The invention relates to a liquid to solids heat exchanger and to a process for retorting carbon-containing solids (e.g. oil shale) using such heat exchanger. The heat exchanger contains a liquid pool reservoir (17), means (40) for heating or cooling the liquid pool, means (51) for supporting the solids such that there is heat exchange between the solids and the liquid pool without direct contact of the solids and the liquid pool, and oscillatory means (80) to cause the solids to be conveyed while exchanging heat with the liquid pool.
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LIQUID TO SOLIDS HEAT EXCHANGER

BACKGROUND OF THE INVENTION

This invention relates to the heating and cooling of solids by heat exchange with liquids as well as to the thermal decomposition, also called retorting, of solids such as oil shale, coal, industrial and municipal wastes, and the like, hereinafter referred to as carbon containing solids. Retorting involves the heating of such solids to temperatures at which they thermally decompose, releasing hydrocarbons, such as oil vapors and gases, which are then converted into fuels. Oil shale, which contains a minor amount of organic matter called kerogen and a major amount of mineral matter, is considered one of the best candidates of all carbon containing solids for the production of motor and heating fuels.

The heat exchanger of this invention is applicable not only to retorting, but also to heating or cooling of solid materials in general. The liquid to solids heat exchange, and in particular, the exposure of a wall in an oscillating pan for a pressurized contact with a liquid through the immersion in a liquid pool are distinctly different from the prior art.

Characteristically, the prior art comprises an oscillating chamber for this purpose. The liquid flows in the chamber, which may be rectilinear or helical, not unlike in
a conduit while exchanging heat with the solid materials. U.S. Patent 2,805,841 describes a typical illustration of such a chamber. In a heating application, referred to in the patent, albeit not shown on its drawings, the liquid flows inside the chamber by gravity while being pumped to or from an external heat source in order to transfer heat therefrom to the solid materials. The liquid of necessity flows by gravity because the pipes supplying the liquid cannot be connected to the chamber except by flexible piping connections. However, the latter are feasible only for liquid temperatures which are substantially below the peak retorting temperature. A submersed piping assembly for heating, as in this invention, is also precluded for the same reason, because this would necessitate flexible piping connections between the piping assembly inside the oscillating chamber and the piping supplying the heating fluid.

SUMMARY OF THE INVENTION

The heat exchanger of this invention comprises:

(a) a liquid pool within a reservoir;
(b) means for heating or cooling said liquid pool;
(c) at least one wall for supporting the solids, said wall having a top surface and a bottom surface, said wall having side walls being immersed in said liquid pool such that the bottom surface but not the top surface of said wall is in contact with the liquid pool;
(d) means for imparting an oscillatory motion to
said wall thereby causing any solids present on
said top surface to be conveyed along the top
surface while exchanging heat with the liquid pool.

Preferably the side walls are a duct such that the
bottom surface forms a closure for one end of the duct
with the other end of the duct being immersed in the liquid
pool such that the bottom surface but not the top surface
is in contact with the liquid pool and the level of the
liquid pool within the duct is at a higher elevation than
the level of the liquid pool outside the duct. Further, it
should be understood that, for the purposes of this invention,
the term "immerse" is intended to cover embodiments
wherein the wall is plunged or dipped into the liquid pool
as well as those wherein the liquid pool is drawn up
(e.g. through a duct by application of vacuum) to contact
the bottom surface of the wall.

The process for pyrolyzing the carbon-containing solids
(e.g. oil shale) to produce hydrocarbons comprises:
(a) transferring heat from a liquid pool to the solids contained on a surface by immersion of the surface in the pool such that there is no direct contact between the solids and the pool, thereby pyrolyzing the solids; and

(b) recovering the hydrocarbons from the pyrolyzed solids.

The preferred mode of the process involves additionally:

(c) transferring heat from the pyrolyzed solids contained on said surface to a liquid pool by immersion of the surface in the liquid pool such that there is no direct contact between the pyrolyzed solids and the pool; thereby cooling the pyrolyzed solids; and

(d) conveying the carbon-containing solids and the pyrolyzed solids along said surface by means of an oscillatory motion imparted to the surface such that the carbon-containing solids and the pyrolyzed solids form a substantially continuous layer, said pyrolysis occurring in a first zone.
of the layer, and said cooling occurring in a second zone of
the layer located downstream of, and substantially
contiguous to, the first zone.

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a longitudinal view of the heat exchanger of this
invention, in section, taken along line 1-1 shown in Fig. 2.

Fig. 2 is a side view of the heat exchanger, in section,
taken along line 2-2 shown in Fig. 1.

Fig. 3 is a top view of the heat exchanger, in section,
taken along line 3-3 shown in Fig. 1.

Fig. 4 is a top view of the liquid seal embodiment of the
heat exchanger of this invention, in section, taken along
line 4-4 shown in Fig. 2.

