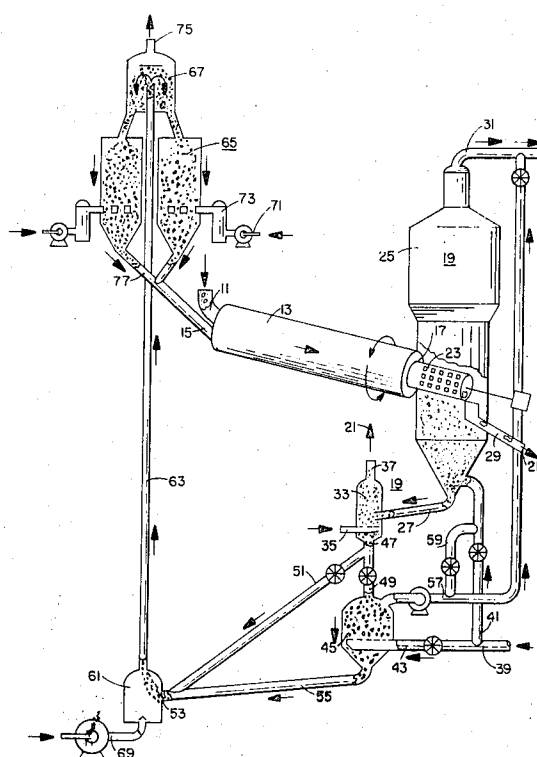


3,008,894	11/1961	Culbertson.....	208/11
3,018,243	1/1962	Nevens	208/11
3,020,227	2/1962	Nevens et al.	208/11
3,058,903	10/1962	Otis.....	208/11
3,252,886	5/1966	Crawford	208/11
3,573,197	3/1971	Gessner	208/11
3,803,021	4/1974	Abdul-Rahman	208/11
3,803,022	4/1974	Abdul-Rahman	208/11

40 Claims, 2 Drawing Figures



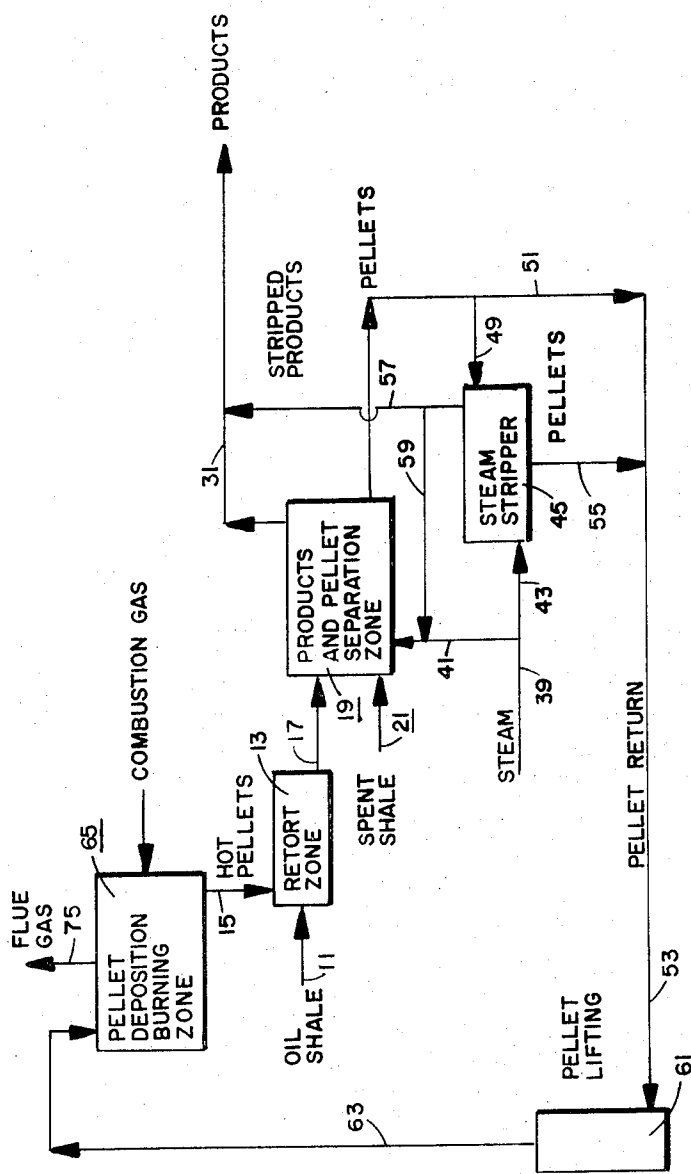


FIG. 1

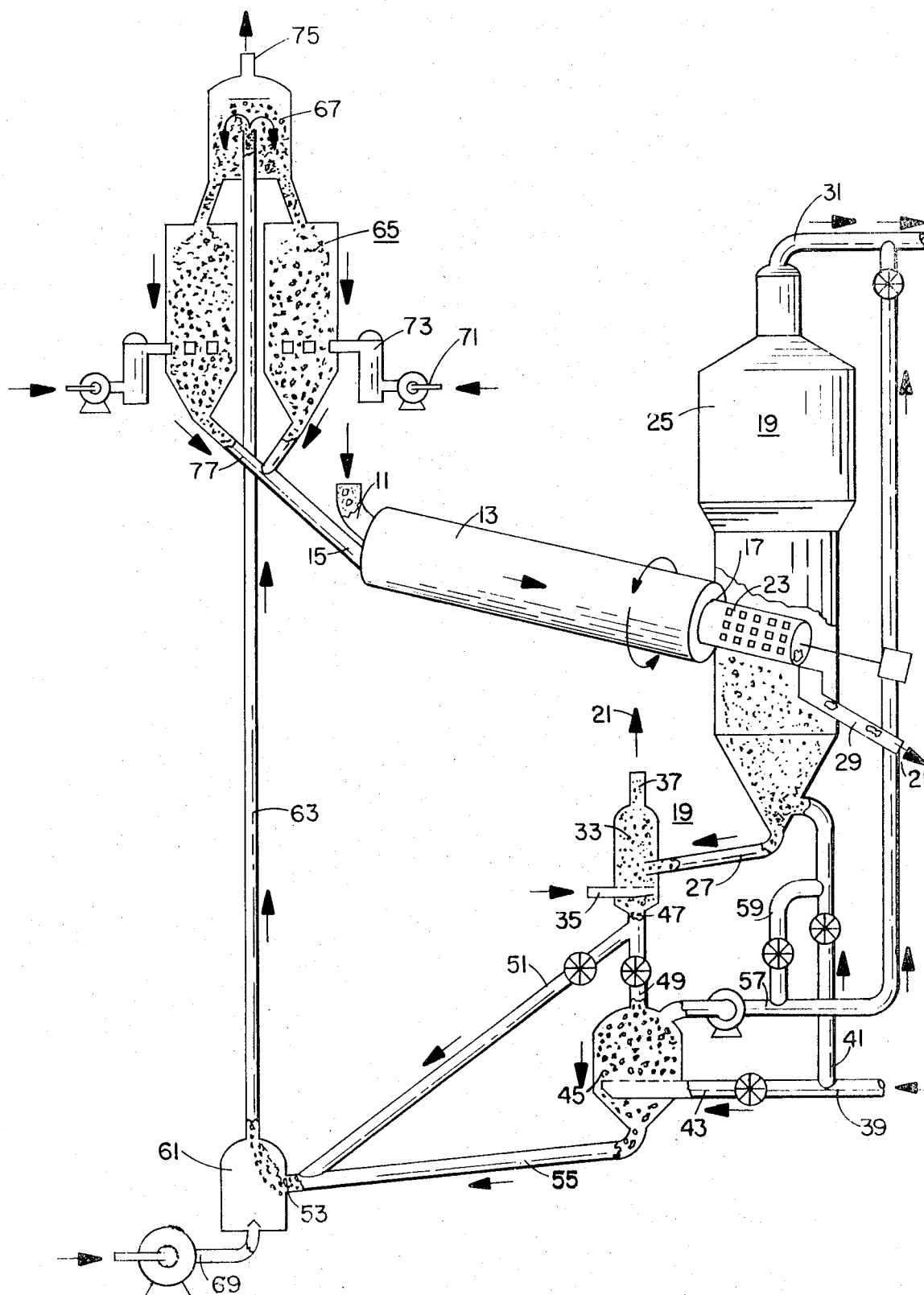


FIG. 2

RETORTING OIL SHALE WITH SPECIAL PELLETS AND STEAM STRIPPING

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of copending application 285,732, filed Sept. 1, 1972, entitled "Retorting Oil Shale with Special Pellets and Steam Stripping," now abandoned, which was a continuation-in-part of copending application Ser. No. 284,288, filed Aug. 28, 1972, entitled "Retorting Oil Shale with Special Pellets," now abandoned. All of said applications have been filed by the same inventors as this application and owned by a common assignee.

