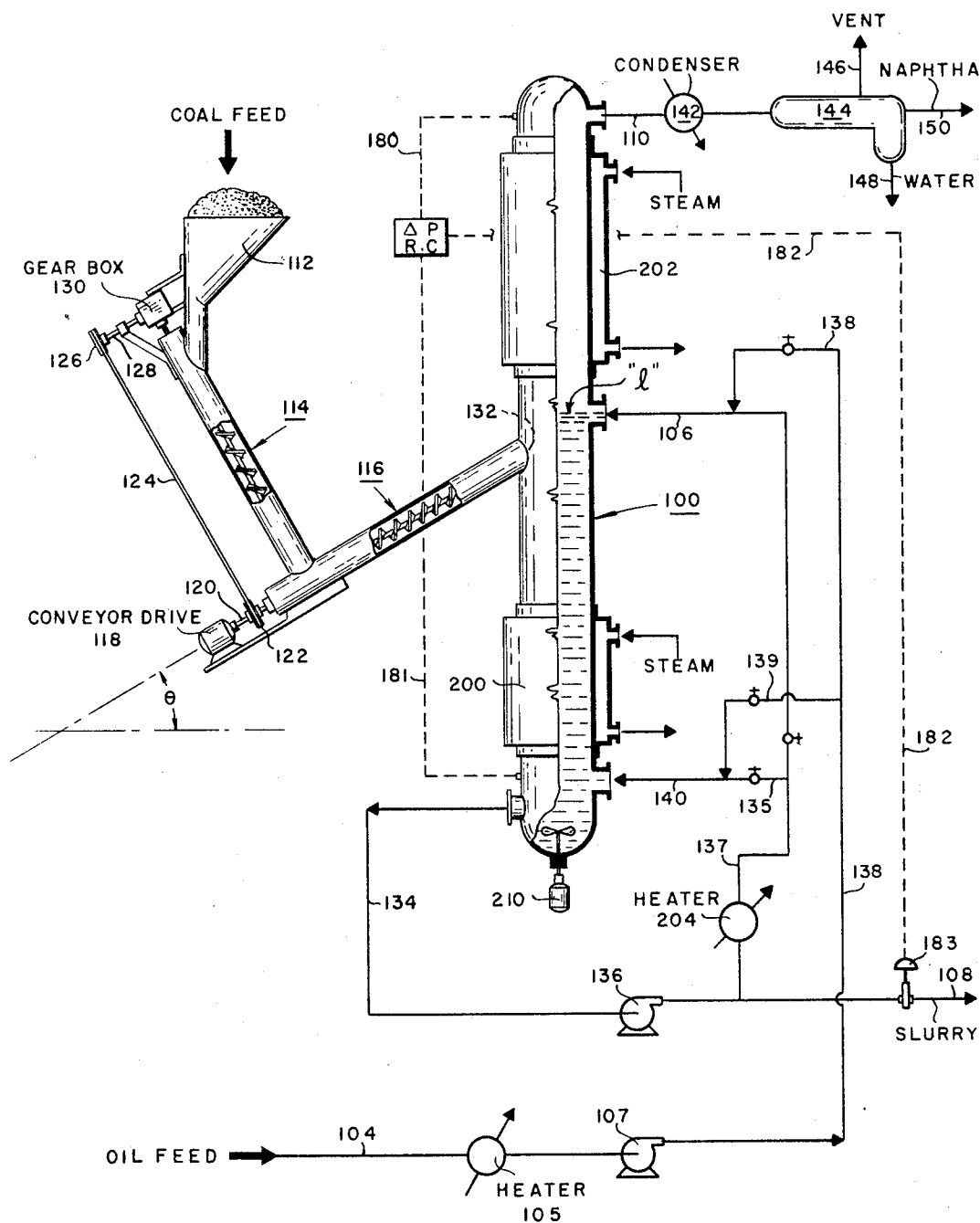


FIG. 1.

