May 9, 1967 E. F. KONDIS ET AL 3,318,798

RETORTING OF OIL SHALE

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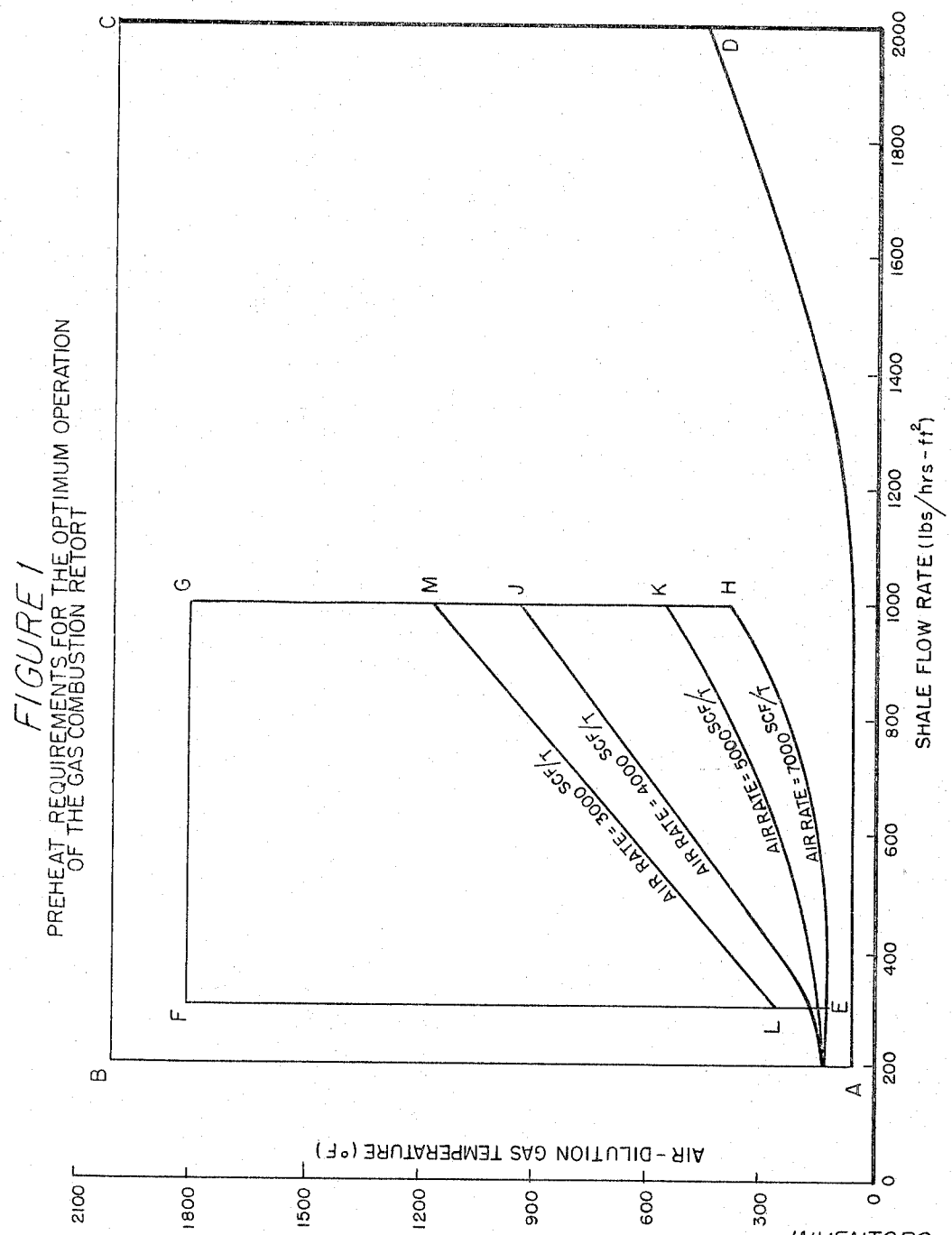