BACKGROUND OF THE INVENTION

This invention relates to a process for retorting of the solid carbonaceous organic matter in crushed oil shale. In the process, special heat-carrying pellets are cycled in a particular way to a retort zone and thence at least some of the pellets are subjected to steam stripping to remove some of the deposition previously formed on the pellets.

As a preliminary stage in the production of petroleum oils and gases, the solid carbonaceous organic solid matter or kerogen in oil shale is pyrolyzed or retorted. The term retorting denotes thermal conversion of kerogen or organic matter to oil vapors and gas thereby leaving particulate spent shale and includes separation of the oil vapors and gas from the spent shale. The spent shale contains residual carbonaceous organic matter and matrix mineral matter. In an overall commercial operation, the products or yield of retorting are processed in additional stages, for example, solids separation, condensation, fractionation, coking, hydrogenation, and the like, depending on the types of marketable products being produced.

Frequently, the yields of various processes are compared with Fischer Assay yields. For a description of the Fischer Assay refer to "Method of Assaying Oil Shale by a Modified Fischer Retort" by K. E. Stanfield and I. C. Frost, R. I. 4477, June 1949, U.S. Department of Interior.

When the kerogen is retorted, a normally gaseous fraction, a normally liquefiable vaporous fraction, and an organic residue are formed. The product distribution between gas, liquid, and residue is indicative of the distribution of the various boiling point fractions in the liquid product. It is highly desirable to obtain a liquid product that is directly adaptable to prerefining and avoids or lessens the amount of residue or 975°F. plus fraction that must be subjected to coking or other similar treatments. In many retorting processes control over the product distribution is virtually absent, and in others, any attempt to reduce the need for coking and the like by altering the boiling point distribution in the liquids either results in too much unusable material, or too much gas product, or too much organic residue or 975°F. plus fraction, or any combination thereof, which in turn eventually result in a loss of liquid oil yield. Any advantage obtained by attempting to control product or residue conversion is frequently offset by undesirable shifts in other variables or results. In addition, the kerogen content of the oil shale inherently or naturally fluctuates between rich and lean and many processes

are not sufficiently flexible to control product distribution when the kerogen content varies.

Some advances to more flexible and efficient control over the products of retorting and of other variables have been made by using solid heat-carrying bodies which exhibit good heat transfer properties and supply the heat needed for retorting with a reduction in process problems. In such processes, the heat-carrying bodies and the oil shale feedstock are inter-mixed thereby retorting oil vapors and gases from the feedstock. The heat-carrying bodies are usually heated in a separate heating zone by burning combustible fuel material, such as heavy resid or natural gas. But in general, this method of heating necessitates additional equipment and creates additional handling problems.

Others have proposed cycling the spent shale and supplying some of the heat by burning the residual carbonaceous organic matter or solid organic char developed in the retort zone, or cycling catalyst particles and supplying some of the heat by burning carbon deposited on the catalyst (for example, U.S. Pat. No. 3,281,349). In this latter process, the surface area of the catalyst particles is not specified. Some types of catalyst particles frequently have high surface areas which result in loss of valuable liquid product and excessive gaseous product, excessive residue, excessive heating of the catalyst during burning, loss of valuable heat values, higher oxygen demands, and other disadvantages.

In addition, a large amount of fine (e.g., minus 14 U.S. Standard Sieve size) particulate spent shale is usually present during burning and reheating. This spent shale contains organic carbon and increases oxygen demands, causes loss of useful heat values, and adversely enlarges the size of equipment. Fine spent shale or other materials also interfere with control of the burning and other stages of the process and create many other problems especially when the entrained spent shale is smaller than other heat-carrying bodies. Moreover, the presence of appreciable amounts of fine spent shale severely limits the type of equipment which can be used for burning the residue.

Generally, burning in the presence of fine spent shale requires the use of lift pipes or fluidized systems. Both forms of burning systems have a large excess of oxygen which rapidly burns the organic matter and both forms have many disadvantages in the process of this invention.

Copending application Ser. No. 410,200, which is a continuation-in-part of application 284,288, which is incorporated herein, provides a process for retorting oil shale using hot special pellets in a way which regulates the amount of combustible organic carbon residue or deposition formed on the pellets during retorting of oil shale and improves the recovery of useful components and liquid product distribution. The deposition acts as a principal source of fuel for heating the pellets. The process relies on the interrelation between the surface area of the pellets and other process conditions and variables; however, additional flexibility in the operation of the process, especially the retort zone, is desired primarily because it has been found that the retorting stage of the process requires constant control and adjustment and altering one variable affects other variables and results, and because it is desirable at times to use higher surface area pellets or to operate the retort zone under conditions such that the deposition formed

on the pellets during retorting of the oil shale is more than sufficient to supply a major portion of the fuel required for heating the pellets. In addition to loss of valuable product, an over supply of deposition creates certain problems. For example, there is an increase in oxygen demands and the probability of overheating the pellets. In addition, the burner equipment may not be large enough to allow sufficient residence time or bed size. Such retorting conditions could arise, for example, when a vein of rich oil shale is encountered and the design and the pellet surface area or the size of the retorting equipment are such that it would be undesirable or inefficient to adjust operations to the rich shale. There are other situations which arise during retorting of oil shale where recovery of some of the deposition on the pellets or the spent shale, or both, is desirable. When such situations arise or when other objectives change or fluctuate, more process flexibility is advantageous. Briefly, therefore, a principal object of this invention is to provide greater flexibility to a retorting process of the type disclosed in copending application Ser. No. 410,200, filed Oct. 26, 1973.

SUMMARY OF THE INVENTION

In a retorting process, crushed carbonaceous solid organic matter is retorted in a retort zone with special heat-carrying pellets in a manner which produces product gases and oil vapors, combustible deposition, and particulate spent shale. The process emphasizes product quality, reduces the need for gaseous or liquid fuels which are normally required in the production of syn-crude from solid carbonaceous materials, and avoids waste of valuable residue on the pellets, or the pellets and spent shale. The process cycles special hot heat-carrying pellets in a way which produces or leaves a combustible carbon-containing deposition on the spent shale and on the pellets and renders the deposition on the pellets more useful as a fuel for heating the pellets that are used to retort oil shale. In the process, some or all of this deposition on the pellets is burned in a pellet deposition burning zone after the pellets have been separated from the spent shale to heat or reheat the pellets. Some of the combustible deposition is recovered prior to such burning by contacting the spent shale and pellets, or at least a portion of the pellets, or both, with steam at a temperature sufficient to strip some of the deposition from the particulate solids or pellets. Since the steam stripping stage or stages are performed after the retorting stage, the retorting stage or other earlier stages may be operated under conditions which increase the amount of combustible deposition formed during such stages. The steam stripping stage or stages, therefore, provide greater flexibility to the overall process, especially the retorting stage. Preferably, for increased flexibility and other reasons, a steam stripping stage is carried out on the pellets after the pellets have been separated from most of the spent shale.

The special pellets are comprised of particulate or divided solid heat carriers whose physical properties and characteristics, especially surface area, size, shape, temperature, and amount, coact with other variables to control the amount of organic combustible deposition formed on the pellets during the process, especially during the retorting stage, and to accomplish the other objectives and advantages of the process.

