Feb. 6, 1962 T. D. NEVENS ETAL 3,020,227

PROCESS AND APPARATUS FOR HEATING SOLID INERT HEAT-CARRYING BODIES

Filed Dec. 21, 1959

3 Sheets-Sheet 1

Fig. 1

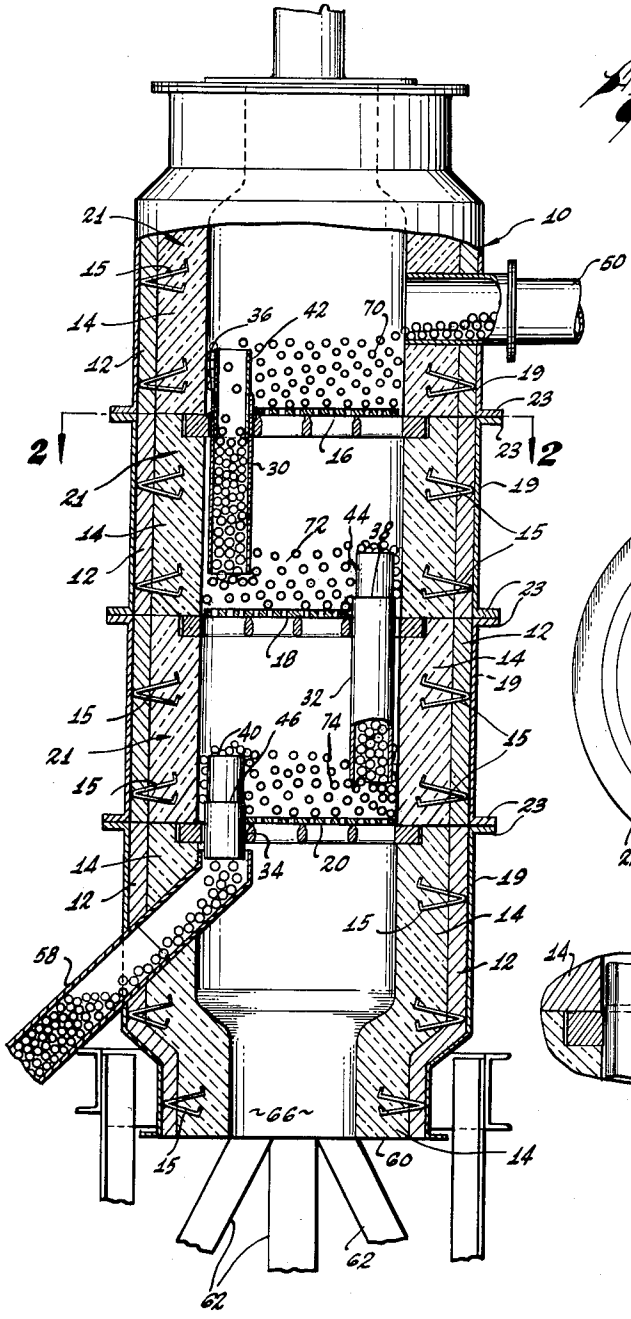
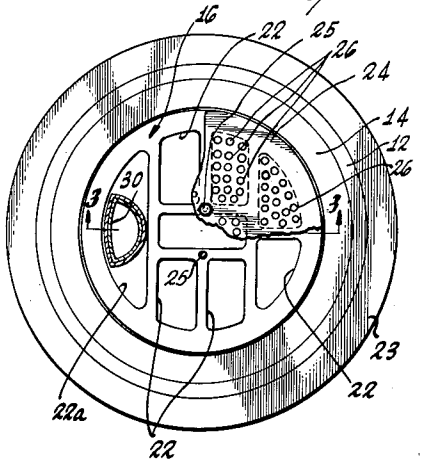