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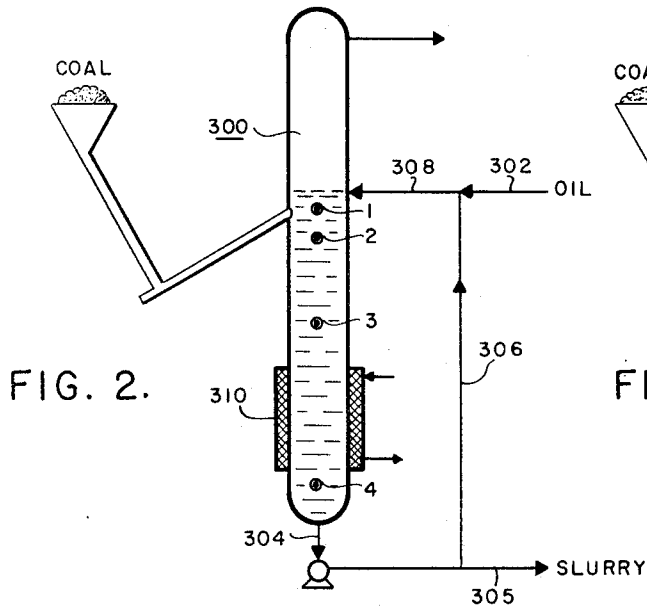
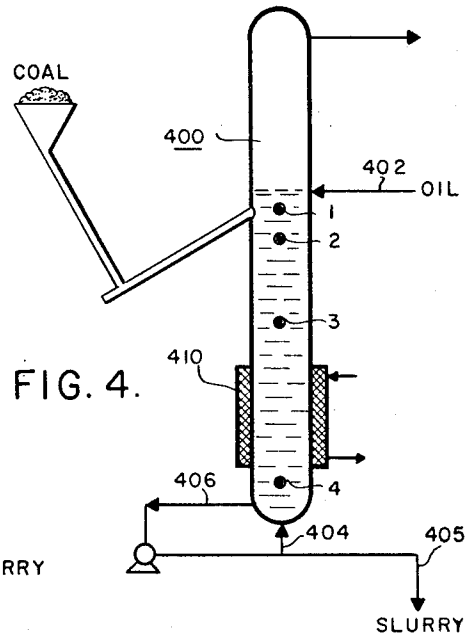
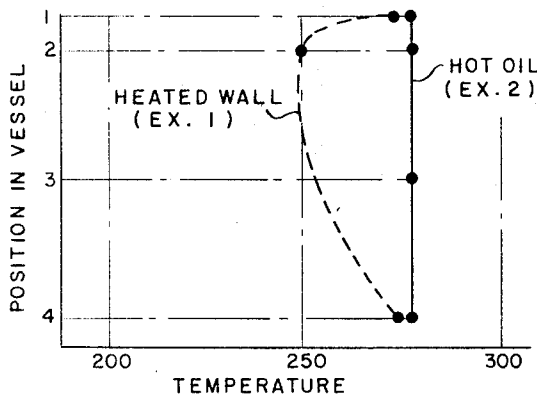
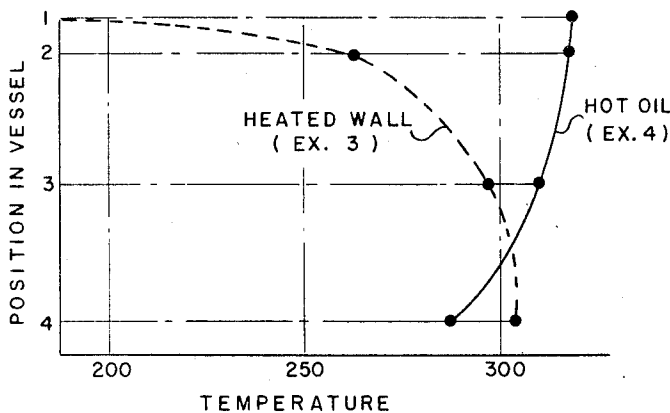
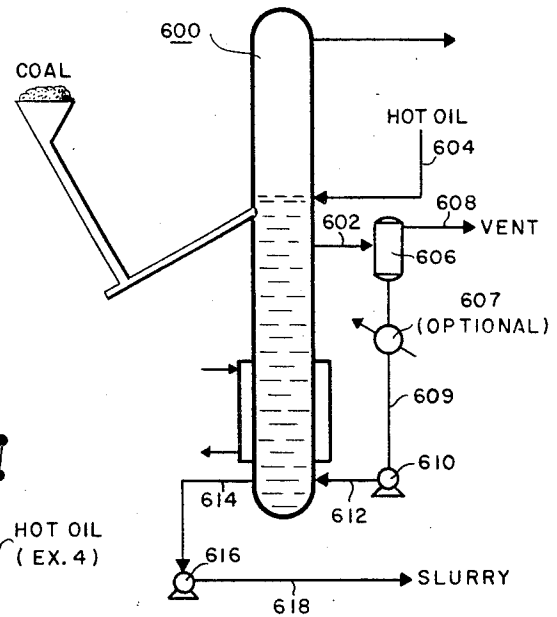
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2 Sheets-Sheet 2