In the process, mined oil shale which contains solid carbonaceous organic matter and other mineral matter

and which has been crushed and may have been preheated is pyrolyzed or retorted in a retort zone with the special hot heat-carrying pellets at a temperature and in an amount sufficient to provide at least 50 percent of the sensible heat required to retort the oil shale. Retorting the shale produces gas and oil products which are recovered and particulate spent shale. Retorting also tends to deposit or leave a carbon-containing deposition on the special pellets and the spent shale.

After retorting the oil shale, at least 75 percent of the total particulate spent shale and at least 95 percent of the particulate spent shale smaller than the pellets are separated from the pellets. This separation may be performed before or after the steam stripping stage, but in either event it is performed before burning of the combustible deposition on the pellets. Preburn separation avoids the problems caused by the presence of fine matter during burning. One way to accomplish this separation is to first screen large spent shale and agglomerates from the pellets and thereafter subject the pellets and spent shale to gas elutriation with a noncombustion supporting gas. Another way to enhance the degree of total separation is to control the sphericity factor of the pellets to at least 0.9, or to crush the raw oil shale to a smaller than normal size, that is, to minus 6 U.S. Sieve Series size.

Either before or after, or both before and after, separation of the spent shale, at least a portion of the pellets and/or spent shale are subjected to steam stripping to remove some of the combustible organic deposition formed or left on them. The stripped organic matter is added to the total product from the process. The pellets bearing the combustible deposition left after steam stripping are eventually passed to a pellet deposition burning zone where at least a portion of combustible deposition is burned to heat the pellets.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, FIG. 1 is a schematic flowsheet of the process of this invention; and

FIG. 2 is a partly schematical, partly diagrammatical flow illustration of a system for carrying out a preferred sequence of the process of FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

A process for retorting crushed oil shale containing carbonaceous organic matter and other mineral matter is described in general terms having reference to FIG. 1 and in more particular terms having reference to FIG. 2.

Raw or fresh oil shale which has been mined and pulverized, crushed or ground for the most part to a predetermined maximum size for handling in a retorting system by any suitable particle diminution process is fed directly from a crusher or from a hopper or accumulator by way of shale inlet line 11 into retort zone 13. At the same time, special heat-carrying pellets substantially hotter than the shale feed are fed by gravity or other mechanical means to the retort zone by way of pellet inlet pipe 15. The pellets and shale feedstock could be fed to the retort zone by way of a common retort zone inlet.

Crushing of the raw mined shale expedites more uniform contact and heat transfer between the shale feedstock and hot pellets and more uniform deposition of a carbon-containing deposition on the pellets. In normal practice, the degree of crushing is simply dictated

by an economic balance between the cost of crushing and the advantages to be gained by crushing when retorting the kerogen from the shale. Generally the shale feedstock is crushed to about minus three-fourths inch and no particular care is taken to produce or restrict production of finer material. In this process, crushing has a special purpose and aids in a preburn separation step. In one embodiment, for reasons which will be hereinafter shown and despite the added costs and standard practice, the mined shale is crushed to a substantially finer size wherein at least 95 percent by weight of the crushed oil shale will pass through a U.S. Sieve Series size 6 screen.

The crushed oil shale may or may not be preheated by direct or indirect heat from any source including indirect heat exchange with pellets or flue gases generated during this retorting process. If the shale feedstock is preheated, the temperature of the feedstock will not exceed 600°F. The shale feedstock will usually be fed by way of a metered weight controller system for reasons hereinafter made apparent and which may include a preheat and/or gas lift system. The preferred system for preheating the raw shale is to lift the shale in lift pipes with the hot flue gases generated in the combustion phase of the process.

The hot special heat-carrying pellets are especially characterized by having a principal size during use of between approximately about 0.055 and 0.5 inch and preferably between about 0.055 and 0.375 inch, and a surface area during use of between 10 and 150 square meters per gram. The surface area is the average effective surface area of the pellets as they enter the retort zone. The importance of surface area is hereinafter discussed in detail. The heat-carrying pellets are at temperatures ranging between 1,000°F and 1,400°F, which is about 100°F to 500°F higher than the designed retorting temperature within the retort zone. The most favorable practical temperature range depends on the process variables and more particularly on the specific advantages and characteristics of this process. The quantity of pellet heat carriers is controlled to cooperate with other variables so that the pellet-to-shale feedstock ratio on a weight basis is between one and three with a ratio between 1.5 and 2.5 being preferred. This ratio is, moreover, such that the sensible heat in the pellets is sufficient to provide at least 50 percent of the heat required to heat the shale feedstock from its retort zone feed temperature to the designed pyrolysis temperature. The retort zone feed temperature is the temperature of the oil shale after preheating, that is, the temperature of the shale upon entry into the retort.

The average retort temperature ranges between about 850°F. and 1,200°F. depending on the nature of the shale feedstock, the pellet-to-shale ratio, the type of product distribution desired, heat losses, and the like. The relative mass and size of the pellets are selected in a manner hereinafter set forth which facilitates separation of the pellets from spent shale, controls the amount of combustible carbon-containing deposition deposited on the pellets, optimizes other facets of the retorting process, and makes allowance for wear or size reduction of the pellets as they are cycled and recycled through the retorting process.

The term pellets refers to subdivided or particulate bodies a majority of which have the characteristics and properties herein required and which are composed of the same or dissimilar materials having the specified

surface area and strength and of irregular shape, cylindrical shape, approximately oval or spherical shape, or purely spherical shape. The preferred pellets have a sphericity factor of at least 0.9 which, in addition to the usual advantages of facilitating movement of the pellets through the retorting process and of providing optimum solid-to-solid heat transfer and contact between the pellets and oil shale feedstock, has an advantage particularly useful in separating the pellets from other solids produced in the process as hereinafter set forth. The sphericity factor is the external or geometric surface area of a sphere having the same volume as the pellet divided by the external surface area of the pellet.

The pellets are made up of materials, such as, *alumina* or *silica alumina*, which are not consumed in the process and which are subdivided or particulate matter having significantly high internal surface area, but not excessively high. The pellets are sufficiently wear or breakage resistant and heat resistant to maintain enough of their physical characteristics under the conditions employed in the process to satisfy the requirements herein set forth, to effect retorting of the oil shale, and to permit controlled burning of a carbon-containing deposition formed on the pellets during the process. More specifically, the pellets do not disintegrate or decompose, melt or fuse, or undergo excessive surface area reduction at the temperatures encountered during such burning and the thermal stresses inherent in the process. The pellets will, of course, undergo some gradual wear or size reduction.

As will be shown, the size of the pellets is related to the other variables and to the preburn spent shale separation step of this process. The original or fresh pellets are generally comprised of particulate sensible heat carriers in a size range between about 0.1 inch and 0.5 inch and preferably between 0.1 inch and 0.375 inch, and are for the most part maintained during use at a plus 14 U.S. Sieve Series screen size, that is, approximately about 0.055 inch or greater. Finer pellet grain sizes are undesirable in the process of this invention.

Suitable pellet materials are also found in cracking catalyst; however, the retorting process of this invention is not to be considered as relying on active catalytic sites. Many catalysts have surface areas far in excess of the maximum surface area of 150 square meters per gram provided in this process. For example, some silica alumina catalyst may have a surface area ranging between 180 and 700 square meters per gram. As will hereinafter be discussed and as indicated by the trend shown in TABLE 1, high surface areas tend to cause too much combustion carbon-containing deposition or coke-like deposition being deposited in the retort zone. As herein pointed out, a post-retorting steam stripping stage or stages overcome some of the undesirable effects of too much deposition; however, it is preferred that these undesirable effects be avoided by selecting pellets with a surface area of 150 square meters per gram or less, thereby maintaining the flexibility provided by the steam stripping stage or stages.