Fig. 2



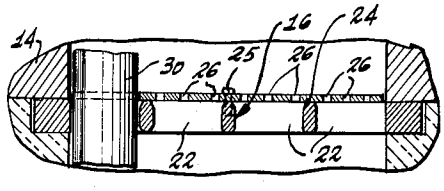


Fig. 3

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3 Sheets-Sheet 2

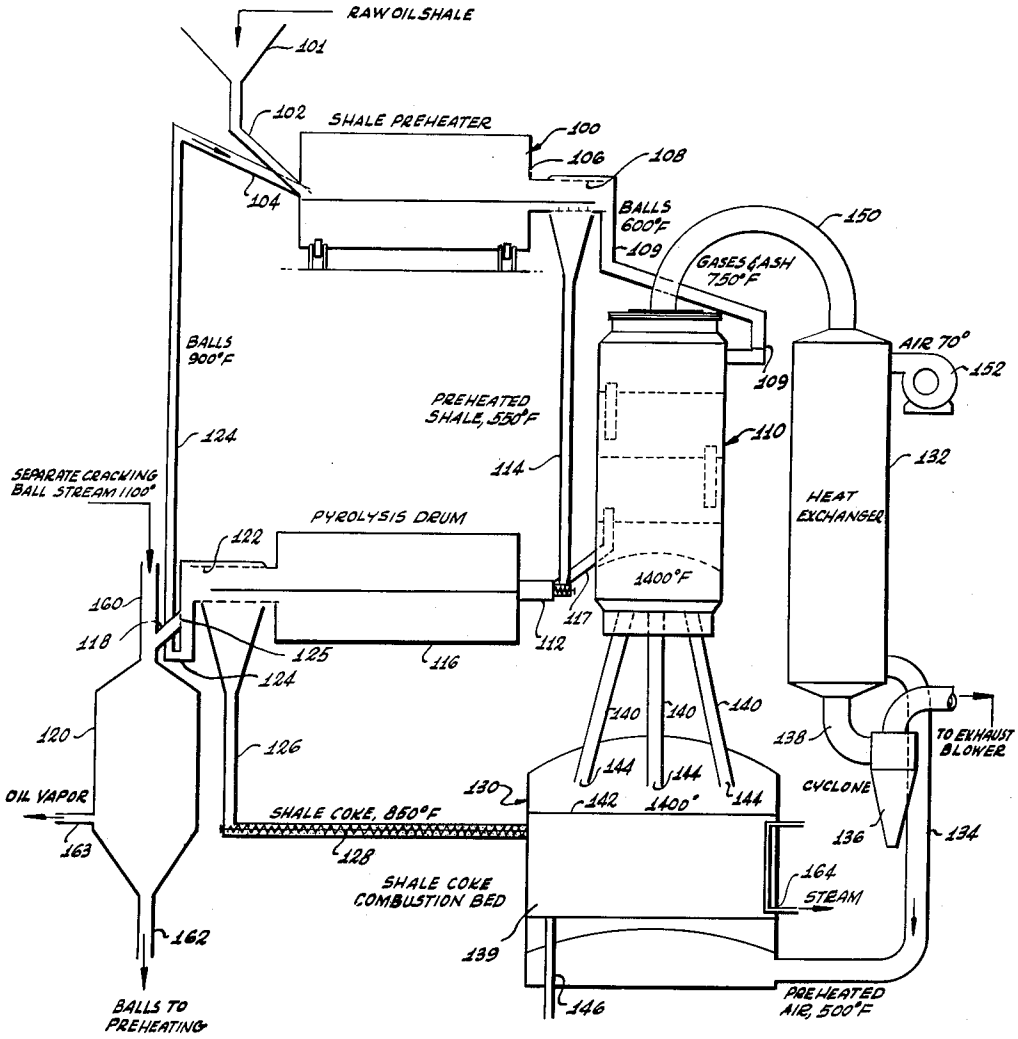


Fig. 4

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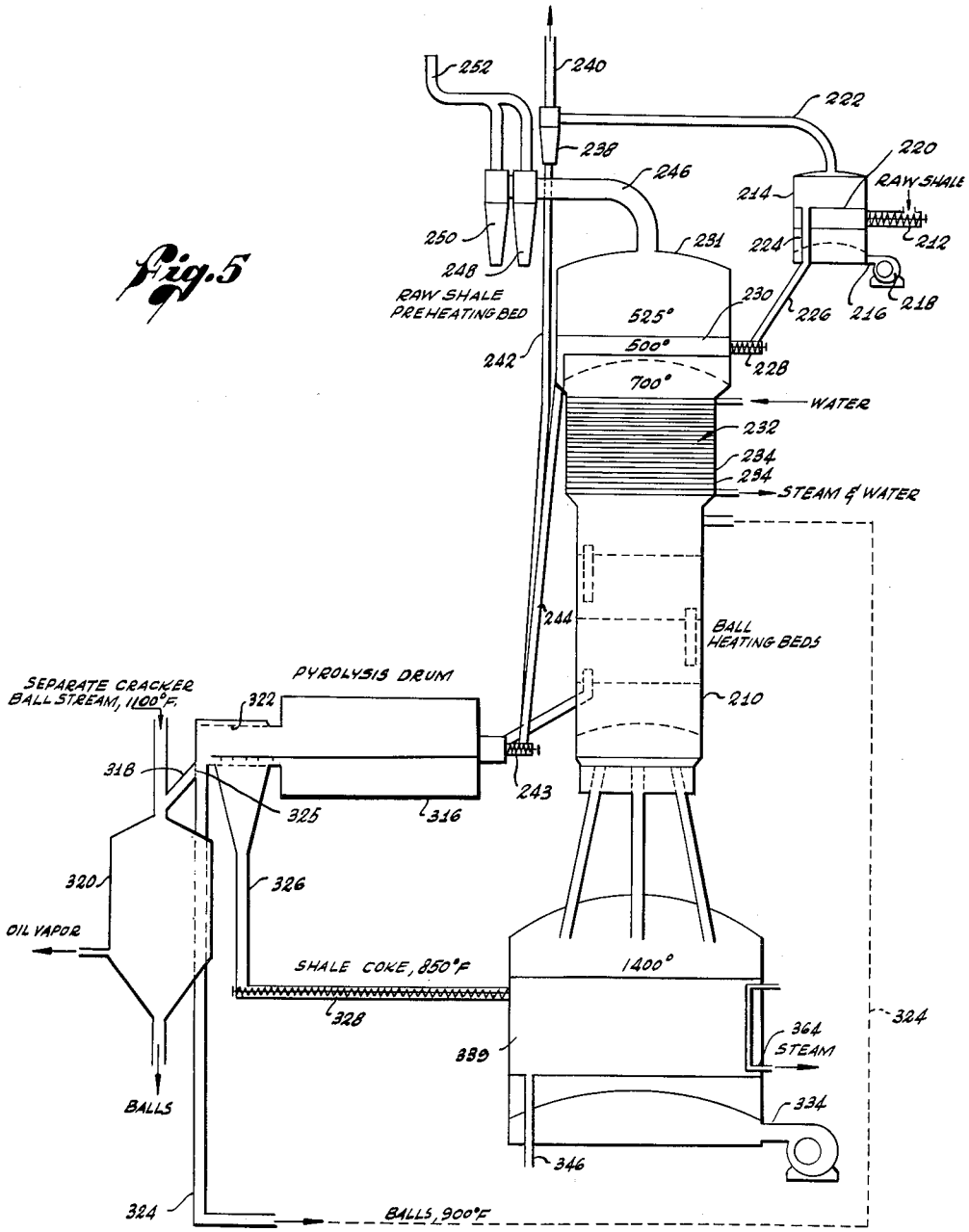
Feb. 6, 1962 T. D. NEVENS ETAL 3,020,227

PROCESS AND APPARATUS FOR HEATING SOLID INERT HEAT-CARRYING BODIES

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3 Sheets-Sheet 3

Fig. 5



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3,020,227

PROCESS AND APPARATUS FOR HEATING SOLID INERT HEAT-CARRYING BODIES

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Filed Dec. 21, 1959, Ser. No. 861,086
13 Claims. (Cl. 208—11)

This invention relates to improvements in heating devices for heat-carrying solid bodies, and relates especially to a process and apparatus for heating generally spherical or irregularly-shaped heat-carrying bodies, which bodies provide heat for use in processes such as the production of oil from oil shale, tar sands, and other solid carbonaceous materials, and ore reduction.

In the production of oil from oil shale, the oil shale is subjected to pyrolysis, or destructive distillation, and the residue left contains fixed combustible carbon. In the case of oil shale, the residues are termed herein, and in the claims as "shale coke." The shale coke is combusted in air, the resulting products of combustion being combusted gases and shale ash (the combusted shale coke). In the production of oil from tar sands, the tar sands are subjected to a stripping, i.e. nondestructive distillation. The term "stripping" will be used herein generically to denote both destructive and nondestructive distillation.

Among the various proposals in the prior art for the production of oil from oil shale, the pyrolysis of oil shale means of heat transfer with solid heat-carrying bodies made of steel, alumina, or other ceramic material, is particularly advantageous for a number of reasons. Among these are the relatively great amount of heat-transfer effected between the solid bodies and oil shale, reduction in dust problems, and the production of undiluted oil vapors from the pyrolysis zone. The cracking, either in whole or in part, of the oil vapors resulting from pyrolysis, has also been suggested by means of the same heat-carrying bodies because of the effectiveness of such a process in eliminating dust from the vapors and because of the simplicity and economy of such a process in which the heat-carrying bodies used for cracking are also present and used in the other parts of the retorting system.

Inasmuch as the heat-carrying bodies are usually generally spherical, they will be referred to, for the sake of brevity, as thermospheres or balls. It will be understood however, that the term "thermospheres," or "balls" as used herein, includes irregularly shaped solids as well as approximately spherical and purely spherical, heat-carrying bodies.

In the past, the primary means for heating the solid bodies has involved the passage of heated air through a packed tower of the heat-carrying solid bodies. While this mode of heating the heat-carrying bodies is conventional and is, in some respects, an excellent means of heating these solid bodies, several drawbacks are inherent in such means.

Firstly, in forcing the requisite amount of heated air through a packed tower of solid bodies, a considerable pressure is required. It is the usual practice in the pyrolysis of oil shale to combust shale coke in the presence of air to thereby provide heat for the heating of solid bodies. The combustion step necessarily requires a large amount of air for efficient combustion of the carbon in the shale coke. Consequently, the large amount of air that is necessarily heated by this means requires that a high blower pressure be employed in forcing the resulting products of combustion, e.g., carbon monoxide, carbon dioxide, and water vaper, through a packed tower. Another difficulty present in a large diameter packed bed of

moving bodies through which gases pass is due to the channelling of both gas and bodies in such a bed.