Referring to Figs. 1, 2 and 3, the heat exchanger of
this invention includes a first unit on which solids
are deposited from hopper 38 and a last unit from which
the solids are discharged through duct 63 and chute 32 into
hopper 39. The heat exchanger preferably includes a
plurality of intermediate units having the same configuration
as that of the last unit except for duct 63 and chute 32
which would be omitted.
Each unit, whether it is the first unit, last unit, or an intermediate unit, comprises a liquid pool contained in reservoir 1, and a pan 50 consisting of wall 51, duct 52 and guards 54. The liquid pool comprises one or more liquids, but preferably comprises two liquids. One of the preferred liquids is a sodium-potassium alloy. This liquid extends from guards 54 and from wall 51 to an interface with a buffer liquid at line 5 and to an interface with an inert gas (preferably nitrogen) at line 6. The buffer liquid occupies the spaces between vessel 10 and duct 52 up to line 5, and between duct 52 and walls 16 and 17 up to line 7. The buffer liquid is preferably an alloy of two or more fusible metals which is inert to the gases present above line 7. The selections of the liquids for the liquid pool, the buffer liquid, and inert gas, are not critical; suitable choices may be found in P.L. Giringer's book entitled "Heat Transfer Media".

Conduits 24 and 47 are connected to a nitrogen source. Conduit 47 branches off into two conduits 46 which terminate under guards 54. Prior to filling reservoir 1 with the liquids, air is withdrawn through conduits 46 and replaced with nitrogen which enters through conduit 24. Thereafter, both liquids are introduced through conduits (not shown in the drawings). A vacuum drawn through conduit 46 causes the nitrogen to be displaced by the liquids.
As the vacuum is drawn both liquids are gradually added until they reach the levels of lines 5, 6 and 7. Lines 5, 6 and 7 refer to the midpoint of the movement of pan 50 which moves not only to and fro but also up and down. Concurrent with the movement of the pan, the liquid at level 6 moves down and up as pan 50 moves up and down. However, the liquid is in a pressurized contact with wall 51 during the entire movement because of the upward pressure exerted as a result of the immersion plus the vacuum.

It is possible to choose liquids for the liquid pool which would eliminate the necessity for the use of nitrogen. For example, the liquid portion inside and outside the lower part of duct 11 may be replaced with an inert liquid such as the buffer liquid. In such case, conduit 24 on the outside of tank 1 may be connected to cover 27 instead of the nitrogen source. Thus, the gaseous spaces on the outside of duct 52 and duct 11 may be interconnected and the pressure above the liquids in those spaces would be equalized. Alternatively, the liquid pool may comprise a single liquid provided that such liquid is chemically inert towards the gases present in reservoir 1.

The solids are supported on the top surface of wall 51 and conveyed thereon by an oscillatory motion while
exchanging heat with the liquid pool which is heated or cooled by conduit assembly 40. The transversely parallel bars 53 communicate with oscillating mechanism 80 which imparts an oscillatory motion to wall 51 and duct 52. The bottom surface of wall 51 forms a gas-tight closure for the top end of duct 52. Pan 50 is, by means of bars 53, disposed at an elevation such that the bottom end of duct 52 is immersed in the liquid pool. A vacuum inside duct 52 lifts the liquid pool inside duct 52 up to the bottom surface of wall 51 causing the liquid pool to exert an upward pressure on wall 51. The use of a vacuum together with the immersion makes it possible for the liquid pool inside duct 52 to be in a pressurized contact with the bottom surface of wall 51. The liquid level of the pool outside duct 52 will thus be at a lower level than that inside duct 52, thus keeping the liquid pool at a safe distance from that end of wall 51 from which the solids depart, i.e. the liquid pool is thereby prevented from contacting the top surface of wall 51 and the solids contained thereon.

For the purposes of this invention, the term "pan" (no. 50) is intended to connote a structure capable of supporting solids. Such structure may have the shape of a trough, tray, deck or the like. The wall 51 may be surrounded by guards, or vertical sidewalls on all sides except that corresponding to the solids discharging end.
Duct 52 is preferably rectangular, but may have any other desired cross section, and each wall 51 may contain a plurality of ducts 52 on the bottom surface thereof. As may be seen from Figs 1-3, wall 51 preferably juts out from duct 52 so that the discharging and receiving ends of adjacent pans 50 can overlap. Such overlapping relationship makes it possible for multiple walls 51 to form a substantially continuous conveying path in which each pan 50 expands thermally at its own rate. Walls 51 are preferably only slightly inclined (e.g. 1-5 degrees) from the horizontal to the extent required for an overlapping relationship. Transverse plate 67 is attached to wall 51 of the first pan 50 upstream of chute 31. Duct 63 which comprises transverse plates 64 and 65, two parallel side plates 66 and top plate 62, is attached to the discharging end of the last pan 50.