Active catalytic sites tend to have effects similar to excessively high surface areas. As a result, in this process, although cracking catalysts may be used, it is preferred that the pellets bear no added active acid cracking catalytic catalyst sites or the like when the pellets are added to the retort zone. What is preferred are pellets that have the size and surface area limitations

herein set forth. Of course, the retorting phase of this process and the subsequent deposition combustion phase could be conducted with a catalyst with some loss of flexibility in such a manner as to kill or limit active catalyst sites and limit or destroy excessive available pellet surface area; but as mentioned previously, it is preferred that the pellets not bear such sites and have or rapidly develop the prescribed surface area range naturally. Thus, the pellets could be comprised of particulate or subdivided matter, for example, catalyst particles, composed or manufactured of materials which can be treated to reduce their surface area and which are of appropriate size, but which originally had a surface area in excess of 150 square meters per gram, and which have been treated to reduce the effective surface area to less than 150 square meters per gram. An originally high surface area can be permanently reduced by methods similar to the way that catalyst particles lose their effective surface area as they age when used in catalytic cracking or hydrogenation units, or by subjecting the particles to rapid or prolonged aging at temperatures and fluid pressures sufficient to reduce the surface area of the particles. A preferred way to cause this reduction in surface area is to subject the particles to temperatures above 1,400°F. and in the presence of steam at pressures between 0.5 and 7 atmospheres until the surface area is reduced to the desired level. By way of illustration, it has previously been reported in accelerated aging experiments that by subjecting a *silica-alumina* catalyst to one atmosphere of steam for one hour at 1,585°F. the surface area was reduced from about 180 square meters per gram to about 95 square meters per gram, and in a similar experiment at 1432°F. the surface area was reduced from about 400 square meters per gram to about 100 square meters per gram. The high surface area particulate matter thus treated may originally have been comprised of high surface area particles with active acid catalytic sites. In such case, the particles could also be treated to deactivate their active acid catalytic sites by subjecting them to conditions and chemicals known to poison or kill such active acid catalytic sites, for example, by treatment with sodium bicarbonate, sodium hydroxide, or sodium carbonate.

The retort zone is any sort of retort which causes intimate contact or mixing of the crushed oil shale and pellets. The preferred retort is any sort of horizontal or inclined retorting drum that causes the oil shale and pellets to undergo a tumbling action. This sort of retort is herein referred to as a rotating retort zone. This type of retort zone is quite flexible over a wide range of conditions and has the advantages of causing rapid solid-to-solid heat exchange between the pellets and shale feedstock thereby flashing and pyrolyzing the oil and gas vapors from the shale in a way which allows the vapors to separate from the solids without passing up through a long bed of solids and which minimizes dilution of the product vapors by extraneous undesirable retorting gases; of allowing for a high shale throughput rate at high yields for a given retort volume; of providing for greater control over residence time; of aiding in preventing overcoking and agglomeration of the pellets and shale; of facilitating formation of a more uniform controlled amount of combustible carbon-containing deposition or coke-like deposition on the surface area of the pellets; and of causing flow of the pellets and shale through the retort zone in a manner which aids in

eventual separation of the pellets from the spent shale. The amount of deposition or coke-like deposition deposited on the pellets during the retorting stage of the process is an important feature and will be discussed later in more detail. The retorting process is carried out in concurrent or parallel flow fashion with the hot pellets and the raw shale feedstock being fed into the same end of the retort zone. The retort zone may be maintained under any pressure which does not hamper efficient operation of the retort, interfere with production of valuable retort vapors, or cause excessive deposition of residue on the pellets. Generally, pressurization of the pyrolysis or retort zone causes considerable difficulties especially if a rotating retort zone is used. The pressure employed is, therefore, generally the autogeneous pressure.

In the retort zone, the hotter pellets and cooler crushed shale feedstock are admixed and intimately contacted almost immediately upon being charged into the retort zone. The shale particles are rapidly heated by sensible heat transfer from the pellets to the shale. Any water in the shale is distilled and the kerogen or carbonaceous matter in the shale is decomposed, distilled, and cracked into gaseous and condensable oil fractions, thereby forming valuable vaporous effluents including gas, oil vapors, and superheated steam. Pyrolysis and vaporization of the carbonaceous matter in the oil shale leaves a particulate spent shale in the form of the spent mineral matrix matter of the oil shale and an unvaporized or deposited amount of carbon-containing deposition.

As the aforementioned vaporous effluents are formed, a combustible organic carbon-containing deposition or coke-like residue will be formed or deposited on the pellets if the effective surface area of the pellets has not already been covered with all of the deposition that it can sustain. The variables and stages of this process as herein set forth are related in a manner which controls the total amount of combustible carbon-containing deposition thus deposited especially the amount deposited during the retorting stage of the process. The total amount of combustible deposition formed or deposited on the pellets upon one passage through the process is at least sufficient upon combustion to provide at least 50 percent of the heat required to reheat the pellets. The amount of deposit formed on the pellets during the retorting stage is important in two respects. First, the total amount of combustible deposition on the pellet is important since as will hereinafter be shown this combustible deposition is burned in a controlled manner to generate major portion of the heat necessary for heating the pellets to carry out the retorting phase of the process. Second, the total amount of combustible deposition especially the coke-like deposition formed during retorting affects the relative yields of gas and condensable or final liquefied products. This in turn affects the distribution of various boiling point fractions in the liquefied products. The amount of combustible pellet deposition available for burning is basically controlled by the amount deposited in the retorting stage of the process and by the amount removed in the subsequent steam stripping stage as hereinafter described. The amount of deposition deposited is more specifically regulated by the interrelation of several variables, such as pellet-to-shale ratio, pellet size and surface area, pellet inlet temperature to the retort zone, and the outlet temperature of the retort

zone. Additional operating leeway and regulation may be obtained by residence time or throughput rate in the retort zone, partial or complete combustion of the combustible deposition, control of combustion time or amount of oxidizing gas used during burning, the non-catalytic characteristics of the pellets, and the size of the pores at the surface of the pellets. As can be readily seen by this description of the process, the degree of regulation or control provided by a single variable is never independent and the flexibility of regulation varies with the type of variable.

The pellet surface area is considered one of the most important variables. The effect of pellet surface area is illustrated by the test results set forth in TABLES 1, 2, and 3. The effect of pellet surface area on the amount of combustible carbon-containing deposition formed on pellets in the retort zone and on the distribution of carbon deposition between the pellets and spent shale is illustrated in TABLE 1. The effect of pellet surface area on liquid product distribution when a modified Fischer retort was used is illustrated in TABLE 2. The effect of pellet-to-shale ratio and, therefore, the total surface area of the pellets is illustrated in TABLE 3. The total surface area is determined by the surface area per gram of pellets and the total pellet weight which in turn is controlled by the pellet-to-shale ratio and shale throughput rate. The results illustrated in these tables lead to several conclusions. First, if the surface area exceeds 150 square meters per gram, too much coke-like deposition may be produced on the pellets during the retorting stage of the process when the pellet-to-shale ratios specified herein are used. This in turn indicates an undesirable or excessive shift toward gaseous products in the retort zone. As indicated previously, this also affects the flexibility of the process to adjust to expected fluctuations in the other process variations and objectives.

If the surface area of the pellets is less than ten square meters per gram, either too little total coke-like deposition will be formed in the retort zone or the burning of the deposition will not be sufficient to provide a major portion of the heat required to heat the pellets to the desired temperature and to carry out the retorting phase of this process. This would necessitate the use of supplementary fuels and as stated previously, this has significant disadvantages to the objects of this process.