In addition to the use of hot gases for the heating of the solid bodies, it has been heretofore proposed to utilize the heat in solid particles entrained by the gases, these entrained particles usually emanating from a fluidized bed of shale coke or the like. The hot particles entrained with the hot gases are found to considerably increase the heat capacity of the gaseous heating medium and to thus cause a substantial reduction in the need for any considerable contact time of such gases with the solid heat-carrying bodies. The entrained solids in the gases present further problems in the normal counter-current packed tower method of heating the balls since frequently they will be held up by the balls. The problems of large bed depth are thus accentuated in such entrained solids processes.

Another type of ball heater has been suggested by the present inventors in the form of a horizontal elongated moving thermosphere bed of shallow thickness with the heating gas blowing upwardly therethrough. This type of ball heater also has some excellent features, and avoids some of the problems of the packed tower, especially avoiding the excessive pressure drop problem in the packed tower arrangement. However, the shallow thermosphere bed is not ordinarily conducive to a large amount of heat-transfer, and accordingly a moving bed of very large path length and several passes (with their inherent sealing problems) are usually required before the requisite amount of heat-transfer is obtained.

Bearing in mind the foregoing facts, it is a major object of the present invention to provide a process and apparatus for heating solid bodies, spherical or nonspherical, wherein the requisite amount of heat-transfer to the solid bodies is obtained in a relatively short path length while avoiding the great pressure drop usually encountered in the prior art packed tower type of heater.

Another object of the present invention is to provide a process and apparatus for heating thermospheres wherein the thermospheres are fluidized by a heating and fluidizing gas containing entrained solids, thereby enabling the thermospheres to be heated efficiently to a required temperature over a relatively short path length, while avoiding an excessive pressure drop through the thermospheres.

A further object of the present invention is to provide a process and apparatus for the production of oil from oil shale, tar sands, and the like wherein the oil shale, tar sands, and the like are stripped by means of direct solid-to-solid contact with solid bodies, and the solid bodies are heated in a fluidized state, by means of the combustion products of the carbonaceous residue of oil shale, tar sands, and the like.

Still another object of the present invention is to provide a process and apparatus for the production of oil from oil shale and the like wherein the oil shale, tar sands and the like are stripped by means of thermospheres heated in the fluidized ball heater of our invention, and the oil vapors and gases are cracked by means of a separate thermosphere circuit having its own thermosphere heater.

Yet another object of the present invention is to provide a process and apparatus for the production of oil from oil shale, tar sands, and the like, wherein the oil shale, tar sands, and the like are stripped by direct contact with thermospheres, the thermospheres being reheated for additional stripping, in a fluidized state, by means of the combustion products of the carbonaceous residue of oil shale, tar sands, and the like and the oil shale, tar sands, and the like are preheated prior to stripping, by means of the same combustion products.

These and other objects and advantages of our inven-

tion will become clearly understood by referring to the following description and accompanying figures in which:

FIGURE 1 is an axial cross-section, in side elevation, of one preferred embodiment of our thermosphere or ball heater;

FIGURE 2 is a plan view of our ball heater taken along the line 2—2 of FIGURE 1;

FIGURE 3 is a cross-section, in side elevation, taken along the line 3—3 of FIGURE 2;

FIGURE 4 is a schematic representation of one preferred process embodying the invention; and

FIGURE 5 is a schematic representation of another preferred embodiment of our invention.

In general, our process and apparatus for heating thermospheres, or balls, consists in fluidizing the balls by means of hot combustion gases, the combustion gases preferably containing finely divided solid material. This finely divided material is, generally speaking, combusted residue. For example, in the case of the combustion of shale coke, shale ash comprises the finely divided entrained material. The gas velocity required for fluidization of the balls is necessarily sufficiently high so that any of the finely divided material will not be retained within the balls. At the same time, the rate of heat transferred to the balls, in their fluidized state, both by the finely divided solids and gases, is considerably greater than is the case in a packed bed, and further, the problem of retention of finely divided solids by the packed bed is completed obviated. In addition, balls are readily removed by such a process without resulting channnelling of gases or of balls, as would be liable to occur in packed beds.

Referring now specifically to FIGURE 1, a thermosphere or ball heater 10 of our invention is shown, in cross-section, having an outer wall 12 made of an insulating material, such as asbestos, and an inner liner 14 composed of a higher heat duty insulating refractory material such as kaolin. The inner and outer walls 12 and 14 are reinforced and unified by a plurality of spaced V-shaped rods 15 which are imbedded in, and tie both of said walls. The rods may be made of stainless steel, or other suitable material. The composite liner is built up of discrete cylindrical sections 21. Each section 21 has an outer supporting metal jacket 19, the ends of the jackets having one or two flanges 23, for abutment with an adjacent jacket. Abutting flanges 23 are bolted or welded.

A plurality of perforated members or grates 16, 18 and 20 are interposed at different levels in the ball heater 10, and are affixed to the composite liner 14 in any suitable manner. The grate members 16, 18 and 20 are made of a highly resistant refractory material such as Meehanite (a highly heat-resistant cast iron). Taking grate member 16 as typical, and referring particularly to FIGURES 2 and 3, the grate member is formed with a plurality of openings 22, and a heavy perforated plate 24 is affixed to the upper side of the grate by bolts 25, as shown in FIGURES 2 and 3. The size of openings 26 in the plate 24 is slightly smaller than the diameter of the balls or thermospheres, and it is found that for optimum performance a total open area in the plate of approximately 17% of the ball heater should be employed.

The openings in the grate 16 and plate 24 allow gases and finely divided solids to pass upwardly therethrough while, of course, preventing downward movement of the balls. The upward movement of hot gases and hot finely divided solids enables heat to be transferred to the balls in a manner that will presently be described.

Three downcomers or downspouts 30, 32 and 34, which may be generally semicylindrical in shape, are mounted to, and pass through, the gate opening 22*a* of grates 16, 18 and 20, respectively. The tops of the downspouts 30, 32 and 34 are designated by the numerals 36, 38 and 40, respectively, are set a predetermined distance above the upper surface of the grates to which they are mounted. This distance may be varied by means of telescoping downspout extensions, these extensions being designated by numerals 42, 44 and 46. Other modes of downspout adjustment may also be satisfactorily used.

The top of the downspout 30 is mounted below the mouth of the ball inlet pipe 50, and on the opposite side (the left in FIGURE 1) of the ball heater 10, adjacent the inner wall of the liner 14. The downspout 32 and its extension 44 are mounted so that the extension top 38 lies above the bottom end 52 of downspout 30, and preferably so that it is approximately diametrically opposed to downspout 30. The third downspout 34 and its extension 46 are mounted so that the extension top 40 lies above the bottom end of spout 32. The bottom end of downspout 34 is connected to an outlet pipe 58.

The ball heater 10 is fitted at its bottom end 50 with one or more open skimming tubes 62, through which a gaseous fluidizing medium is passed into the bottom space 66 of the ball heater. Other means for entry of the gaseous fluidizing medium may also be used. However, this mode is preferable for reasons that will be described hereafter.