FIGURE 1

PREHEAT REQUIREMENTS FOR THE OPTIMUM OPERATION OF THE GAS COMBUSTION RETORT

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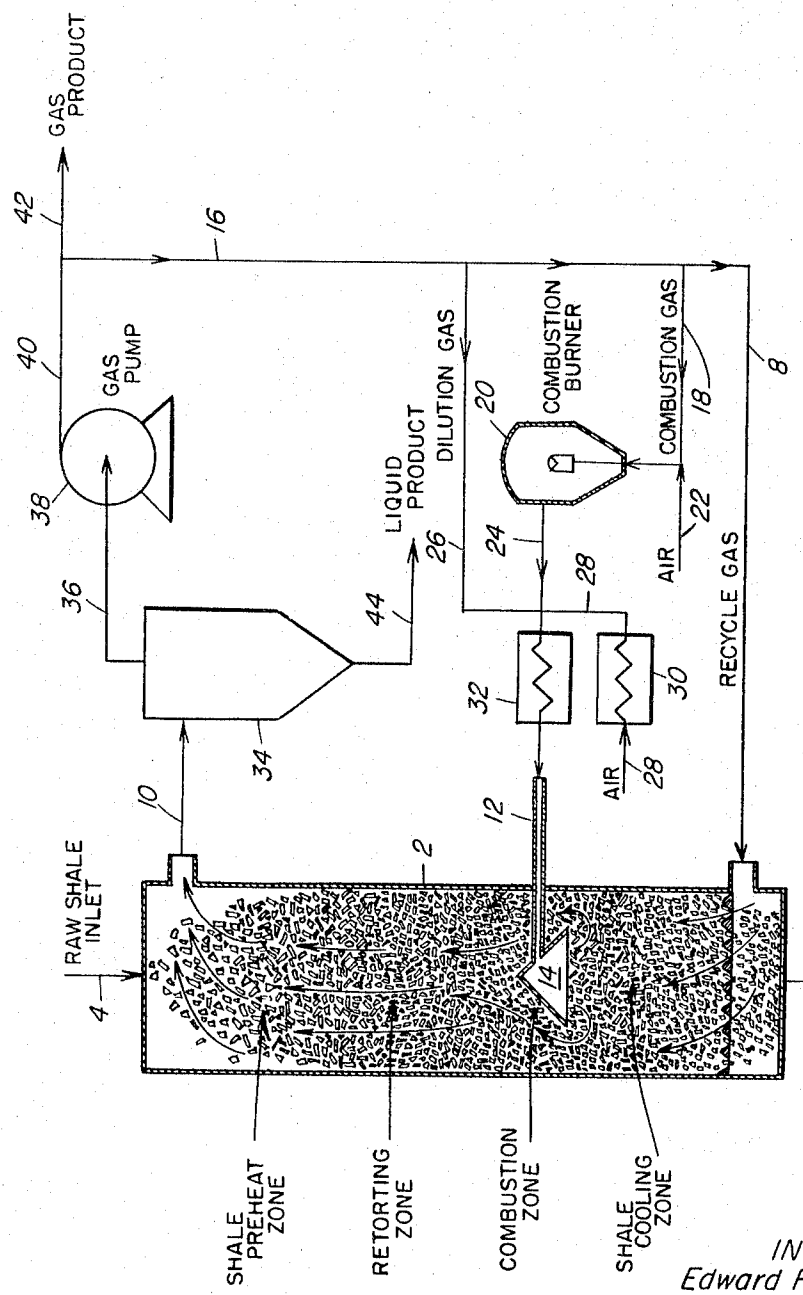


FIGURE 2

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RETORTING OF OIL SHALE

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This invention relates to the method and means for producing shale oil by retorting of oil shale material. In one aspect, the invention relates to the method of improving the conditions maintained in an oil shale retorting operation to maximize the recovery of desired hydrocarbon products. More particularly, the present invention is related to defining the operating conditions for relatively high shale throughput rates and the method of maintaining the defined conditions which will permit substantially optimum recovery of desired product.

Shale oil technology as we know it today has not reached an advanced commercially attractive stage and considerable work is yet to be done in developing a system of commercial acceptance for the economic recovery of valuable oil product. Oil shale is a sedimentary rock which contains a solid organic material known as kerogen. When this oil shale is heated to an elevated temperature, the kerogen is decomposed by pyrolysis to shale oil, gas and a carbonaceous residual.