TABLE 1

EFFECT OF PELLET SURFACE AREA ON CARBON DEPOSITION		
PELLET AREA m ² /g	WT. PERCENTAGE OF CARBON	
	ON PELLETS	ON RESIDUAL SHALE
28.0	0.725	3.90
28.5	0.89	3.65
29.0	0.93	3.95
32.5	0.94	3.71
46	1.24	3.49
No Pellets	—	4.30

TABLE 2

EFFECT OF PELLET SURFACE AREA ON LIQUID PRODUCT DISTRIBUTION			
PRODUCT BOILING RANGE	NO PELLETS	PELLET AREA*	
		47m ² /g	96m ² /g
150° - 400°F.	12%	27%	34%
400° - 700°F.	37%	46%	48%
700° - 900°F.	32%	22%	14%
900°F.+	19%	5%	4%

*Pellet : Shale Ratio = 2:1

TABLE 3

EFFECT OF PELLET : SHALE RATIO ON LIQUID PRODUCT DISTRIBUTION				
PRODUCT BOILING RANGE	NO PELLETS	PELLET : SHALE RATIO		
		1:1	1.5:1	2:1
150° - 400°F.	14%	25%	30%	34%
400° - 700°F.	38%	45%	47%	48%
700° - 900°F.	31%	22%	17%	14%
900°F.+	17%	8%	6%	4%

As illustrated in TABLES 2 and 3, the effective surface area of the pellets and the pellet-to-shale ratio in the retort zone affect liquid product distribution of the products from the retort zone. Increasing the surface area and the pellet-to-shale ratio tends to decrease the yield of condensable product vapors and increase production of gases. As mentioned previously, this process seeks to optimize the balance between gas, oil products and combustible deposition on the pellets. Any combustible deposition exceeding fuel requirements is wasteful. This balance, therefore, places restrictions on the retorting stage which restrictions are partially alleviated in this process by a post-retorting steam stripping stage which recovers some of the deposition. As a result, the operator has additional leeway when selecting the pellet-to-shale ratio and the original surface area of the pellets. All variables considered, it has been concluded that an original pellet surface area between 10 and 150 square meters per gram is acceptable with the range of 10 to 100 being preferred and that operating with a pellet-to-shale ratio between one and three is preferred with a ratio between 1.5 and 2.5 being more preferred.

As illustrated in TABLE 1, of particular additional significance is the fact that a substantial portion of the carbon-containing deposition on the pellets does not come from a loss in products, but instead is derived from the residual carbonaceous material that would normally be left on the spent shale. In other words, the residual carbonaceous material that would have otherwise been left on the spent shale divides itself partially between the pellets and the spent shale. The post-retorting steam stripping stage can also be used to recover some of this deposition from the pellets.

The mixture of pellets and shale moves through the retort zone toward retort exit 17 and the gaseous and vaporous effluents containing the desired hydrocarbon values separate from the mixture. Since there is no need to use carrier, fluidizing, or retorting gases in the retort zone, the gaseous and vaporous effluents are able to leave the retort essentially undiluted by extraneous fluids except for any water or steam vapor added to

prevent or retard carbonization, or to sweep product vapors from the solids, or for other reasons to the retort or effluent collection chamber. In a rotating retort system, the mixture movement is continuous and is aided by the action or design of the retort and by continuous withdrawing of pellets and spent shale from the exit end of the retort zone. If a rotating retort zone is used, caking or coking together of the heat-carrying pellets or spent shale will be kept low. Moreover, a rotating-type of retort zone is especially suited to varying the residence time, that is, the length of time that the shale and pellets remain in the retort zone by allowing variations in pellet-to-shale ratio and volume of shale throughput. As previously indicated, greater than normal leeway in control over these variables is especially advantageous to regulation of the amount of deposition deposited on the pellets during the retort stage of the process. The residence time for the pellets required to effect retorting and deposition of the pellet deposition is on the order of about 3 to about 20 minutes with residence times of less than 12 minutes for the pellets being preferred. The shale residence time depends on its flow or movement characteristics and since the shale is not uniform in size and shape, the shale residence time varies.

The mixture of pellets and spent shale exits from retort zone 13 at a temperature between 800°F. and 1150°F. by way of retort exit 17 into separation zone 19 for separation of the vapor, pellets, and spent shale. The separation zone may by any sort of exiting and separation system accomplishing the functions hereinafter mentioned and may be comprised of any number of units of equipment for separating and recovering one or more of these three classes of retort zone effluents either simultaneously, or in combination, or individually. In the process of this invention, it is critical that at least 75 percent of the total spent shale be separated from the pellets in the separation zone to eventually be collected in separation zone exit line 21. In addition, at least 95 percent of the spent shale smaller than the pellets is separated. As shown in FIG. 2, the retort zone mixture is first passed through revolving screen or trommel 23 which has openings or apertures sized to pass the pellets and spent shale of the same or smaller size than the pellets. The trommel extends into product recovery chamber 25. In the trommel, the gaseous and vaporous products separate from the mixture of pellets and spent shale and, at the same time, at least a portion of the larger spent shale particles or agglomerates are separated from the pellets and spent shale. Spent shale and pellets flow through the openings in trommel 23 and drop to the bottom of recovery chamber 25 to exit via retort exit line 27. Any spent shale too large to pass through the openings in the trommel pass outward through exit 29. The product vapors and gases resulting from retorting the oil shale collect overhead in recovery chamber 25 and rapidly pass to overhead retort products line 31 at an exit temperature between about 750°F. and 1050°F. where the product vapors are usually subjected to hot dust separation (not shown) and/or fractionation or partial fractionation (not shown), and/or other stages (not shown) of the overall operation. The hot dust separation may be interior or exterior, or both, of recovery chamber 25 and the dust thus collected may be combined and handled with other spent shale. Hot dust or fines separation may be accomplished by hot gas cyclones, quenching and washing,

agglomeration with sludge or a separately condensed heavy product fraction, centrifuging, filtration, or the like. Partial fractionation may be accomplished by condensing only a high boiling fraction of the vapors, e.g., 900°F.+ materials.

As mentioned previously, the gases are not diluted by other gases and are, therefore, readily used in the overall shale operation. Some gas may be needed for supplementary fuel and some for production in the usual manner of hydrogen if hydrogenation is used in the overall shale operation. The optimum amount of gas production is just enough to satisfy these requirements as this process stresses the liquid oil products produced in the overall shale operation.

As shown in FIG. 2, the spent shale and pellets in recovery chamber 25 are discharged via exit line 27 at a temperature between about 750°F. and 1,050°F. where these particulate solids are passed or conducted by gravity or other means of conveyance to gas elutriation system 33 which is a part of separation zone 19. In the elutriation system, a major portion, and more preferably substantially all, of the remaining spent shale is separated from the pellets. It is essential that elutriation be accomplished in a way which retains the desired amount of carbon-containing deposition on the pellets; consequently, the elutriating gas fed by line 35 is a non-combustion supporting gas. By conducting the process with pellets in the size range between about 0.055 and 0.5 inch and preferably between 0.055 and 0.375 inch, at least 75 percent of the total spent shale may be separated by action of the trommel and subsequent gas elutriation at a velocity of between 18 and 25 feet per second if most of the raw shale feedstock was crushed to about minus three-fourths inch. Based on an average of six sieve analyses of spent shale produced by retorting of minus ¾ inch shale feedstock in a rotating retort using ceramic ½ inch balls, about 16 percent by weight (analyses range 8 percent to 27 percent) of the spent shale is retained on a U.S. Sieve Series size 14 screen which is in a size range similar to the pellets. Gas elutriation with irregular or cylindrical shaped pellets only separates about 2.0 to 4.0 percent of this portion of the spent shale from the pellets. Therefore, on an average between 12 percent and 13 percent of the spent shale is difficult to separate by screening and elutriation depending on whether the pellets cover the entire size range of this part of the spent shale. As mentioned previously, retention of more than 25 percent of the spent shale interferes with proper operation of the pellet deposition burning zone even if most of the spent shale entering the burning zone is originally in the same size range as the pellets. Upon combustion, this spent shale would disintegrate further to fine ash and cause erratic operation of the combustion zone. Separation of the spent shale prior to the supplemental deposition stage of this process is also desirable. Otherwise, some of the combustible deposition would be deposited on the spent shale. In addition, some allowance is made for spent shale and ash buildup as the pellets are cycled and recycled through the process.