In the normal operation of the ball heater 10, thermospheres or balls enter the ball heater via ball feed line 50, and initially form a bed 70 resting on the upper grate 16 and associated perforated plate 24. The top 36 of downspout extension 42 is adjusted so that it is preferably from 3" to 9" above the grate 16, thereby causing the fluidized bed 70 to be 3" to 9" in depth.

Combustion gases, containing entrained solid combusted particles (e.g. shale ash produced in the combustion of shale coke), enter the bottom 66 of the ball heater and proceed upwardly through the heater at a gas velocity sufficiently high to fluidize the upper, intermediate, and lower thermosphere beds 70, 72 and 74, respectively.

It is found that the minimal gas velocity sufficient to fluidize the thermosphere bed is high enough to prevent retention of any of the combusted residue particles passing into the beds and normally, the preferred gas velocity is at or above the minimum fluidization velocity.

As the thermospheres in the bed 70 are fluidized, a random turbulent motion is imparted to them. As the fluidization of the bed 70 proceeds, the balls move across the grate, in random fashion, from their point of inlet to the downcomer 30 and downcomer extension 42, the balls meanwhile being heated by the upwardly moving hot combustion gases. The balls are then discharged, in random fashion, into the downspout extension 42 through downcomer 30 and onto the grate 18, and associated perforated plate 24.

The top of downspout extension 44 preferably lies above grate 18 by about 3" to 9" so that a 3" to 9" bed thickness of thermospheres is built up on grate 18. This bed is fluidized due to the velocity of the upwardly flowing gases, the fluidized bed being designated by the numeral 72. The balls, in fluidized bed 72, due to their random motion, are discharged into the downspout 32, after being further heated by the combustion gases and entrained solids passing upwardly around them.

The top of the downspout extension 46 lies about 3" to 9" above the gate 20 so that the balls discharged from downspout 32 form another fluidized bed 74 of 3" to 9" in thickness. The balls in the bed 74 are further heated by the upwardly moving combustion gases and entrained solids.

The balls in the fluidized bed 74 are in random motion, as previously mentioned, and, in their random motion, are discharged into downspout extension 46, downspout 34, and thence into discharge pipe or passage 58.

It will thus be seen that the path of balls being heated is such that any one ball makes a plurality of passes in a generally transverse direction with respect to the hot upwardly flowing combustion (or other hot) gases and solid particles entrained therein. Specifically, the balls first pass generally from right to left across grate

16, in random turbulent motion, picking up heat in an extremely efficient manner from the fluidizing gas. They then pass generally from left to right across grate 18, and pas yet a third time, in the same random turbulent fluidized manner, across grate 20, to be discharged, after attaining the desired temperature. Since higher he at transfer rates obtain between the fluidized balls and hot gases and entrained solids than would exist if the balls were present in the form of a packed bed, a shallower total bed of balls may be employed. In the fluidized bed of balls channeling of either gases or balls is eiliminated. Moreover, relatively small equipment may be used because of the high heat transfer rates and the low pressure drop through the ball heater.

A feature of our preferred ball heater 10 is the provision made for discharge of the balls through a downcomer onto a lower grate. It will be noted that the bottom ends of downcomers 30 and 32 lie substantially below, e.g. 1" to 4", the top of the downcomer extension 44 and 46 respectively, so that the bottom ends of downcomers 30 and 32 lie within fluidized thermosphere beds 72 and 74. Thus, as the balls are discharged into the downcomers 30 and 32, they cannot fall freely into the fluidized beds 72 and 74. The stacking of balls, in the downcomers, caused thereby is highly advantageous since, in effect, a gas seal is formed by such ball-stacking or ball-packing. The ball column, so formed, should have a depth sufficient to provide a resistance to gas flow in the downcomer such that the velocity therethrough, for the existing pressure drop across the bed, is less than required for fluidization of the contained balls; so under such circumstances the balls will flow downwardly through the downcomer. The necessary height of this ball column is on the order of 4" to 12" in the disclosed ball heater.

As fluidization proceeds, and balls pass from a given fluidization bed, e.g. bed 72, into its associated downspout extension, e.g. extension 44, additional balls are discharged from the appropriate downcomer, e.g., downcomer 30, onto the bed to maintain the fluidized bed at a constant level. Since a continuous gas seal is formed in the above-described manner, only a small gas flow upwardly through the downcomers is possible and practically no upward flow of balls to an upper level takes place.

Since heat is being removed from the hot gases as they pass upwardly through the ball heater, the gases become progressively lower in temperature and their density decreases. In order to have about the same velocity of gas in each bed of the heater, therefore, the area of the lowest bed 74 is preferably made greater than the area of the middle bed 72, which is, in turn, made greater than the area of the uppermost bed 70. Thus, the degree of fluidization in the three beds is made substantially the same.

It will thus be seen that a ball heater is provided wherein balls can be heated, in a fluidized state, by means of upwardly moving combustion gases, containing entrained solids therein. The ball heating is accomplished in a plurality of successive ball passes, the first pass commencing at an upper (cooler) level in the ball heater, and the last pass ending at a lower (hotter) level in the ball heater. The pressure drop through the ball heater is minimized because of the shallow depth of each bed of balls and the fluidized state of the beds, while the balls are enabled to proceed downwardly by means of the gas seal arrangement above-described.

It is also possible, and in some instances it may be preferable, to allow balls that are moved into a downcomer by the just-described fluidization process to be then led out of the heating apparauts proper, and then positively fed by screw conveyor means or the like onto the next lower level for a further heating.

A preferred use of our ball heater 10 is in connection with the production of oil from oil shale. Referring now particularly to FIGURE 4, one schematic representation of a preferred process for the production of oil from oil shale is shown in combination with the ball heater 10 of our invention. FIGURE 5 shows another schematic representation of the production of oil from oil shale utilizing fluidized heating of balls.

Referring now to FIGURE 4 especially raw oil shale, preferably crushed to about —3/8" mesh size, is fed from hopper 101 into a rotatable preheating drum 100, via conduit 102. Substantially hotter heat-carrying bodies, or thermospheres, enter the preheating drum 100 via conduit 104, along with the raw shale, and in parallel flow therewith, although counterflow is sometimes employed. The raw shale is intermixed, intimately and continuously, with the balls in the rotating drum 100, and the oil shale is preheated to a temperature preferably ranging between 400° to 600° F. at the discharge end 106 of the drum.

The oil shale, at the discharge end 106, has a substantially smaller average size than the balls due to the fact that the inlet shale is pulverized and/or crushed to a certain extent in its travel through the drum by means of the balls or thermospheres. Because of the size difference, the balls and oil shale are readily separated from each other by a trommel 108, which is rotatable with the drum 100. The balls, now cooled, proceed along an inclined passage 109 to the ball heater 110, which is of essentially the same construction as ball heater 10, previously shown and described.

The balls, after being heated in ball heater 110 to a desired temperature, e.g. 1000° to 1400° F., enter conveyor line 112, via line 117, along with preheated oil shale, entering the conveyor line from conduit 114. The packed balls in the line 117 and the preheated shale in the conduit 114 act as gas seals to prevent the escape of vapors and gases therethrough. The hot balls and preheated oil shale are then intimately intermingled in a rotatable pyrolysis drum 116, which may be of the type described in Patent No. 2,872,386, Olof Erik August Aspegren, inventor. The oil shale is pyrolyzed in drum 116 and the resulting oil vapors and gases are sent to a cracker 120, via line 118, for the coking or visbreaking thereof, or other thermal decomposition, (these all being termed generically herein as cracking). The cracking operation will be described hereafter.