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COAL DRYING

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10 Claims

ABSTRACT OF THE DISCLOSURE

An apparatus and method for drying coal particles are disclosed. Coal is moved upwardly in a screw conveyor and introduced adjacent to but below the surface of a pool of a heat transfer liquid (such as oil) in a confined drying zone. To provide heat for vaporization of water, the slurry of solids in heat transfer liquid is preferably removed near the bottom of the drying zone, heated, and reintroduced into the drying zone at about the surface of the drying liquid.

Drying conditions include a temperature from 220° F. to 600° F.

The present invention relates to the drying of coal. More particularly, it relates to the drying of crushed coal prior to liquefaction thereof. In its most specific aspects, the present invention relates to the drying of coal by direct heat transfer from a heat transfer fluid under conditions which minimize foaming and gas slugging in the drying zone.

Coal has been dried by contact with hot gases. However, due to the danger of explosion or fire if oxygen is present, and to the need for grinding the coal to small (e.g., <4 mesh) sizes, the gas-drying of coal is not well adapted for use in a coal liquefaction plant. By contrast, the present invention maintains the coal in a slurry during the drying process, and that slurry can be charged directly into a liquefaction reactor. The heat transfer liquid employed in the present process can be the same hydrocarbon liquid used as a solvent in the liquefaction reactor, thus avoiding the need for separate handling of the drying liquid and reaction solvent. The present process is well suited for incorporation into a liquefaction scheme using a hydrogen-donor solvent, since such solvents are generally high-boiling and otherwise well adaptable for service in the drying process of the present invention. Suitable liquefaction processes are disclosed in U.S. Pat. 3,018,241 and U.S. Pat. 3,117,921.

In attempting to dry coal in a heat-transfer liquid, a number of problems must be solved. It has been found that the rapid evolution of steam may cause frothing and slugging if the coal is introduced anywhere except near the surface of the heat-transfer liquid. Further, in order to assure that the major part of the water is vaporized while the coal is near the surface, the heat input to the drying zone should be directed to that area. Introduction of coal into the vapor space above the slurry creates problems in separating the fine particles from the gas phase. Another problem is the introduction of coal into the drying zone in a manner which avoids gas leakage and solids plugging. Star wheel feeders are troublesome and tend to plug as the coal becomes wetted by the evolved vapors. Screw conveyors ordinarily tend to allow vapor or liquid leakage, but when used in accordance with the present invention are entirely suitable.

The invention will be more clearly understood by reference to the discussions below which are directed separately to the apparatus and to the process.

FIG. 1 is an elevational section of the apparatus of the present invention, schematically showing the flow of the various streams;

FIG. 2 is a schematical diagram of the circulation sys-

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tem used in Examples 1 and 2, showing the points at which temperatures were taken;

FIG. 3 illustrates the temperature profiles for Examples 1 and 2;

FIG. 4 is a schematic diagram of the circulation system used in Examples 3 and 4, showing the points at which temperatures were taken;

FIG. 5 illustrates the temperature profiles for Examples 3 and 4; and

FIG. 6 shows schematically the circulation system for the improved process shown in Example 5.

THE APPARATUS

The apparatus of the present invention can best be understood by reference to the drawings wherein, in FIG. 1, and elevational section of the apparatus of the present invention is shown to comprise a vertically disposed elongated vessel 100 into which coal is fed by way of feed means 116. Oil is fed from feed line 104. Recirculating oil is introduced by way of line 106. Slurry is removed from the system by way of line 108, and vaporous products are removed overhead by way of line 110.