Since the spent shale having a size similar to the pellets is difficult to elutriate while the spent shale smaller than the pellets is readily separated by elutriation, and practically complete, it is desirable to alter the character of the spent shale or of the pellets to accomplish a greater degree of separation while holding heat losses in the pellets to a reasonable level. One way to accom-

plish this objective is to crush at least 95 percent by weight of the shale feedstock to a minus 6 screen size. This results in a separation of at least 95 percent of the total spent shale from the pellets and the trommel may also be eliminated. As mentioned previously, crushing to this size is costly and normally not done; however, in view of the fact that in this invention it is essential that the bulk of the spent shale be separated from the pellets prior to reheating of the pellets, the cost of additional crushing may be justified. Another way to accomplish the objective of this separation prior to reheating the pellets has been discovered. It has been found that if the pellets are essentially spherical, that is, have a sphericity factor of at least 0.9, the efficiency of separation by gas elutriation is greatly increased when the raw shale is crushed to a minus three-fourths size. Spherical pellets have improved flow properties over the spent shale and for a given screen size particle exhibit greater weight per particle. Gas elutriation with spherical pellets will separate about 97 percent or more of the spent shale retained on a U.S. Sieve Series size 14 screen and complete separation of the smaller spent shale. Thus, if spherical pellets are used, gas elutriation will separate at least 95 percent of the spent shale in the separation zone. As mentioned previously, therefore, the preferred shape of the pellets is spherical, that is, the preferred pellet should have a sphericity factor of at least 0.9.

The separated spent shale is carried out of the elutriating chamber overhead through line 37. The spent shale is collected and may be combined and handled with other spent shale for eventual compaction and waste disposal or sale for use in manufacturing other products.

As previously mentioned, at least a portion of the pellets with the combustible carbon deposition previously deposited on the pellets are subjected after the retorting stage to steam stripping to remove or recover some of the combustible deposition. The deposition is removed by contacting the pellets with steam at a temperature sufficient to strip some of the combustible material from the pellets. The combustible material is carried with the steam and is recovered as additional product or yield from the process. Steam stripping may be conducted in one or more stages. The steam stripping stage or stages of the process may be conducted on the mixture of pellets and spent shale, or on at least a portion of the pellets after separation from the spent shale, or on both by use of two stripping stages. Treatment of the mixture has the advantage of recovering more of the combustible material, but has the disadvantages of increasing fine solids in the products, of increasing steam requirements, of providing less positive control over the amount of deposition left on the pellets, and of creating other operating difficulties. It is, therefore, much preferred that the steam stripping of the pellets be conducted on the pellets after the spent shale separation stage of the process. In addition, the increased yield advantage obtained by steam stripping the entire solids mixture can be partially offset by selecting pellets with a higher surface area. As previously illustrated and noted in relation to TABLE I, the combustible material normally left or deposited on the spent shale tends to divide itself between the spent shale and pellets depending on the surface area of the pellets. Less combustible material is left on the spent shale if higher surface area pellets are used. Steam stripping permits the

use of higher surface area pellets since stripping can be used to remove excess combustible deposition prior to burning the deposition, provided however, that the increased recovery advantages are not offset by an excessive shift in the balance between gas and oil production and product quality. The percentage of pellets treated by steam stripping and the amount of combustible deposition removed by steam stripping, therefore, provide flexibility and adaptability in controlling the total amount of combustible deposition on the pellets passed to the pellet deposition burning stage of the process and permit greater leeway in the amount of the combustible deposition formed on the pellets during earlier stages of the process, especially the retorting stage.

Accordingly, as illustrated in the drawings, steam from line 39 is passed either by way of steam line 41 to the bottom of collection chamber 25 which acts as a steam stripping zone to contact the mixture of pellets and spent shale, or by way of steam line 43 into steam stripping zone 45 to contact at least a portion of the separated pellets. The pellets separated in elutriation system 33 pass by gravity or other means from the separation zone via exit line 47 either by way of stripper feed line 49 to steam stripping zone 45 or by way of bypass line 51 to bypass the steam stripper and flow directly to pellet return line 53.

The steam stripping stage or stages should be carried out at a temperature between 800°F. and 1,150°F., and preferably at a temperature between 850°F. and 1,050°F. At temperatures higher than 1150°F., the probability of adversely reducing surface area is increased. Whether or not a surface area reduction occurs, depends primarily on temperature, steam pressure, and the surface area and nature of the pellets. With higher surface areas and/or temperatures, a surface area reduction is more likely to occur. At temperatures below 800°F., the steam stripping action is inefficient. The primary factors controlling the amount of organic deposition stripped are the amount of pellets or total solids treated, the steam-to-pellet or solids ratio, the amount and nature of the combustible deposition, the surface area of the pellets, the stripping zone temperature, and residence time. The residence time of the pellets or pellets and spent shale during stripping will preferably be less than 10 minutes. Preferably, the stripping will be conducted in a manner such that the final amount of deposition left on the pellets is less than 1.5 percent by weight of the pellets subjected to steam stripping, and will on an average range between 0.3 and 1.5 percent by weight depending primarily on the percentage of pellets subjected to steam stripping.

When the steam stripping stage is carried out on some or all of the pellets after the spent shale has been separated, steam stripping zone 45 acts as first stripping zone and the treated pellets collect in stripper exit line 55 and pass to pellet return line 53. The steam and stripped deposition products collect in the top of the steam stripper and exit the stripper by way of overhead line 57. The steam plus stripped products is then either passed in the usual manner for eventual product recovery operations, or to a second steam stripping zone as hereinafter described. As illustrated in FIG. 2, at least a portion of the steam plus products may be simply passed to overhead retort products line 31.

When the stripping stage is carried out on the mixture of pellets and spent shale in collection chamber 25, the steam and stripped products collect with the re-

retort products in chamber 25 and are thereby at least partially recovered.

One way of steam stripping both separated pellets and the mixture of pellets and spent shale with some steam is illustrated in the drawings. The separated pellets in steam stripping zone 45 are first contacted with steam to remove a portion of the combustible deposit on the pellets in zone 45. At least a portion of the steam plus stripped or removed deposition are then passed through overhead line 57 to bypass line 59 and thence to steam line 41 to flow into collection chamber 25 which acts as a second steam stripping zone. In collection chamber 25 the steam removes additional combustible material from the pellets and residue in chamber 25. The steam plus the depositions removed in both zone 45 and chamber 25 collect with the retort products and the removed depositions are thereby eventually recovered.

The pellets in pellet return line 53 pass to pellet lifting system 61 where the pellets are lifted preferably to an elevation which allows gravity feed to retort zone 13 by way of lift line 63 to pellet deposition burning zone 65, which as shown in FIG. 2 has surge hopper 67 for collecting the lifted pellets and leveling out fluctuations and from which the pellets fall into pellet deposition burning zone 65. While any conveying and lifting system holding heat losses to a reasonable value may be used, it is preferred as shown in FIG. 2 that the pellet lifting system be a pneumatic conveying system which will operate in the conventional manner to lift the pellets to the pellet deposition burning zone. The lift gas enters the lift system via line 69 at a velocity between 25 and 70 feet per second and the lift time is, therefore, very short. As a result, air may be used as the lift gas without causing uncontrolled combustion of the deposition on the pellets and the detrimental effects attendant to such uncontrolled burning.

As mentioned previously, the pellets bear a combustible carbon-containing deposition which was absorbed or deposited during the process and which was not removed in the steam stripping zone. This combustible deposition is burned in combustion or pellet deposition burning zone 65 to provide at least 50 percent or more of the heat required to reheat the pellets to the temperature required to effect retorting of the shale. The combustible deposition is burned in a manner similar to the way that catalytic cracking catalysts particles are regenerated and which is controlled to avoid excessive heating of the pellets which would excessively reduce the effective surface area of the pellets to less than 10 square meters per gram. A progressive bed burner with a gas flow of about 1 to 2 feet per second is preferred. A combustion supporting gas, for example air, a mixture of air and fuel gas generated in the process, flue gas with the desired amount of free oxygen, is blown into the pellet deposition burning zone at a temperature at which the combustible deposition on the pellets is ignited by way of combustion gas inlet 71 which in FIG. 2 includes a blower. Steam may also be used to control burning provided that the steam does not excessively reduce the surface area of the pellets. The combustion supporting gas may be preheated in heaters 73 by burning some of the gases produced in the process to reheat the pellets to the minimum ignition temperature. The quantity of combustion supporting gas, e.g., about 10 to 15 pounds of air per pound of carbon deposit, affects the total amount of carbon-containing