The somewhat cooler balls and smaller sized oil shale residues (shale coke) are separated from each other by means of trommel 122. The balls leave the trommel, via elevator means in line 124, to be sent to the preheater drum 100 while the shale coke is sent, via line 126, and screw conveyor line 128, to a combustion zone or furnace 130. The balls form a gas seal in line 124 inasmuch as the elevating means (not shown) is positioned some distance away from the trommel 122. The gas seal prevents any leakage of gases into line 124. The shale coke in the line 126 also acts as a vapor and gas seal.

A screen 125 is interposed at the entrance to line 118 to prevent balls from entering therein.

Air for the combustion of the shale coke is first preferably preheated by means of fairly hot exhaust gases and ash (leaving the ball heater 110) in a heat exchanger 132 of any conventional type capable of handling the load of dust in the exhaust gases. The preheated air is then sent to the combustion zone 130, via line 134, for the combustion of shale coke.

The shale coke is fluidized by the velocity of the incoming preheated air and combusted in this fluidized state, the fluidized shale coke burner bed being designated by the numeral 139. The resulting combustion products, i.e. the combustion gases and shale ash, are employed for the heating of the thermospheres or balls, which, as mentioned, enter the top of the ball heater 110, via line 109.

A single tube or a plurality of skimming tubes 140 extend downwardly from the bottom of the ball heater

110 to just above the surface 142 of the fluidized shale coke burner bed 139. The skimming tubes 140 remove the combustion gases from the furnace 130 and also remove that fraction of the shale ash below a certain predetermined size. The tubes 140 are positioned above the surface 142 of the bed 139 so that only the more finely divided ash enters the bottom 144 of the tubes 140, to be drawn upwardly in the gas stream. The larger or coarser shale ash particles are not entrained with the combustion gases to any great extent, but rather are subjected to attrition within the burner bed 139, until the reduction in size is such that they can be entrained by means of the combustion gas velocity existing just above the burner bed.

Referring back to FIGURE 1, the combustion gases and entrained ash pass through skimming tubes 62 (equivalent to skimming tubes 140 in FIGURE 4) and enter the bottom inlet end 66 of the ball heater 10. They then pass through, and fluidize, successive thermosphere beds 70, 72 and 74 as described previously. The ball heater 110 comprises equivalent structure to that shown in ball heater 10, the grate members and downspout arrangement in ball heater 110 being shown in phantom. The thermosphere beds themselves are not shown in ball heater 110 but are equivalent to those shown in ball heater 10.

After the combustion gases and entrained ash have been passed upwardly through the various thermosphere beds, the gases and ash are cooled (e.g. to 700° F.) but still retain some extractable heat. If desired therefore, the heat in these gases and ash may be utilized to preheat air, and to this end the exhaust gases and ash are sent, via overhead line 150, into heat exchanger 132, to heat air blown into the heat exchanger by blower 152. The cooled exhaust gas and ash leave heat exchanger 132 via line 138. The ash is removed by cyclone 136, and the exhaust gas is sent to waste or utilized in some manner.

It will be noted that while the ball heater 10 or 110 is shown with three thermosphere beds only, it may be desirable to have one, two, four, or more thermosphere beds, depending upon the amount of heating of balls that is desired, and other factors. For example, in the embodiment of FIGURE 4, where the oil shale is preheated in a preheating drum 100, the balls are sometimes cooled to a great degree and it may sometimes be more economical to utilize four thermosphere beds rather than three. Regardless of the variation in the number of thermosphere beds, the principles of operation of the ball heater remain the same, as described previously.

It is desirable to purge the shale coke burner bed 139 of broken thermospheres and any other large fragments or particles of noncombustible material fed to the bed. To this end, a purge line 146 leads from the bottom of the burner bed 139. The amount of purging is controlled by a gamma ray level control or by means of the pressure drop across the bed 139, or in any other suitable manner.

Turning now to the cracking of oil vapors and gases in the cracker 120, the oil vapors and gases, to be cracked, preferably contact a separate ball stream of a predetermined average temperature, entering the cracker via line 160. The ball stream moves downwardly through the cracker 120 in the form of a packed bed. The utilization of a ball stream circulating only between a cracking and ball heating step, and maintained completely separate from the ball stream circulating between the pyrolysis, preheating and associated ball heating steps, is preferable. Usually, a single ball stream circulating among pyrolysis, cracking, and preheating and ball heating steps is utilized and is satisfactory in many instances. However, the use of two separate ball circuits, as described, allows the optimum sized balls to be employed for the cracking step, as well as for the pyrolysis step. Also, the optimum inlet temperatures of the balls for the cracking, as well as for the pyrolysis, can be employed.

The ball cracker also acts as a means of dust removal, the dust entrained by the oil vapors and gases being trapped by the balls in the cracker 120. The balls, upon passing through the cracker 120, are sent to a reheating step via line 162. The balls generally do not give up much heat during the cracking step, e.g., they may be reduced 25–100° F. in temperature. This small loss of heat in the balls can be made up by means of more or less conventional ball-heating units or by means of a fluidized unit similar to the one described (not shown). The cracked oil vapors leave cracker 120 via line 163.

Instead of passing the vapors and gases from the pyrolysis drum 116 downwardly through the cracker 120 in the same direction as the balls passing therethrough, the vapors and gases may be led to the bottom of the cracker 120 and taken off from the top thereof. Such an arrangement results in somewhat better economy because of counterflow contact of vapors and balls, with the vapors and gases being removed from the cracker at the place where a minimum of dust exists on the balls and where a maximum of cracking occurs by reason of the high ball temperature.

It will be understood that other means of cracking, aside from ball-cracking, may be used. However, the ball-cracking is preferably employed for reasons previously set forth.

It sometimes not necessary to utilize for ball heating all the heat produced by the combustion of certain shale cokes, and, to this end, steam generating coils 164 can be interposed in the shale coke burner bed 139 for the purpose of extracting heat from the burner bed.

The preferable ranges of operating temperatures within which the various material streams fall are listed below:

	°F.
Raw shale inlet to shale preheater (line 102)	30–100
Preheated oil shale outlet (line 114)	400–600
Ball outlet (line 109) to ball heater	450–750
Ball inlet to pyrolysis drum 116 (line 117)	1000–1400
Oil vapor and gas effluent from pyrolysis (line 118)	750–950
Ball outlet (line 124)	800–1100
Shale coke outlet (line 126)	750–950
Combustion gas and ash, initially (line 140)	1300–1800
Exhaust gas and ash (line 150)	600–900
Preheated air (line 134)	400–700
Ball stream inlet to cracker (line 160)	900–1200
Ball stream outlet from cracker (line 162)	800–1175

The preferable weight ratio of balls to oil shale lies between 1:1 and 3:1. Also, the preferable size of steel or ceramic ball for fluidization lies between about ⅜" diameter to ¾" diameter, and the preferable combustion gas velocity for fluidization of ceramic balls lies between 1200 and 2500 feet/minute. The minimum gas velocity for fluidization for ⅜" diameter steel balls is about 2000 feet/minute, and for ⅜" diameter ceramic balls is about 1000 feet/minute.