The coal feed, comprising crushed coal having a particle size preferably no greater than ½ inch, is introduced into a feed hopper 112, from whence it is passed into a first screw (or drag-type) conveyor 114 which is downwardly inclined and which communicates with an upwardly directed screw conveyor 116. For conveyors smaller than about 3 inches in diameter, screw conveyors are preferred. For conveyors larger than about 3 inches in diameter, drag-type conveyors are preferred. Using screw conveyors as examples, the conveying screws may be driven by a common motor such as the electric driver 118 which is connected to the screws by way of the shaft 120, the sheave 122, the belt 124, the sheave 126, the shaft 128, and the gear reducer 130. The first conveyor 114 is driven at a slower speed than the second conveyor 116 so as to prevent packing and accumulation of the coal within the conveyor 114. The conveyor 116 is upwardly inclined, at an angle θ so as to prevent the passage of vapors back through the screw conveyors of the feed system. The angle θ may range from 15° to 75°. It has been found surprisingly that by providing an upwardly directed conveyor which communicates with the vessel 100 below the liquid level therein, a paste is formed at the upper extremity of the conveyor 116 which serves as a seal and prevents liquid from running down into the conveyor 116 so long as the conveyor 116 contains its capacity of coal.

The coal is introduced into the vessel 100 through the coal inlet 132, and is contacted therein with oil which has been heated to a point above the boiling point of water but yet below the point at which the coal will soften and tend to agglomerate. An oil temperature within the zone can range from 220° F. to 600° F., while the pressure is generally from 0 to 25 p.s.i.g. Preferably, a temperature of about 300° F. will be maintained at the bottom of the vessel 100, so as to assure the minimum amount of moisture being included in the coal slurry to be withdrawn from the system.

The oil feed, as hereinabove stated, is introduced as a liquid or vapor stream by way of line 104, preheated in exchanger 105, and passed via pump 107 and line 138 into the vessel 100 by way of line 106. Recycle oil is withdrawn through line 134 as a slurry containing some of the coal particles, and is passed through pump 136 into recycle line 137 and line 106 for reintroduction into the vessel 100. For bottom circulation, oil feed is diverted through lines 139 and 140 while recycle oil is diverted through lines 135 and 140.

As stated before, the vaporous products are removed overhead, condensed by way of heat exchanger 142, settled

in vessel 144, and separated into a vent gas stream (re-through lines 139 and 140 while recycle oil is diverted by way of line 148) and a naphtha product stream (removed by way of line 150). The naphtha stream can be recycled and reintroduced as the oil feed to the system.

The liquid level within the vessel is maintained at the indicated level "I" by means of suitable control equipment such as the differential pressure control system shown in the dashed lines 180 and 181, attached to pressure taps in the top and the bottom of the vessel respectively. The sensed differential pressure is transmitted by ΔP recorder and controller and converted into a control signal which, by way of line 182, is transmitted to the control valve 183 which controls the amount of slurry withdrawn from the system. Thus, the liquid level is automatically controlled by withdrawing the correct amount of slurry to compensate for the feed streams introduced into the vessel, and the water and oil streams removed overhead.

Heat may be supplied to the system by any of a number of means, the simplest being by heating the fresh oil before introduction into the drying zone. If additional heat is required, it may be supplied by means of a steam jacket or a steam coil internally or externally mounted at the proper points on the vessel itself. FIG. 1 shows the use of external steam chambers both at the bottom, as exemplified by chamber 200, and at the top by chamber 202. The chamber at the bottom 200 is used to maintain the oil heat sufficient to vaporize water brought into the system with the wet coal while the jacket 202 is used to prevent condensation of the water before it is removed from the system. Alternatively, a heater 204 is provided in the recycle oil line so as to raise the temperature of the recycle oil for direct admixture with the oil and coal inside the vessel 100.

As will be seen by advertence to FIG. 1, the coal is introduced into the vessel 100 just below the liquid level and adjacent the introduction point for hot recycle oil, when this expedient is used. This is important since it encourages the formation and flashing of steam while the coal is near the top of the liquid column, so that the great bulk of the steam is manufactured and removed from the system before the coal has passed downwardly a substantial distance. By accomplishing this, the tendency of steam to agglomerate into large bubbles and slug the column is avoided, since only a minor portion of the steam production is carried out in the lower reaches of the column.