One of the simplest systems for processing oil shale known today is a gas-combustion retort comprising four sections known as (1) a shale preheating section forming the upper part of the retort wherein the shale of a desired size is introduced and brought up to retorting temperatures by direct heat exchange with a heat yielding fluid, (2) a retorting section wherein the kerogen component of the shale is decomposed to shale oil vapors and shale gas, (3) a combustion section wherein controlled combustion of available combustible material is effected to provide at least a portion of the heat energy required in the retorting operation, and (4) a shale cooling section wherein the spent shale particles are cooled to a desired low temperature suitable for handling while preheating at least a portion of recycled gases obtained from the shale oil product of the retorting operation. In the system of the gas-combustion type herein discussed, crushed shale material of a desired size and hereinafter referred to as granular particle material is passed downwardly through the zones comprising the retort as a relatively dense moving bed of granular material of a particle size which substantially avoids heat diffusion limitations for a given capacity unit while recycle gases passed thereto move generally upwardly through the retort and countercurrent to the downwardly moving shale.

Some advantages of the above discussed system are attributable to its simplicity, potential large capacity and relatively efficient utilization of heat made available thereto. Accordingly, in an acceptable operation, the spent shale particles are cooled sufficiently in the retort to leave the retort at a relatively low temperature suitable for handling without resorting to expensive heat resistant equipment. This heat exchange in the lower portion of the retort between the recycled gas and spent shale granules when properly effected contributes measurably to the thermal efficiency of the process for the reasons more apparent from the following discussion.

It is an object of this invention to improve the operation of a gas-combustion oil shale retort.

Another object of this invention is to effectively utilize the heat available and supplied to a shale oil retort to optimize kerogen decomposition and recovery of decomposition products therefrom for shale throughout rates above 350 lbs./hr. (ft.^{2}).

A further object of this invention is to control the temperature profile of a gas combustion retort in a direction tending to maximize recovery of oil shale decomposition products.

Other objects and advantages of this invention will become more apparent to those skilled in the art from the following discussion.

The present invention relates to identifying the area of operability of a gas-combustion oil shale retort which can be considered commercially competitive and correlating the operating conditions required to be maintained for desired kerogen decomposistion therein in a relationship tending to optimize those condtions permitting relatively high oil shale throughput rates. More particularly, the present invention relates to defining a preferred region of operability of a gas-combustion retort and identifying a correlation of operating conditions which will permit one to operate in a preferred region of oil shale throughput rates and maximum recovery of desired kerogen decomposition products.

In one aspect of this invention it has been found that the preferred region of operability of a gas combustion retort is confined by (1) a low oil shale flow rate of about 300 lbs./hr.-ft.^{2}; (2) an upper shale flow rate of the order of about 1000 lbs./hr.-ft.^{2} limit which begins to impose an undesired high pressure drop across the retort thereby requiring usage of expensive compressor equipment to provide adequate gas flow rates; and (3) an upper gas temperature boundary of about 1800° F. selected to avoid creating excessive costs in structural and material problems, and (4) an upper shale temperature boundary of about 1500° F. selected to avoid excessive thermal cracking and undesirable high carbonate decomposition temperatures. In addition, it has been found that employing air rates in excess of about 7000 s.c.f./t. of air falls outside a reasonable operating range since above this air rate the pressure drop in a retort of about 12 feet high would be in excess of about 1 atmosphere, the shale outlet temperature would exceed a desired upper limit of about 500° F. and peak shale temperatures would exceed about 1500° F. leading to excessive thermal cracking and undesired high carbonate decomposition.

Furthermore, the method of operation herein described permits a preferred gas phase burning to the exclusion of substantial coke burning and little, if any, kerogen burning; a better temperature control within the retort; more kerogen can be decomposed above the combustion zone; a high B.t.u. content off-gas may be obtained and recovered from the retort and more rigid spent shale particles will be present thereby significantly reducing the dust carry over from the retort.

In addition, by maintaining a shale temperature profile in the retort in accordance with this invention, the formed shale oil vapors are condensed into a relatively fine mist which can pass upwardly through the shale particles for outside the retort.

Although it is possible to operate a gas-combustion retort outside the preferred limits defined by FIGURE 1 attached hereto, it is substantially less desirable for many reasons and generally outside the scope of this invention for the reasons herein expressed. That is, if shale rates below about 300 lbs./hr.-ft.^{2} are used, large number of retorts are required. On the other hand, employing shale rates above about 1000 and as high as up to about 2000 lbs./hr.-ft.^{2} although possible, cause a condition of excessive or large pressure drop in the retort requiring additional compressor equipment and generally undesirable operating conditions leading to inefficient decomposition and recovery of decomposed kerogen.