An example of our process follows: Turning first to the ball heater 110, a heat balance on a ball heater, having specific dimensions, when employed to heat balls from 600° F. to 1400° F., is set forth below.

Heat input:
- Via line 109—2000 lbs. balls per hour, 600° F.
- Via line 140—
  - Shale ash—1200 lbs. per hour, 1400° F.
  - Gases of combustion—600 lbs. per hour, 1400° F.

Heat output:
- Via line 117—2000 lbs. balls per hour, 1300° F.
- Via line 150—
  - Shale ash—1200 lbs. per hour, 750° F.
  - Gases of combustion—6000 lbs. per hour, 750° F.

The average inside diameter of the ball heater **110** is 20 inches. The ball heater height is 6 ft. The grate members **16**, **18** and **20** are spaced approximately 18" apart. The bed depth on grate member **16** is approximately 5 inches, while the bed depth on grates **18** and **20** is approximately 3 inches.

The temperature of the balls on grate members **16**, **18** and **20** is approximately 750° F., 1000° F., and 1300° F. respectively.

In the process of FIGURE 4, the balls, once heated to 1300° F., are sent to drum **116**, via conveyor **112**, for the stripping of oil shale.

Approximately 1300 lbs. of oil shale per hour (the yield by Fischer assay of the oil shale being about 20 gallons oil per tone of oil shale) are preheated in drum **100**, to a temperature of about 550° F. and enter the drum **116**, to intimately contact the balls, entering at the rate of 2000 lbs. per hour. The balls leave the drum **116** at a temperature of about 900° F. for the preheating of fresh oil shale in drum **100**.

Approximately 100 lbs. of oil vapors and gases are produced and leave the drum **116**, via line **118**, to enter cracker **120** for cracking by means of a separate 1100° F. ball stream, as described previously.

Approximately 1200 lbs. of shale coke, having a temperature of about 850° F., are produced and sent to a combustion zone **130** for combustion with preheated air. The resulting products of combustion comprise 1200 lbs. per hour of shale ash, and 6000 lbs. per hour of combustion gases. The exhaust ash and gases are sent to a heat exchanger **132**, the exhaust ash and gases having an approximate 750° F. temperature. These exhaust ash and gases are then used to preheat air to a 550° F. temperature.

Turning now to FIGURE 5, a modification of our invention, with respect to the production of oil from oil shale, is shown. In this modification, the mode of preheating of the oil shale has been somewhat modified but the pyrolysis and cracking remain essentially the same as described with reference to FIGURE 4. The combustion step of the shale coke remains approximately the same as described with reference to FIGURE 4.

The primary difference between the FIGURE 5 embodiment and FIGURE 4 embodiment lies in the fact that the oil shale is preheated by direct contact with the combustion gases and ash rather than by contact with balls. The combustion gases and ash utilized are those that have just passed through the ball heater **210** and are cooled by various means so as to have a maximum temperature of about 700° F. just prior to passage through the oil shale.

Referring now especially to FIGURE 5, raw shale is introduced by a screw conveyor **212** into an elutriator **214**. The inlet raw shale has been previously crushed to a mesh size of about $-\frac{1}{4}$" or $-\frac{1}{2}$" and is maintained in a fluidized state by means of the gas velocity of an air stream entering the elutriator **214**, via line **216**, and blown in by blower **218**. A fluidized bed **220** of cold oil shale is thus maintained in elutriator **214**.

The raw oil shale in bed **220**, except for fines (which are treated as will be described hereafter), leaves the elutriator **214** via a standpipe **224**, and is sent via lines **226** and **228** to a second fluidized bed **230** (maintained within a chamber or zone **231**) mounted above the ball heater **210** and in communication therewith. The raw shale in the line **226** acts as a gas seal to prevent the passage of gas therethrough. The raw shale may be preheated to a maximum temperature of 600° F. since above this temperature, pyrolysis commences with consequent loss of oil vapors and gases. Hence, the temperature of the raw shale fluidized bed **230** is maintained within fairly narrow limits, e.g. 400° to 600° F.

The bed **230** is preferably heated, and fluidized, by means of the combustion gases and fine ash leaving the ball heater **210**. The exhaust combustion gases and ash usually have a temperature, at the exit of the ball heater **210**, higher than that necessary to preheat the oil shale to 400 to 600° F. Hence, the temperature of the exhaust gases and ash is regulated (i.e. lowered) by first passing the exhaust combustion gases and ash through a steam boiler **232** comprising, for example, a series of tubes in the form of a coil **234**. The somewhat cooled exhaust gases and ash are then used to fluidize and preheat the oil shale in bed **230** to the desired temperature without danger of overheating the raw shale. While a steam boiler **232** has been shown for the purpose of lowering the combustion gas and ash temperature, a gas-to-gas heat exchanger, or other suitable means, may also be employed.

It will be noted that the raw shale bed **230** will continually have shale ash fines blown through it along with the fluidizing combustion gas. The size of the raw shale, forming bed **230**, is therefore set so that, at a chosen fluidizing rate, only the shale ash fines will be elutriated from bed **230**, but not the raw shale feed. For this reason, the raw shale feed in bed **220** is also preliminarily sized, by air elutriation means, so that raw shale fines are elutriated from bed **220**, leaving raw oil shale of a sufficiently large size to be sent to bed **230**. In this manner, very little raw shale will be elutriated from bed **230**.

Other suitable means of separation of fines from the raw oil shale, such as by screening, may be employed, in addition to, or in lieu of the separation by elutriation.

The raw shale fines elutriated from bed **220** are removed from the elutriating air stream by cyclone **238**, the air leaving via line **240**. The raw shale fines are then sent to the pyrolysis drum **316**, via line **242** and conveyor line **243**, for pyrolysis, along with preheated oil shale entering the pyrolysis drum via line **244**, and the same conveyor line **243**. The raw shale in the line **242** and the preheated shale in the line **244** act as gas seals to prevent the passage of vapors and gases therethrough. The amount of raw oil shale fines is small relative to the amount of preheated oil shale entering the pyrolysis drum **316**.

The exhaust combustion gases and ash leave the fluidization zone or chamber **231**, via conduit **246**. The ash is removed by cyclones **248** and **250**, and the combustion gases sent to waste or further processing via line **252**.

Since the combustion gases directly contact the raw shale feed in the fluidization bed **230**, it is important that very little, if any, oxygen be present, in the combustion gases. If oxygen were present, oxidation of kerogen or bitumen in the oil shale would occur. In order to insure the absence of oxygen in zone **231**, the combustion of shale coke is conducted as nearly as possible with the stoichiometric quantity of oxygen necessary for complete combustion.

The balls in the heater **210** are fluidized by the resulting combustion gases from shale coke combustion bed **339** containing shale ash, and the movement of balls and combustion products through the heater **210** is essentially the same as that described with reference to ball heaters **10** and **110** of FIGURES 1 and 4 respectively.

The heated balls leave the heater **210** at a predetermined temperature for mixing with, and pyrolysis of, oil shale in the rotatable pyrolysis drum **316**. The pyrolysis and cracking steps are identical with those previously described with reference to FIGURE 4 and need not be described in detail. Suffice it to say that the oil vapors and gases resulting from pyrolysis are preferably cracked on a ball stream, in cracker **320**, as previously described.