If desired, a small amount of bottom recycle through line 140, together with a mixer 210, may be used to prevent settling of the coal on the bottom. Alternatively, a bottom recycle stream may be used rather than the top recycle which is preferred. However, when the bottom recycle is used, the amount of steam which is formed in the lower reaches of the vessel is understandably increased.

THE PROCESS

By the process of the present invention, wet coal is dried by introducing it below the surface of a hot oil pool so as to create steam and remove moisture from the coal in an overhead vapor stream, and removing the coal in an oil slurry.

The drying process is carried out by heat transfer from a heat transfer liquid which is substantially inert to the coal and to the water under the drying conditions. When the dried coal is to be liquefied in a solvent extraction process, that solvent will be preferred. Suitable heat transfer liquids are coal extract oils, cresote oils, hydrocarbon oils, chlorinated hydrocarbon oils, glycols and heavy alcohols. Preferably, a hydrocarbon oil boiling in the range from 325° F. to 1100° F. and having a specific gravity of about 1.00 at 60° F. will be employed as the heat transfer liquid. Such oils can be obtained as products of the liquefaction of coal after hydrocracking thereof.

The drying zone is provided with a pool of the inert

heat transfer liquid in a quantity sufficient to retain the coal in the drying zone for an average residence time of 5 to 30 minutes. The coal feed rate will provide about 0.1 to 1.0 pound of coal per pound of liquid introduced into the pool. The pool of liquid will be maintained at a temperature from about 220° F. to about 600° F., preferably 300° F. Particulate coal, containing at least 1 weight percent of liquid water (usually from 5 to 40 weight percent of liquid water) is continuously introduced into said drying zone at a point below but adjacent to the surface of the liquid, so that the coal can by gravity pass downwardly through the pool of heat transfer liquid. Preferably, the particle size of the coal will be from 8 mesh to 0 mesh.

A stream of hot heat transfer medium (in the liquid, vapor or mixed phase) is continuously introduced into said drying zone at a locus contiguous to said coal inlet point, said hot heat transfer liquid or vapor being at a temperature from 225° F. to 1000° F. (preferably about 500° F.). The rate of introduction of the hot heat transfer liquid is from 1 to 10 pounds of heat transfer liquid per pound of coal introduced into said zone. By contacting the freshly introduced coal with the hot heat transfer liquid, a substantial portion of the liquid water on the coal will be vaporized while the coal is near the surface of the liquid, and the vaporization will be substantially complete before the coal has passed more than about 18 inches from the point of coal injection. This avoids bubble agglomeration and slugging.

Additional steam will be generated by vaporization of water as the coal passes downwardly through the heat transfer zone, and this vapor will rise through the column and join with the steam which was generated at the coal inlet point. A vaporous stream is removed overhead from said zone, which comprises the vaporized water, a certain amount of vaporized heat transfer liquid, and some non-condensable gases which had been occluded in the coal. These vaporous and gaseous products may be passed through a condenser and separated in a settling drum.

A recycle stream may be set up by withdrawing a side stream near the surface of the heat transfer liquid pool, venting any noncondensables and vaporous products therefrom, and returning the side stream to the bottom of the tower. A suitable recycle ratio would be from 1 to 200 volumes of side stream per volume of hot heat transfer liquid added to the drying zone.

In order to illustrate the present invention, a number of runs were made using the apparatus of FIG. 1, but operating it in different manners. These runs are shown below in the examples.

EXAMPLES

Examples 1 and 2

These examples were carried out while utilizing top recirculation, the recycle oil stream comprising about 180 volumes per volume of fresh oil being introduced. The flow scheme is shown in FIG. 2, wherein the fresh oil stream (heated or unheated) is introduced by way of line 302 into drying zone 300. A recirculation stream is withdrawn at the bottom of the drying zone by way of line 304 and returned by way of lines 306 and 308 into the upper portion of the drying zone. A slurry stream is withdrawn through line 305 in such quantities as to maintain the liquid level in the drying zone substantially constant. In Example 1, heat was supplied by 10,000 watt electric variable voltage heaters 310, while in Example 2 the fresh oil was heated to a temperature of about 500° F. Thermocouples 1, 2, 3 and 4 were used to obtain the temperature profiles shown in FIG. 3. A propeller-type stirrer (not shown) in the bottom of the drying zone was used to encourage mixing in the zone.