Accordingly, in one aspect the present invention relates to identifying the preferred operating areas of a gas-com-

bustion retort and defining the method of operation including operating conditions employed therein to permit efficient operation of the retort within the defined preferred areas.

In another aspect and perhaps more importantly, the present invention is related to maintaining a temperature profile within the gas-combustion retort for preferred shale throughput rates within the range of above 300 to about 1000 lbs./hr.-ft.^{2} which will permit decomposition and recovery of desired kerogen product in amounts that may be considered substantially optimum without encountering undesired retorting temperature conditions due to insufficient or uncontrolled burning of available combustible materials in the retort.

Accordingly, in the method of this invention, a portion of uncondensible shale gas recovered from the retort and separated from desired kerogen decomposition liquid product is recycled to the retort. A substantial portion of the separated and recycled gas is passed to the lower or bottom portion of the retort for flow upwardly therethrough under conditions to preheat the recycle gas by countercurrent contact with downwardly moving hot shale particles. The remaining recycled portion of recovered shale gas herein referred to as dilution gas is employed when combined with air as a heat carrying gaseous material to the combustion section of the retort. That is, the portion of dilution gas and air mixture passed to the combustion section of the retort is preheated either directly or indirectly, by combustion, for example, or other suitable means to a desired elevated temperature. The minimum extent of gas heating effected by the methods herein described is determined in accordance with the formula relationship hereinafter provided so that upon introduction to the retort the temperature profile of the recycled gaseous material having entered the bottom and passed upwardly through the retort under heat exchange conditions countercurrent to the hot shale particles will not be reduced any substantial amount at the air inlet of the retort combustion section and will be of a heat carrying capacity and combustible material content to substantially limit undesired burning and undesired temperature profiles within the retort.

More particularly, the recycled shale gas herein referred to as dilution gas desirably contains combustible components therein for the reasons herein described.

Other gaseous materials such as steam or flue gas which are considered relatively inert in the process herein described may be combined with the air and/or dilution gas in desired quantities. In addition, the volume of heat carrying gas comprising air and dilution gas passed to the combustion section may be varied considerably depending upon the method of heating employed and within the range of from about 3000 to about 7000 s.c.f./t. of shale. That is, when employing indirect heat exchange means for heating the combustion supporting gas passed to the retort combustion section, use of air volumes less than about 3500 s.c.f./t. and as low as about 3000 s.c.f./t. is sufficient to provide the oxygen combustion supporting requirements of the retort. On the other hand, when partial combustion means are employed for directly heating the air either with or without the presence of dilution gas, a greater volume of air is generally required which will be at least about 3500 s.c.f./t. and more usually at least about 4000 s.c.f./t. to provide the oxygen combustion supporting requirements within the retort. Accordingly, it is important whether direct or indirect heat exchange means are employed to limit the oxygen available for combustion within the retort to substantial combustion of gaseous material while providing kerogen decomposition heat within the retort within the range of from about 300,000 B.t.u./ton up to about 70,000 B.t.u./ton. Therefore, the total heat in the retort is the direct or indirect preheat of the combustion supporting gases referred to as the sensible heat plus the potential heat from consuming the oxygen therein and this combined heat input should be controlled within the range of from about 300,000 to about 700,000 B.t.u./ton of shale.

Thus, by heating the gas streams in the manner herein provided, the amount of air employed may vary over a considerable range of from about 2000 to about 7000 s.c.f./ton of shale so that a higher and desired mix gas temperature is thereby obtained when the gas streams in the retort are combined at substantially the gas inlet of the combustion section. Having a higher gas mix temperature means that the gases have a shorter distance to travel before the oxygen available in the gases is utilized to effect desired limited burning of available combustible materials. Accordingly, more of the heat of retorting is supplied by sensible heat in the gases rather than by heat of combustion on the surface of the shale particles. Thus, by operating in accordance with the method of this invention, significantly more kerogen can be decomposed above the combustion zone and thermal cracking and oxidation of the desired shale oil as it passes out through the surface of the shale particle can be eliminated.