deposition burned and the heat generated by such burning and in turn the temperature of the pellets. The bulk density of the pellets is about 40 to 50 pounds per cubic foot and the specific heat of the pellets varies between about 0.2 and 0.3 British Thermal Units per pound per degree Fahrenheit. The gross heating value of the carbon-containing deposition is estimated to be about 15,000 to 18,000 Btu per pound. The amounts of carbon dioxide and carbon monoxide produced in the fuel gases created by burning the pellet deposition indicate the amount of combustion supporting gas required or used and the amount of carbon-containing deposition not burned. Generally, it is desirable to attempt to free the pellets of combustible deposition. In any case, at least 50 percent of the combustible deposition is burned. The unburned deposition stays with the pellets and affects to some degree the total amount of combustible carbon-containing deposition deposited in the next cycle. It should be noted that this type of controlled burning does not selectively burn the same amount of deposit from every pellet. Other factors taken into consideration during burning of the pellet deposition are the pellet porosity, density, and size, the burner chamber size and pellet bed size, residence burning time, the desired temperature for the pellets, heat losses and inputs, the pellet and shale feed rates to the retort zone and the like. The residence burning time will usually be rather long and up to about thirty to 40 minutes. Combustion of the deposition should be controlled in a manner which does not heat the pellets to above 1,400°F. The hot flue gases generated in the pellet deposition burning zone may be removed by burner overhead exit line 75 and used to preheat cool raw shale feedstock or for heat transfer to any other phase or part of the shale operation. For example, this stream could be fed to a carbon monoxide boiler and the heat available from the boiler could be used for processing product vapors or to drive turbines. Of course, additional fuel material or gases may be used to supplement burning of the pellet deposition if this is necessary, but it is to be understood that the pellet deposition supplies the major portion of the sensible heat required for retorting the oil shale and that the variables are set to accomplish this objective along with the other advantages and objectives of this process.

A continuous stream of hot pellets having a temperature above 950°F and not exceeding 1400°F is thereby produced for return and introduction via burner bottom exit line 77 back through pellet inlet line 15 either by gravity and/or mechanical means into retort zone 13. As previously indicated, the rate of passage of the pellets from the combustion zone will be metered or controlled in conventional manners to eventually provide the optimum pellet-to-oil shale feedstock ratio to the retort zone. The optimum ratio is governed by the pellet properties, the surface area of the pellets as they enter the retort zone, the organic content of the raw oil shale, and the other process variables as previously described.

Although the retorting process is carried out in a manner to hold loss of pellets to a minimum, some pellets will be lost in the process and a relatively small quantity of pellets may be added continuously to maintain the pellet quantity.

The foregoing description of the conditions and variables of the process illustrates a preferred method of conducting the process and how the steam stripping

stage of the process coacts with the other process stages especially the retorting stage to accomplish the advantages and objectives herein set forth.

Reasonable variations and modifications are practical with the scope of this disclosure without departing from the spirit and scope of the claims of this invention. For example, while the disclosure of this process and the variables have been limited to oil shale, the process concepts lend themselves readily to retorting any solid organic carbonaceous material containing hydrocarbon values which can be recovered by thermal vaporization of the solid carbonaceous material, such as, for example, coal, peat, and tar sands. By way of further example, while only a single train of units and stages have been described, it is to be understood that any stage or zone could be comprised of more than one stage or zone, each of which could be operated under different conditions to provide the overall combined effect set forth.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a method for retorting crushed oil shale containing carbonaceous organic matter and mineral matter wherein oil shale is retorted by contacting said oil shale with hot pellets in a retort zone to gas and oil products, particulate spent shale, and an organic combustible deposition on said pellets and said spent shale, said pellets having been heated in a pellet deposition burning zone to a retort zone inlet temperature of between 1,000°F. and 1,400°F. mainly by combustion of a combustible carbon-containing deposition on said pellets, said pellets being in amount sufficient to provide at least 50 percent of the heat required to vaporize a major portion of the carbonaceous matter from said oil shale and to heat said crushed oil shale from its retort zone inlet temperature to a retort zone outlet temperature of between 800°F. and 1,150°F., and wherein said gas and oil products are separated and recovered, the improvement comprising contacting in a first steam stripping zone at least a portion of said pellets from said retort zone with steam to remove a portion of said combustible deposition on the contacted pellets, the temperature in said first steam stripping zone being between 800°F. and 1,150°F., recovering at least a portion of the removed portion of said combustible deposition, and passing said contacted pellets to said pellet deposition burning zone.

2. The method according to claim 1 wherein said pellets are comprised of particulate solid heat carriers in a size range between approximately about 0.055 inch and 0.5 inch and have a surface area of between 10 and 150 square meters per gram of pellets, the amount of said pellets also being such that the ratio of said pellets to said crushed oil shale in said retort zone on weight basis is between 1 and 3, and wherein at least 75 percent by weight of the total of said spent shale and at least 95 percent by weight of the portion of said spent shale that is smaller in size than said pellets is separated in a separation zone from said pellets after retorting of said oil shale but prior to said heating of said pellets by combustion of said deposition on said pellets.

3. The method according to claim 2 wherein the particulate solid heat carriers are in a size range between approximately about 0.055 inch and 0.375 inch.

4. The method according to claim 1 wherein the contacted pellets are comprised of pellets that had previously been separated from said spent shale.

5. The method according to claim 3 wherein said pellets are comprised of particulate solid heat carriers in a size range between approximately about 0.055 inch and 0.5 inch and have a surface area of between 10 and 150 square meters per gram of pellets, the amount of said pellets also being such that the ratio of said pellets to said crushed oil shale in said retort zone on weight basis is between one and three, and wherein at least 75 percent by weight of the total of said spent shale and at least 95 percent by weight of the portion of said spent shale that is smaller in size than said pellets is separated in a separation zone from said pellets after retorting of said oil shale but prior to said heating of said pellets by combustion of said deposition on said pellets.

6. The method according to claim 5 wherein the particulate solid heat carriers are in a size range between approximately about 0.055 inch and 0.375 inch.

7. The method according to claim 4 wherein at least a portion of the steam and the removed product are passed from said first steam stripping zone to a second steam stripping zone to contact at least a portion of said pellets and said spent shale to remove a portion of said combustible deposition on the contacted pellets and spent shale in said second steam stripping zone, and at least a portion of the portion of said combustible depositions removed in said first and said second steam stripping zones are recovered.

8. The method according to claim 7 wherein said pellets are comprised of particulate solid heat carriers in a size range between approximately about 0.055 inch and 0.5 inch and have a surface area of between 10 and 150 square meters per gram of pellets, the amount of said pellets also being such that the ratio of said pellets to said crushed oil shale in said retort zone on weight basis is between one and three, and wherein at least 75 percent by weight of the total of said spent shale and at least 95 percent by weight of the portion of said spent shale that is smaller in size than said pellets is separated in a separation zone from said pellets after retorting of said oil shale but prior to said heating of said pellets by combustion of said deposition on said pellets.

9. The method according to claim 8 wherein the particulate solid heat carriers are in a size range between approximately about 0.055 inch and 0.375 inch.

10. The method according to claim 1 wherein at least a portion of said pellets and said spent shale are contacted with said steam to remove a portion of said combustible deposition on the contacted pellets and spent shale, and at least a portion of the removed portion of said combustible deposition is recovered, and said contacted pellets and spent shale are then passed to said separation zone and the separated pellets are thereafter passed to said pellet deposition burning zone.

11. The method according to claim 10 wherein said pellets are comprised of particulate solid heat carriers in a size range between approximately about 0.055 inch and 0.5 inch and have a surface area of between 10 and 150 square meters per gram of pellets, the amount of said pellets also being such that the ratio of said pellets to said crushed oil shale in said retort zone on weight basis is between one and three, and wherein at least 75 percent by weight of the total of said spent shale and

at least 95 percent by weight of the portion of said spent shale that is smaller in size than said pellets is separated in a separation zone from said pellets after retorting of said oil shale but prior to said heating of said pellets by combustion of said deposition on said pellets.