In Example 1, a distinct temperature gradient was seen in spite of the fairly well-mixed condition. The use of the wall heater caused the temperature to be highest

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at the bottom of the zone. The fresh oil was charged at a temperature of 80° F., mixed with recycle oil at a temperature of about 275° F. and coal at a temperature of about 80° F. As can be seen by FIG. 3, the temperature immediately dropped to about 250° F. and then gradually increased. The coal in the slurry contained about 1.8 weight percent moisture as compared to 11.5 weight percent moisture in the coal feed. No excessive foaming or slugging were experienced.

In Example 2, a fairly constant temperature was obtained in the drying zone, indicating that substantially all of the moisture was vaporized at the surface immediately upon contact of the coal with the mixture of fresh and recycle oil. The temperature of the heated oil was about 500° F. and of the mixture of fresh and recycle oil was about 275° F. No excessive foaming or slugging was experienced. The coal in the slurry contained 1.3 weight percent moisture as compared to 15.9 weight percent in the coal feed.

Examples 3 and 4

These examples were carried out while utilizing bottom recirculation, the recycle oil stream comprising about 180 volumes per volume of fresh oil being introduced. The flow scheme is shown in FIG. 4, wherein the drying zone 400 is seen to be supplied with oil by way of line 402 and a bottom recirculation system is provided by way of lines 404 and 406, line 406 being located 18 inches above line 404. A slurry stream is withdrawn by way of line 405 in such quantities as to maintain a constant level of liquid in the drying zone 400. In Example 3, heat was supplied by 10,000 watt electric resistance heaters 410, while in Example 4 the fresh oil was heated to about 500° F. Thermocouples 1, 2, 3 and 4 were used to obtain the temperature profiles shown in FIG. 5. A propeller-type stirrer (not shown) was used in the bottom of drying zone 400 in order to encourage mixing in the zone.

In Example 3, a distinct temperature gradient was seen, which was similar to that of Example 1 in that the highest temperature occurred at the bottom of the zone. However, due to the use of bottom recycle, this temperature was not reflected in the top-of-zone temperature as was the case in Example 1. In Example 3, the fresh oil was charged at a temperature of about 80° F. and mixed with coal which was at a temperature of about 80° F. The temperature gradually increased under the influence of the wall heater to a temperature of 180° F. at point 1, 262° F. at point 2, and an exit temperature of about 305° F. Substantial slugging was not experienced. The moisture content of coal in the slurry was about 1.04 weight percent as compared to 14.5 weight percent in the coal feed.

In Example 4, a distinct temperature gradient was observed due to the less effective mixing. The temperature gradually declined from about 315° F. to about 287° F. The temperature of the heated oil was about 500° F. The coal in the slurry contained 0.5 weight percent moisture as compared to 15.9 weight percent in the coal feed.

The data from Examples 1-4 are shown below in Table II.

TABLE II.—SUMMARY OF EXAMPLES

	Ex. 1	Ex. 2	Ex. 3	Ex. 4
Temperature, ° F.:				
Top of liquid.....	272	277	180	320
Bottom of liquid.....	275	277	305	287
Moisture on coal, wt. percent:				
Coal feed.....	11.5	15.9	14.5	15.9
Coal in slurry.....	1.8	1.3	1.04	0.5
Type of recirculation.....	Top	Top	Bottom	Bottom
Type of heat input.....	(1)	(2)	(1)	(2)
Temperature of hot oil, ° F.....		500		500

¹ Heated wall.

² Hot oil.

Example 5

The data obtained from Examples 1-4 have led the

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inventor to conclude that an improved process might be carried out as shown in FIG. 6. In that figure, a drying zone 600 is provided which is similar to the apparatus of FIG. 1, but the liquid withdrawal and recirculation system is modified so that a recycle stream is withdrawn near the liquid surface, e.g., by line 602, from a point lower than the hot oil inlet 604. The recycle liquid is passed through a flash zone 606 to allow removal of steam via line 608, and is then passed via line 609, pump 610 and line 612 into the lower portion of the drying zone (e.g., adjacent the bottom thereof). Slurry is withdrawn from the bottom via line 614, pump 616, and line 618.