The balls are separated from the shale coke by trommel means **322**, and are sent to the ball heater **210** via line **324**. A screen **325**, interposed at the entrance to line **318**, prevents entry of balls therein. A gas seal is provided in line **324** by forming a packed bed of balls therein prior to the elevation of the balls. In this manner, the

oils and gases enter cracker **320**, and do not enter line **324**.

The shale coke is sent to combustion bed **339** via lines **326** and **328**, to be combusted with air at ambient temperature, blown in via line **334**.

The combustion zone **339** is provided with a purge line **346**, and steam generator **364**, as described with reference to FIGURE 4.

An example of the process of FIGURE 5 is set forth below: raw shale enters elutriator **214**, via line **212**, and has a mesh size of —½ inch, the average mesh size being about 4 mesh. The larger raw shale entering line **226** has an average mesh size of 3 mesh, and lies in the range of about —½ inch to 10 mesh. The preheated shale size, in line **244**, also averages 3 mesh and lies in the range of about —½ inch to 10 mesh. The fine entrained spent shale has a size of —10 mesh and averages 65 mesh. Finally, the fine raw shale size, in line **242**, has a size of —10 mesh, and averages 20 mesh. The ball size is approximately ½ inch, the balls being composed principally of alumina.

The operation, dimensions, and spacing of the grate members of the ball heater **210** are the same as described, with reference to heater **110**, and to the example previously given.

In the process of FIGURE 5, the balls, after being heated to 1300° F., are sent to drum **316**, via line **243**, for the stripping of oil shale.

Approximately 1300 lbs. of oil shale per hour are preheated in bed **230**, to a temperature of about 500° F., and enter the drum **316** to intimately contact the balls, entering at the rate of 2000 lbs. per hour. The balls leave the drum **316** at a temperature of about 900° F. for the preheating of fresh oil shale in drum 100. Approximately 100 lbs. of oil vapors and gases are produced and leave the drum **316** to enter cracker **320** for cracking by means of a separate 1100° F. ball stream

Approximately 1200 lbs. of shale coke, having a temperature of about 850° F., are produced and sent to a combustion bed **339** for combustion with preheated air. The resulting products of combustion comprise 1200 lbs. per hour of shale ash, and 6000 lbs. per hour of combustion gases.

The combusted gases and ash, at about a 1400° F. temperature, pass through heater **210**, as described, and also pass through a water boiler section **232**, to reduce the temperature of gas and ash to such a degree that it does not raise the temperature of the shale in bed **242** above 600° F. A suitable gas and ash temperature for this purpose is about 700° F. The 700° F. gas and ash pass through raw shale bed **230**, and are exhausted at a temperature of about 525° F.

A process for heating thermospheres, in a fluidized state, has been described with particular reference to the use of such process in the production of oil from oil shale, tar sands, and the like. Several embodiments of the use of our invention and a preferred embodiment of our ball heater have been shown and described. Changes and modifications can be made that lie within the scope and spirit of this invention and hence we intend to be restricted only by the scope of the claims, which follow.

We claim:

1. A process for the production of oil from carbonaceous material, which comprises: heating and simultaneously grinding said carbonaceous material by solid-to-solid milling contact with hotter solid heat-carrying bodies in a heating and grinding zone, to produce oil vapors and gases and a fluidizable combustible residue of smaller average size than said solid heat-carrying bodies; transferring said fluidizable combustible residue to a combustion zone; fluidizing and combusting said combustible residue in said combustion zone by means of a fluidizing combustion-supporting gas; transferring said heat-carrying bodies to a reheating zone to form therein a plurality of vertically spaced shallow beds of heat-carrying bodies; blowing the combustion gas resulting from combustion of said combustible residue through said beds of heat-carrying bodies to fluidize them and reheat them; moving said heat-carrying bodies successively downwardly from bed to bed in said reheating zone; withdrawing said heat-carrying bodies from a lower bed of said reheating zone and transferring them back to said heating and grinding zone to heat and grind additional carbonaceous material.

2. A process according to claim 1 in which at least a portion of the oil vapors and gases produced in the heating and grinding zone are cracked following their removal from said zone.

3. A process for the production of oil from carbonaceous material, which comprises: preheating said carbonaceous material to a temperature of below 600° F.; further heating and simultaneously grinding said carbonaceous material by solid-to-solid milling contact with hotter solid heat-carrying bodies in a heating and grinding zone, to produce oil vapors and gases and a fluidizable combustible residue of smaller average size than said solid heat-carrying bodies; transferring said fluidizable combustible residue to a combustion zone; fluidizing and combusting said combustible residue in said combustion zone by means of a fluidizing combustion-supporting gas to produce hot combustion gas and hot combusted residue; transferring said heat-carrying bodies to a reheating zone to form therein a plurality of vertically spaced shallow beds of heat-carrying bodies; blowing hot combustion gas and hot combusted residue through said beds of heat-carrying bodies to reheat them, the velocity of said combustion gas being such as to fluidize said heat-carrying bodies and to entrain said combusted residue; moving said heat-carrying bodies successively downwardly from bed to bed in said reheating zone; discharging said reheated heat-carrying bodies from a lower bed of said reheating zone; and heating additional carbonaceous material with said reheated heat-carrying bodies.

4. The process of claim 3 wherein said heating of carbonaceous material below 600° F. takes place by the intermixing thereof with hotter solid bodies initially employed in the heating of said preheated carbonaceous material.

5. The process of claim 3 wherein said carbonaceous material is oil shale.

6. A process for the production of oil from carbonaceous material, which comprises: heating and simultaneously grinding preheated carbonaceous material by solid-to-solid milling contact with hotter solid heat-carrying bodies in a heating and grinding zone, to produce oil vapors and gases and a fluidizable combustible residue of smaller average size than said solid heat-carrying bodies; transferring said fluidizable combustible residue to a combustion zone; fluidizing and combusting said combustible residue in said combustion zone by means of a fluidizing combustion-supporting gas; transferring said heat-carrying bodies to a reheating zone to form therein a plurality of vertically spaced shallow beds of heat-carrying bodies; blowing the combustion gas resulting from combustion of said combustible residue through said beds of heat-carrying bodies to fluidize them and reheat them, and thence through a bed of raw particulate carbonaceous material, to fluidize and preheat said raw material in a preheating zone; transferring the preheated carbonaceous material to said heating and grinding zone; moving said heat-carrying bodies successively downwardly from bed to bed in said reheating zone; withdrawing said heat-carrying bodies from a lower bed of said reheating zone and transferring them back to said heating and grinding zone to heat and grind said preheated carbonaceous material.

7. The process of claim 6 wherein said raw carbonaceous material, prior to its preheating, is fed to an elutriation zone, a gas is passed through said carbonaceous material to fluidize particles thereof larger than a predetermined size and to elutriate particles thereof smaller

than said predetermined size, said elutriated particles being transferred to said heating and grinding zone, and said larger fluidized particles being transferred to said preheating zone.