Tables I and II, presented below, shows an order of magnitude of the following improvements which may be effected when operating a gas-combustion oil shale retort in accordance with this invention.

For example:

(1) A greater portion of the kerogen is decomposed before the shale particles enter the combustion zone.
(2) Operation at much higher shale rates is possible.
(3) Higher gas cooling rates are obtained in the mist forming zone which result in a more desirable mist and less refluxing of the shale oil.
(4) Greater overall heat efficiency, producing lower spent shale temperatures.
(5) High heat value gas is obtained for recycle to the retort.

TABLE I.—THE EFFECT OF PREHEATING THE AIR-DILUTION GAS ON THE PERFORMANCE OF THE GAS-COMBUSTION RETORT FOR 1-INCH PARTICLES

Retort Length=12 Feet
Total Recycle Gas Rate=16,000 s.c.f./ton
Brine=15 lbs./ton
Shale Richness=30 Gal./ton
Dilution Gas-to-Air Ratio=0.4 v./v.

	Type of Operation			
	No Preheat		With Preheat	
	Range of Shale Rate			
	Low	High	Low	High
Type of Preheat	None	None	Indirect	Indirect
Operation Conditions:				
Shale Rate, lbs./hr.-ft.^{2}	300	750	300	750
Air Rate, s.c.f./t.	4,000	4,000	3,200	3,200
Air-Dilution Gas Temperature, ° F.	133	140	927	1,132
Performance Temperature, ° F.:				
Off-Gas	133	(1)	133	137
Spent Shale	285	(1)	248	279
Peak Gas	1,175	(1)	1,335	1,390
Peak Shale	1,140	(1)	1,201	1,246
Decomposition, Percent:				
Kerogen	100	(1)	100	100
Carbonates	9	(1)	14	14
Kerogen Decomposed Above Combustion Zone, Percent	5	(1)	95	84
Products Burned, Percent:				
Coke	17	(1)	8	6
Gas	12	(1)	21	23
Shale Oil	0.5	(1)	0.1	0.1
Gas Cooling Rate in Mist Forming Zone, ° F./sec.	1,245	(1)	1,430	2,600
Heating Value of Dry Gas Make, B.t.u./s.c.f.	139	(1)	172	172

[1] Inoperable.

TABLE II.—THE EFFECT OF PREHEATING THE AIR-DILUTION GAS ON THE PERFORMANCE OF THE GAS-COMBUSTION RETORT FOR 3-INCH PARTICLES

Retort Length=16 Feet
Total Recycle Gas Rate=16,000 s.c.f./ton
Brine=90 lbs./ton
Shale Richness=30 gal./ton
Dilution Gas-To-Air Ratio=0.4 v./v.

	Type of Operation			
	No Preheat		With Preheat	
	Range of Shale Rate			
	Low	High	Low	High
Type of Preheat	None	None	Direct	Direct
Operating Conditions:				
Shale Rate, lbs./hr.-ft.^{2}	300	750	300	750
Air Rate, s.c.f./t.	4,000	4,000	4,000	4,000
Air-Dilution Gas Temperature, ° F.	150	150	1,370	1,800
Performance Temperature, ° F.:				
Off-Gas	--------	--------	160	210
Spent Shale	--------	--------	410	500
Peak Gas	--------	--------	1,238	1,340
Peak Shale	--------	--------	1,083	1,134
Decomposition, Percent:				
Kerogen	--------	--------	100	100
Carbonates	(1)	(1)	8	7
Kerogen Decon posed Above Combustion Zone, Percent	(1)	(1)	67	66
Products Burned, Percent:				
Coke	(1)	(1)	4	3
Gas	(1)	(1)	31	32
Shale Oil	(1)	(1)	0.2	0.1
Gas Cooling Rate in Mist Forming Zone, ° F./sec.	(1)	(1)	740	1,560
Heating Value of Dry Gas Make, B.t.u./s.c.f.	(1)	(1)	139	139

[1] Inoperable.

Accordingly, by the method of this invention, the gas-combustion retort temperature profile throughout the height for a shale flow rate within the range of from about 300 to about 1000 lbs./hr.-ft.^{2} for air flow rates in the range of from about 3000 s.c.f./t. to about 7000 s.c.f./t. is very carefully controlled and regulated by preheating of the air-dilution gas mixture passed to the combustion section of the gas-combustion retort in an amount which will permit operating within the profile of FIGURE 1 defined by EFG and H and the curves lying within the limits of the area EHJLM.