12. The method in accordance with claim 11 wherein the particulate solid heat carriers are in a size range between approximately about 0.055 inch and 0.375 inch.

13. A method for retorting of crushed oil shale containing carbonaceous organic matter and mineral matter comprising

- a. feeding crushed oil shale and pellets to a retort zone, said pellets being comprised chiefly of particulate heat carriers being in a size range between 0.5 inch and approximately about 0.055 inch and having a surface area of between 10 and 150 square meters per gram of pellets, said pellets being at a retort zone inlet temperature between 1,000°F. and 1,400°F. and in a quantity such that the ratio of said heat-carrying pellets to said crushed oil shale entering said retort zone on a weight basis is between one and three, said ratio also being such that the sensible heat in said pellets is sufficient to provide at least 50 percent of the heat required to heat said crushed oil shale from its retort zone feed temperature to a retort zone outlet temperature of between 800°F. and 1,150°F.;
- b. retorting in said retort zone gas and oil products from said crushed oil shale, thereby forming particulate spent shale and a combustible deposition on said pellets and said spent shale;
- c. causing said pellets and said spent shale to pass from said retort zone to a particle separation zone and separating from said pellets at least 75 percent by weight of the total spent shale and at least 95 percent by weight of the portion of said spent shale that is smaller in size than said pellets, prior to heating said pellets in a pellet deposition burning zone;
- d. recovering gas and oil products generated by retorting of said crushed oil shale;
- e. passing at least a portion of said pellets from said separation zone to a first steam stripping zone and at the same time passing steam to said first steam stripping zone into contact with said pellets in said first steam stripping zone to remove a portion of said combustible deposition on the contacted pellets in said first steam stripping zone, the temperature in said first steam stripping zone being between 800°F. and 1,150°F.;
- f. passing said steam and the removed combustible deposition from said first steam stripping zone and eventually recovering at least a portion of said removed combustible deposition;
- g. passing said contacted pellets from said first steam stripping zone to a pellet deposition burning zone;
- h. passing any of said pellets from said separation zone not passed to said first steam stripping zone to said pellet deposition burning zone;
- i. heating all of said pellets passed to said pellet deposition burning zone to an outlet temperature of between 1000°F. and 1400°F. by burning the combustible carbon-containing deposition on said pellets with a combustion supporting gas; and

j. thereafter passing said heated pellets from said pellet deposition burning zone to said retort zone.

14. The method according to claim 13 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

15. The method according to claim 13 wherein the particulate heat carriers are in a size range between 0.375 inch and approximately about 0.055 inch.

16. The method according to claim 13 wherein the separation of step (c) is comprised of first passing said pellets and said spent shale through apertures in a trommel to screen out at least a portion of the spent shale and any agglomerates larger than said pellets, and thereafter subjecting the remaining pellets and spent shale to gas elutriation with a noncombustion supporting gas to effect further separation of the spent shale from the pellets.

17. The method according to claim 16 wherein the particulate heat carriers are in a size range between 0.375 inch and approximately about 0.055 inch.

18. The method according to claim 16 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

19. The method according to claim 13 wherein the pellets have a sphericity factor of at least 0.9 and at least 95 percent by weight of the total spent shale is separated from said pellets in step (c).

20. The method according to claim 19 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

21. The method according to claim 13 wherein at least 95 percent by weight of the crushed oil shale of step (a) has been crushed to a size to pass through a U.S. Sieve Series size 6 screen and at least 95 percent by weight of the total spent shale is separated from said pellets in step (c).

22. The method according to claim 21 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

23. The method according to claim 13 wherein at least a portion of said steam and said removed combustible deposition passed from said first steam stripping zone are passed to a second steam stripping zone to contact said pellets and said spent shale from said retort zone prior to the separation phase of step (c) to remove a portion of the combustible deposition on said pellets and said spent shale in said second steam stripping zone, the temperature in said second steam stripping zone being between 800°F and 1150°F; and at least a portion of the combustible depositions removed in said first and said second steam stripping zones are recovered.

24. The method according to claim 23 wherein the particulate heat carriers are in a size range between 0.375 inch and approximately about 0.055 inch.

25. The method according to claim 23 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first

steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

26. The method according to claim 23 wherein the separation of step (c) is comprised of first passing said pellets and said spent shale through apertures in a trommel to screen out at least a portion of the spent shale and any agglomerates larger than said pellets, and thereafter subjecting the remaining pellets and spent shale to gas elutriation with a noncombustion supporting gas to effect further separation of the spent shale from the pellets.

27. The method according to claim 26 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

28. The method according to claim 23 wherein the pellets have a sphericity factor of at least 0.9 and at least 95 percent by weight of the total spent shale is separated from said pellets in step (c).

29. The method according to claim 28 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

30. The method according to claim 23 wherein at least 95 percent by volume of the crushed oil shale of step (a) has been crushed to a size to pass through a U.S. Sieve Series size 6 screen and at least 95 percent by weight of the total spent shale is separated from said pellets in step (c).

31. The method according to claim 30 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

32. A method for retorting crushed oil shale containing carbonaceous organic matter and mineral matter comprising

- a. feeding crushed oil shale and pellets to a retort zone, said pellets being comprised chiefly of particulate heat carriers being in a size range between 0.5 inch and approximately about 0.055 inch and having a surface area of between 10 and 150 square meters per gram of pellets, said pellets being at a retort zone inlet temperature between 1,000°F. and 1,400°F. and in a quantity such that the ratio of said heat-carrying pellets to said crushed oil shale entering said retort zone on a weight basis is between one and three, said ratio also being such that the sensible heat in said pellets is sufficient to provide at least 50 percent of the heat required to heat said crushed oil shale from its retort zone feed temperature to a retort zone outlet temperature of between 800°F. and 1,150°F.;
- b. retorting in said retort zone gas and oil products from said crushed oil shale, thereby forming particulate spent shale and an organic combustible deposition on said pellets and said spent shale;
- c. contacting in a first steam stripping zone said pellets and said spent shale from said retort zone with steam to remove a portion of said combustible deposition on said pellets and said spent shale, the temperature in said first steam stripping zone being between 800°F. and 1,150°F.;

d. causing said pellets and said spent shale to pass from said first steam stripping zone to a particulate separation zone and separating from said pellets at least 75 percent by weight of the total spent shale and at least 95 percent by weight of the portion of said spent shale that is smaller in size than said pellets, prior to heating said pellets in a pellet deposition burning zone;

e. recovering gas and oil products generated by retorting said crushed oil shale and at least a portion of the combustible deposition removed from said pellets and spent shale in said first steam stripping zone;

f. passing said pellets from said separation zone to a pellet deposition burning zone;

g. heating all of said pellets passed to said pellet deposition burning zone to an outlet temperature of between 1,000°F. and 1400°F. by burning the combustible carbon-containing deposition on said pellets with a combustion supporting gas; and

h. thereafter passing said heated pellets from said pellet deposition burning zone to said retort zone.

33. The method according to claim 32 wherein the particulate heat carriers are in a size range between 0.375 inch and approximately about 0.055 inch.

34. The method according to claim 32 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

35. The method according to claim 32 wherein the separation of step (d) is comprised of first passing said pellets and said spent shale through apertures in a trommel to screen out at least a portion of the spent shale and any agglomerates larger than said pellets, and thereafter subjecting the remaining pellets and spent shale to gas elutriation with a noncombustion supporting gas to effect further separation of the spent shale from the pellets.

36. The method according to claim 35 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

37. The method according to claim 32 wherein the pellets have a sphericity factor of at least 0.9 and at least 95 percent by weight of the total spent shale is separated from said pellets in step (d).

38. The method according to claim 37 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

39. The method according to claim 32 wherein at least 95 percent by volume of the crushed oil shale of step (a) has been crushed to a size to pass through a U.S. Sieve Series size 6 screen and at least 95 percent by weight of the total spent shale is separated from said pellets in step (d).

40. The method according to claim 39 wherein the average amount of said combustible deposition left on said contacted pellets upon passage through said first steam stripping zone is on said average less than 1.5 percent by weight of said contacted pellets.

* * * * *