8. A thermosphere heating system which comprises: a combustion furnace having air inlet means and solid fuel inlet means, the air and fuel reacting to form a fluidized zone of combustion within said combustion furnace; an insulated elongated enclosure means having an elongated opening extending generally vertically therethrough; conduit means communicating said opening in said enclosure means with said combustion furnace, the bottom end of said conduit means being spaced above the fluidized zone of combustion whereby hot combustion gases and combusted particles of small size only are entrained through said conduit means; means for introducing thermospheres into the upper section of said enclosure means; means for fluidizing shallow beds of thermospheres at successively different height levels therein, said hot combustion gases causing fluidization and heating of said thermospheres at each of said levels; and means for discharging thermospheres from said enclosure means.

9. A thermosphere heating system which comprises: a combustion furnace having air inlet means and solid fuel inlet means arranged so as to form a fluidized zone of combustion, having an ascertainable upper surface, within said combustion furnace; an insulated elongated generally cylindrical enclosure means having an elongated opening extending therethrough, and mounted above said fluidized combustion zone; a plurality of spaced multi-holed members affixed to, and extending substantially across the opening in, said enclosure means, at different height levels therein; a plurality of downspouts, one mounted within said enclosure means, each of said downspouts extending above and below each of said multi-holed members, no downspout overlying the immediately lower downspout; passage means having an inlet mounted above the uppermost multi-holed member through which said thermospheres are fed onto said multi-holed member, said thermospheres being larger than the holes in said multi-holed member, but smaller than the opening in said downspout; conduit means communicating the bottom of said opening in said cylindrical enclosure means with said combustion zone, the bottom end of said conduit means being spaced above the upper surface of the fluidized zone of combustion; blower means for blowing hot combustion gases and combusted particles from said fluidized zone through said conduit means, and through said enclosure means, said combustion gases and particles passing upwardly through said multi-holed members at a velocity sufficient to fluidize said thermospheres and impart heat to them; and means for discharging heated thermospheres from said enclosure means.

10. A plant for the production of oil from carbonaceous material which comprises: a rotatable drum having inlet means for both carbonaceous material and hot solid bodies, and outlet means for oil vapors and gases and solid carbonaceous residue and cooler solid bodies, said drum, upon rotation, causing an intermixing of said carbonaceous material with hot solid heat-carrying bodies in solid-to-solid milling contact, thereby stripping said carbonaceous material to produce oil vapors and gases and a carbonaceous residue; means for separating said solid carbonaceous residue from said solid bodies; a combustion furnace; a first conduit means for transferring said carbonaceous residue to said combustion furnace; a solid body heating furnace; a second conduit means for transferring said solid bodies to said heating furnace; oxidizing gas inlet means communicating with said combustion furnace; passage means communicating said combustion furnace with said heating furnace; blower means for moving combustion products through said heating furnace, said heating furnace comprising a plurality of spaced multi-holed members, and means for conveying said solid bodies from one multi-holed member to another, the holes in said members allowing combustion products to pass therethrough but having a dimension smaller than the average diameter of each of said heat-carrying solid bodies to prevent passage of said solid bodies therethrough, the opening in said means for conveying solid bodies being larger than the size of any of said solid bodies to allow passage of said solid bodies therethrough; discharge means for discharging said solid bodies from said heating furnace; and solid body conduit means leading from said discharge means to said solid heat-carrying body inlet means of said rotating drum.

11. A plant for the production of oil from carbonaceous material which comprises: a first rotatable drum having inlet means for both cold carbonaceous solid material and hotter solid thermospheres, and outlet means for said solids, said drum upon rotation causing an intermixing of carbonaceous material with thermospheres thereby preheating said carbonaceous material and cooling said thermospheres; means for separating said preheated carbonaceous material from said cooled thermospheres; a second rotatable drum having inlet means for both preheated carbonaceous material and hotter solid thermospheres, and outlet means for oil vapors, gases, solid carbonaceous residue and thermospheres, said drum upon rotation causing an intermixing of said carbonaceous material with hot thermospheres in solid-to-solid milling contact, thereby stripping said carbonaceous material to produce oil vapors and gases and a carbonaceous residue; means for separating said solid carbonaceous residue from said thermospheres; a combustion furnace; a first conduit means for transferring said carbonaceous residue to said combustion furnace; a second conduit means for transferring said thermospheres from said second rotating drum to said first rotating drum for the preheating of carbonaceous material; a heating furnace for cooled thermospheres; a third conduit means for transferring said thermospheres from said first drum to said heating furnace; air inlet means communicating with said combustion furnace; passage means communicating said combustion furnace with said heating furnace; blower means operatively associated with said passage means to blow combustion gases and combusted residue from said combustion furnace upwardly through said heating furnace, said heating furnace comprising a plurality of spaced grate members and an equal number of downspouts extending through each of said grate members, no downspout overlying the immediately lower downspout, the openings in said grate members allowing gases to pass therethrough but having a dimension smaller than the average diameter of each of said thermospheres, the opening in said downspouts being larger than the diameter of any of said solid bodies; discharge means for discharging said solid bodies from said heating furnace; and a fourth conduit means for heated thermospheres leading from said discharge means to said inlet means for said second rotating drum.

12. Apparatus according to claim 11 including a cracking unit having an inlet for hot thermospheres and a conduit means for oil vapors and gases leading from said second drum; outlet means from said cracking unit for said cracked oil vapors and gases; an auxiliary heating furnace; outlet passage means from said cracking unit, for said thermospheres, communicating with said auxiliary heating furnace; and conduit means, for said thermospheres, leading from said heating furnace to said cracking unit.

13. A plant for the production of oil from carbonaceous material which comprises: an elutriator having a fluidizing gas inlet, and a carbonaceous material inlet; a standpipe in said elutriator for discharge of said carbonaceous material; an overhead discharge conduit for discharge of fluidizing gas and elutriated material; a heating unit; a first passage means communicating with said standpipe and leading into said heating unit, whereby carbonaceous material is fed to said heating unit; a gas inlet passage

leading to said heating unit, hot combustion gases and hot combusted residue entrained therein passing upwardly into said heating unit through said inlet passage to directly contact said carbonaceous material and transfer heat thereto; a first and second outlet means for preheated carbonaceous material, and for said combustion gases containing entrained solids, respectively; a rotatable drum having inlet means for preheated carbonaceous material communicating with said first outlet means and inlet means for generally spherical solid heat-carrying bodies, and outlet means for oil vapors, gases, solid carbonaceous residue and cooler solid bodies, said drum, upon rotation, causing an intermixing of said carbonaceous material with hot solid heat-carrying bodies in solid-to-solid milling contact, thereby stripping said carbonaceous material of oil vapors and gases and leaving a solid carbonaceous residue; means for separating said solid carbonaceous residue from said solid bodies; a combustion furnace; a first conduit means for transferring said carbonaceous residue to said combustion furnace; a solid body heating furnace; a second conduit means for transferring said solid bodies to said heating furnace; air inlet means communicating with said combustion furnace; blower means communicating with said air inlet means for blowing air, through said inlet means, into said combustion furnace; passage means communicating said combustion furnace with said heating furnace, whereby gases and combusted residue are blown upwardly through said solid body heating furnace and said heating unit, said heating furnace comprising a plurality of spaced grate members and an equal number of downspouts extending through each of said grate members; discharge means for discharging said solid bodies from said heating furnace; and solid body conduit means leading from said discharge means to said inlet means for said rotating drum.

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