By the process shown in Example 5, the coal is initially contacted with hot oil to remove the major portion of the moisture as steam generated near the liquid surface. Most of the coal descends through the drying zone under the influence of gravity rather than being drawn off with the recycle stream 602. Oil is withdrawn through line 602 from a point about 10% of the liquid column below the surface, vented, and recycled from the bottom upwardly, thus avoiding the problem of drawing steam down the column. Instead, the steam will pass overhead or be drawn into the separator 606. If desired, the recycle oil may be additionally heated as shown by exchanger 607, or wall heaters may be used similar to heaters 200 in FIG. 1. In this way, problems of slugging would be avoided by vaporizing most of the moisture with hot oil at the top of the liquid column, and residual amounts of moisture would be vaporized as the coal passed downwardly countercurrent to the hot recycle oil.

Having disclosed my invention, a preferred mode of using the process and a preferred embodiment of the apparatus, what is to be covered by Letters Patent should not be limited by the examples hereinabove given, but only by the appended claims.

I claim:

1. A coal drying apparatus which comprises an elongated vessel having
 - a vapor outlet near the one extremity thereof,
 - a liquid outlet near the other extremity thereof,
 - a solids inlet intermediate said vapor outlet and said liquid outlet,
 - and coal transport means communicating with said solids inlet and fluidly sealed with respect to said elongated vessel,
 - said coal transport means comprising angularly upwardly directed screw or drag-type conveyor means having an inclination with the horizontal of at least 15°.
2. An apparatus in accordance with claim 1 wherein said vessel is vertically disposed and said vapor outlet is at the upper extremity thereof, and wherein said coal transport means comprises angularly downwardly directed conveyor means communicating at its upper end with coal feeding means and at its lower end with the lower end of said angularly upwardly directed conveyor means.
3. An apparatus in accordance with claim 2 wherein the upper end of said downwardly directed conveyor means is higher than said solids inlet.
4. An apparatus in accordance with claim 3 further comprising a recycle inlet intermediate said vapor outlet and said liquid outlet, pump means communicating on the suction side with said liquid outlet and on the discharge side with said recycle inlet, and further comprising means for introducing the stream of liquid oil into the suction side of said pump means.
5. An apparatus in accordance with claim 4 further comprising means for heating the effluent from said pump means.
6. An apparatus in accordance with claim 5 wherein said recycle inlet is intermediate said solids inlet and said vapor outlet.
7. An apparatus in accordance with claim 6 further comprising means for controlling the level of liquid

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within said vessel at a level above said solids inlet and not above said recycle inlet.

8. A method of drying particulate coal containing at least 1 weight percent of liquid water which comprises in a drying zone, maintaining a pool of an inert heat transfer liquid at a temperature from 220° F. to 600° F.,

continuously introducing said coal into said drying zone and into said pool at a coal inlet point adjacent but below the surface of said liquid,

continuously introducing a stream of hot heat transfer fluid in the liquid, vapor or mixed phase into said drying zone at a locus contiguous to said coal inlet point,

said hot heat transfer fluid being at a temperature from 225° F. to 1000° F. and being introduced at a rate from 1 to 10 pounds of heat transfer liquid per pound of coal introduced into said zone,

whereby a substantial portion of said liquid water is vaporized before said coal has passed more than 18 inches downwardly from said coal inlet point, passing said coal and said heat transfer liquid downwardly through said drying zone, while additional liquid water is vaporized,

removing from the bottom of said zone a slurry of

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dried coal particles in said heat transfer liquid, and removing from the top of said zone a vaporous stream including said vaporized water.

9. A method in accordance with claim 8 further comprising the steps of

removing a side stream from said drying zone above said hot heat transfer liquid inlet locus,

separating gaseous and vaporous components from the liquid and solid components of said side stream, and reintroducing said liquid and solid components into said drying zone at a location adjacent the bottom thereof.

10. A method in accordance with claim 9 wherein the volume ratio of said side stream to said hot heat transfer liquid is from 1/2:1 to 200:1.

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