Within these limits, it has been found that the minimum preheat temperature of the air-dilution gas mixture or preheated gas passed to the combustion section of the retort for air rates in the range of from about 3000 to about 7000 s.c.f./t. may be determined by the following equation:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

where:

T is the temperature in ° F.,
S is the shale flow rate in lbs./hr.-ft.^{2},

and

A is the air rate in s.c.f./t. entering the combustion zone.

On the other hand, the maximum preheat temperature employed when operating at shale flow rates in the range of 300 to about 1000 lbs./hr.-ft.^{2} will be a function of the decomposed shale outlet temperature set not to exceed about 500° F., an upper shale temperature limit of about 1500° F., and an upper gas temperature of about 1800° F. set for the reasons hereinbefore described.

Having thus provided a general description of the improved method of this invention and more specific examples in connection therewith, reference is now had to FIGURES 1 and 2 presented herewith for a clear understanding of that to which this invention is directed.

Referring now to FIGURE 1, by way of example, the preferred operating parameters defining the limits within which it is preferred to operate by the method of this invention are confined within the envelope defined by the bounds of EFGH. The envelope EFGH is defined on its vertical axis by the air dilution Gas Temperature (° F.) which defines the temperature of the preheated mix gas temperature introduced to the combustion section of the retort when employing shale flow rates within the range of 300 to about 1000 lbs./hr.-ft.^{2} defining the horizontal axis of the envelope. Within the envelope EFGH curves LM, EJ, EK, and EH define the operating conditions for air rates of 3000, 4000, 5000 and 7000 s.c.f./t. respectively required when operating according to the method herein perferred and defined by the limits of EFGH.

Referring now particularly to FIGURE 2, a diagrammatic arrangement of processing steps is presented which represents one arrangement of steps for practicing the method and essence of the invention herein described. In this arrangement, a shale retort **2** is provided having a shale inlet **4** and a shale outlet **6**. Recycle gas obtained as more fully described hereinafter is introduced to the lower portion of the retort by conduit **8** and withdrawn in part with gasiform products formed in the retort from the upper portion thereof by conduit **10**. An inlet conduit **12** discharging into a gas distributor **14** diagrammatically represented as a conical distributor means is provided in the combustion section of the retort for introducing combustion supporting gaseous material thereto under the condition herein described. In the operation of the retort raw crushed shale is introduced by conduit **4** for flow downwardly through the retort as a dense moving bed of material. The raw crushed shale preferably is of a particle size which will avoid heat diffusion limitations during the particles time of travel downwardly through the retort to the combustion section thereof. In this connection, it is preferred that the crushed shale particles be not substantially greater than about 5 inches through at least one plane of the particle and preferably not greater than about 3 inches through at least one plane of the particle. The raw crushed shale granular particles move downward through the retort; first through a shale preheat section and then the retorting section wherein a major portion and preferably substantially all of the desired kerogen decomposition is accomplished prior to the shale particles moving through the combustion section of the retort. From the combustion section, the shale granules combine to move downwardly as a relatively dense mass of granular material through the shale cooling section and countercurrent to recycle gas passed upwardly therethrough. As indicated above, the shale cooling is effected by directly heating the recycled gas moving upwardly therethrough to the combustion section of the retort. It can be seen, therefore, that beneath the combustion section, the shale particles are generally at a higher temperature than the gaseous material passing countercurrent thereto and that above the combustion section the gasiform material is generally at a higher temperature than the shale particles. Accordingly, operation of a gas-combustion retort is a thermally balanced operation controlled to optimize the temperature profile and efficiency in a manner which will maximize the decomposition of kerogen and recovery of shale oil thereof. To effect and control the thermally balanced operation within the operating ranges herein contemplated and desired, product gas of the kerogen decomposition is separated and recovered for recycle to the shale retort. A portion of the recycle gas in conduit **16** is passed to the lower portion of the retort by conduit **8**. Another portion of the recycle gas is passed to the combustion section of the retort by one of two routes specifically described below. That is, a portion of the recycle gas in conduit **16** may be passed by conduit **18** to a direct fired combustion zone **20** in admixture with air introduced by conduit **22**. The minimum proportion of recycle gas to air passed to the burner **20** to achieve the desired preheat-

ing of the gaseous material and oxygen content thereof passed to the retort combustion section is determined by the extent of minimum preheat required in accordance with the formula relationship herein provided and discussed. Therefore, for different shale and air rates employed, the extent of preheat will be varied as provided herein to permit a stable and efficient retorting operation. The thus preheated air in combustion zone **20** is thereafter passed by conduit **24** communicating with conduit **12** to the gas distributor **14** in the combustion section of the retort. In another embodiment of the method of effecting desired preheating of the gas introduced to the combustion section, a portion of the recycle gas in conduit **16** may be passed by conduit **26** to conduit **24** wherein it is combined with ambient or indirectly preheated air introduced by conduit **28**. A heater **30** may be provided for indirectly preheating the air prior to mixing with the recycle gas in conduit **26**. The thus formed mixture may be passed directly to conduit **12** and then to the combustion section or additional heat may be added to the gaseous mixture passed to the combustion section by way of an indirect heat exchanger **32**. In any of these arrangements, whether used alone or in combination with one another, the air and recycle gas introduced to the retort combustion section is preheated to a desired amount as herein provided to maintain a temperature profile in the retort above the gas inlet to the combustion section which will preferentially increase the ratio of gas burning to coke burning thereby avoiding undesired peak shale temperatures and maximize decomposition of kerogen to desired product without substantially thermally cracking it. In addition, by maintaining a temperature profile within the retort as herein provided, significant reduction in carbonate decomposition is possible since less severe shale temperature peaks are encountered in the retort.

Accordingly, by the method of this invention a heat balanced operation within relatively narrow limits for substantially any shale rates in excess of about 300 lbs./hr.-ft.^{2} may be controlled as desired to assure maximum kerogen decomposition above the combustion section and, therefore, maximum recovery of desired kerogen product.

The decomposed kerogen material in combination with gasiform material introduced and formed within the retort is removed as a fog or mist from the upper portion of the retort by conduit **10** and passed to a separation zone **34** wherein an initial separation is effected to recover recycle gaseous material from substantially a liquid product. The separated and recovered recycle gas is removed from the upper portion of zone **34** and passed by conduit **36** to gas pump or blower **38**. From pump **38** a portion of the recycle gas is passed by conduit **40** to conduit **16** for recycle to the process as hereinbefore discussed. Conduit **42** is provided for removing gas product above that required for recycle to the process.

Having thus provided a general description together with specific examples and embodiments of the invention, it is to be understood that no undue restrictions are to be imposed by reason thereof and many modifications may be made thereto without departing from the spirit thereof.

We claim:

1. A method for thermally distilling oil shale at a shale rate above about 300 lbs./hr.-ft.^{2} which comprises passing crushed oil shale material downwardly through a gas-combustion retort as a relatively dense moving mass of material through a shale preheat zone, a retorting zone, a combustion zone and a shale cooling zone, passing recycled shale gases upwardly through the retort in direct heat exchange relationship with the downwardly moving shale, introducing a combustion supporting gas to the retort combustion zone and controlling gas temperatures within the retort to not exceed above about 1800° F. by supplying a major portion of the heat of retorting through preheating of the introduced combustion supporting gas external to the retort by at least the amount determined from the relationship:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein:

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the combustion supporting gas rate in s.c.f. of equivalent air/t.

2. A method for effecting the destructive distillation of oil shale at shale rates above 300 lbs./hr.-ft.^{2} and air rates below about 7000 s.c.f./t. which comprises passing a mass of crushed shale particles in counter current relationship with a gaseous material passing upwardly through an oil shale retort and controlling the shale-gas temperature profile within the retort above the combustion zone gas inlet under conditions to increase the ratio of gas burning to coke burning by supplying a major portion of the heat of retorting by preheating the combustion supporting gas introduced to the combustion zone external to the retort by at least the amount determined from the relationship defined by:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein:

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the combustion supporting gas rate in s.c.f. of equivalent air/t.

3. A method for effecting kerogen decomposition of oil shale substantially completely above the combustion zone of a gas-combustion retort when retorting oil shale at a rate in the range of from about 300 to about 1000 lbs./hr.-ft.^{2} employing air rates in the range of from about 3000 to about 7000 s.c.f./t. which comprises limiting peak temperatures encountered in the retort by supplying a major portion of the heat of retorting through preheating the air and dilution gas introduced to the combustion zone of the retort outside of the retort by at least the amount determined in accordance with the formula:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein:

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the air rate in s.c.f./t.

4. A method for increasing the combustion ratio of gas burning to coke burning within a gas-combustion oil shale retort with a concomitant gas temperature limitation of about 1800° F. which comprises establishing an oil shale flow rate within the range of 300 to about 1000 lbs./hr.-ft.^{2} and an air rate below about 7000 s.c.f./t. to the retort, burning a portion of recovered oil shale gaseous material in heat exchange relationship with the air external to the retort to form a heated air containing dilution gas suitable for introduction to the retort combustion zone under condition to elevate the temperature of the air containing dilution gas by at least an amount determined from the relationship:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein:

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the air rate in s.c.f./t.

and introucting the thus preheated air containing dilution gas as the major heat source to the retort combustion zone.

5. A method for improving the temperature profile of a gas-combustion retort processing oil shales at a rate in excess of about 300 lbs./hr.-ft.^{2} employing air rates in the range of from about 2000 to about 7000 s.c.f./t. which comprises passing crushed shale particles downwardly through a gas-combustion retort under increasing temperature profile conditions extending downwardly through the retort to the combustion zone thereof, limiting peak shale temperature encountered in the increasing temperature profile to about 1500° F. by supplying a major portion of the retort heat as sensible heat in externally preheated air containing gaseous material, and said air containing gaseous material preheated by at least the amount determined from the relationship:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein;

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the air rate in s.c.f./t.

6. A method for effecting the destructive distillation of oil shale in a gas combustion retort within the bounds of an oil shale flow rate from about 300 to about 1000 lbs./hr.-ft.^{2} and a maximum shale temperature of about 1500° F. within the retort which comprises establishing an air flow rate in the range of 4000 to about 7000 s.c.f./t. to the retort combustion zone and externally preheating the thus established air stream in an amount sufficient to provide a major portion of the heat of retorting by at least the amount determined from the relationship:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein;

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the air rate in s.c.f./t.

7. A method for effecting the destructive distillation of oil shale in a gas combustion retort within the envelope defined by EFGJ of FIG. 1 when employing an air rate of the order of about 4000 s.c.f./t. which comprises providing a major portion of the heat of retorting by externally preheating the air passed to the combustion section of the retort by at least the amount determined from the relationship:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein;

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the air rate in s.c.f./t.

8. A method for effecting the destructive distillation of oil shale in a gas combustion retort within the envelope defined by EFGK of FIG. 1 when employing an air rate of the order of about 5000 s.c.f./t. which comprises providing a major portion of the heat of retorting by preheating the air passed to the combustion section external of the retort by at least an amount determined from the relationship:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein;

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the air rate in s.c.f./t.

9. A method for effecting the destructive distillation of oil shale in a gas combustion retort within the envelope defined by EFGH of FIG. 1 when employing an air rate of the order of about 7000 s.c.f./t. which comprises providing a major portion of the heat of retorting by preheating the air passed to the combustion section external of the retort by at least an amount determined from the relationship:

$$T=38.82-0.11A+1.87S-2.59\times10^{-4}AS+1.63\times10^{-5}A^2+2.09\times10^{-4}S^2$$

wherein;

T is the temperature in ° F.

S is the shale flow rate in lbs./hr.-ft.^{2}

and

A is the air rate in s.c.f./t.

10. A method for thermally distilling oil shale in a gas-combustion retort at shale flow rates in the range of from about 300 to about 1000 lbs./hr.-ft.^{2} which comprises passing retorted recycle shale gases upwardly through an oil shale retort and counter current to downwardly moving shale in an amount sufficient to reduce the retort shale outlet temperature below about 400° F. when limiting the retort upper shale temperature to about 1500° F. and providing a major portion of the heat of retorting by the introduction of combustion supporting gas sufficiently preheated external to the retort combustion zone and in an amount selected from within the range of from about 4000 to about 7000 s.c.f./t.

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