Reservoir 1 comprises outside walls 16 and 17, cover 27, vessel 10 and ancillary piping. Walls 16 and 17 are plates with a bottom flange which is joined to vessel 10. Walls 17 also contain an upper flange which together with walls 16 and cover 27 form a duct-like extension at the entrance and exit from reservoir 1. The plurality of reservoirs with transverse plate 25 in the rear of the first unit and chute 32 in front of the last unit and expansion joints 20 in between the units form a gas-tight enclosure which contains a plurality of liquid pools.
Plate 35 is attached to vessel 10 and plate 34. Reservoir 1 supported by plate 34 on foundation 36 is free to expand thermally relative to the foundation. Chute 32 comprises plates 26, 28, 29 and 30; transverse plate 28 is attached to the upper flange of wall 17. Side plates 29 and plate 30 are extensions of walls 16 and cover 27, respectively. Bar 53 which passes through a slot in cover 27 is enclosed by liquid seal 12 which, together with hoppers 38 and 39 as well as chutes 31 and 32 form a gas-tight enclosure for the conveying path. Any gases present are admitted or withdrawn through conduit 33. Liquid seal 12 includes duct 13; bar 53 moves in an oscillatory motion inside duct 13. Ducts 13 and 14 which are connected by plate 15 form an annulus containing a liquid which may be water, an oil or a metal in the liquid state.

Duct 57, connected by plate 56 to bar 53, is immersed in such liquid while moving in unison with bar 53. Such liquid is partitioned by duct 57 into an inner liquid column (which interfaces with the gases present in reservoir 1 at line 18), and an outer liquid column (which interfaces with the outside air at line 19). Any required replenishment of such liquid may be carried out via conduit 23. Liquid droplets, thrown off due to the oscillatory motion of duct 57, are deflected by baffle bars 22 and 58. Similarly, liquid droplets thrown off by duct 52 are deflected by baffle bars 21 and 68.
Conduit assembly 40, supported on top of vessel 10, is the means utilized for heating or cooling of the liquid pool; conduit assembly 40 comprises a plurality of conduits 41 which are manifolded to transverse conduits 42 and 43. Conduits 44 and 45 (the inlet and exit conduits, respectively) run through the shell of vessel 10 and inside duct 11 and connect to conduits 42 and 43 respectively. Conduits 44 and 45 (shown in Fig. 1 as being cut away near the exit from vessel 10) are connected to a heat source (or sink). A fluid which flows inside conduit assembly 40 absorbs or rejects heat externally to the apparatus and transfers such heat to or from the liquid pool. The liquid pool may also be heated or cooled by a stream drawn from the liquid pool, pumped through an external heat source or heat sink, and returned to the liquid pool.

Mechanism 80 is of the type normally used in oscillatory conveyors of the vibratory type. This mechanism comprises structural frames 81 and 82 which are pivoted to transversely parallel levers 83 which are fulcrummed at 84 in bearings 98 which are supported by brackets 95 from an overhead structure 96 supported on columns 97. Bars 53 are attached to angle irons 85 which are the transverse members of frame 81. Connecting rod 88 which is pinned at 86 to frame 81, is operatively connected at its other end to an eccentric 87 driven by belt 90 and pulleys 91 mounted on shaft 92. Belt 90 in turn is driven by electric motor 94 with pulley 93.
Connecting rod 88 (driven by eccentric 87) imparts an oscillatory motion to frame 81 such that frame 81 moves upward and forward as frame 82 moves rearward and downward in the opposite direction along the arcs prescribed by the pivoted connections at both ends of levers 83. The mass of frame 82 acts as a counterbalance to frame 81 and springs 89 being mounted thereon provide the necessary resiliency whereby mechanism 80 operates at the natural frequency.

Mechanism 80 is but one of many types of oscillatory means which may be employed to convey the solids on wall 51. Another suitable mechanism is of the type which is employed in shaker conveyors; their trajectory follows a straight line and not an arc as in mechanism 80. Yet another type of oscillatory mechanism is a pneumatic or magnetic vibrator which is capable of conveying solids by imparting high frequency oscillations (2000 - 8000 cycles per minute) to wall 51.

The foregoing description of the apparatus and process of my invention is not to be taken as limiting my invention but only as illustrative thereof since many variations may be made by those skilled in the art without departing from the scope of the following claims.
WHAT IS CLAIMED IS:

1. A liquid to solids heat exchanger comprising:
   (a) a liquid pool within a reservoir;
   (b) means for heating or cooling said liquid pool;
   (c) at least one wall for supporting the solids, said wall having a top surface and a bottom surface, said wall having side walls being immersed in said liquid pool such that the bottom surface but not the top surface of said wall is in contact with the liquid pool;
   (d) means for imparting an oscillatory motion to said wall thereby causing any solids present on said top surface to be conveyed along the top surface while exchanging heat with the liquid pool.

2. The heat exchanger according to claim 1 wherein:
   (a) the reservoir has an opening with an annulus surrounding the periphery of the opening;
   (b) the wall contains a chute through which the solids are discharged, said chute being disposed within the annulus, said annulus containing at least one liquid dissimilar from at least one liquid present in the liquid pool, the liquid in the annulus forming a liquid seal between said chute and said reservoir.
3. The heat exchanger according to claim 1 wherein at least part of the wall is inclined at an angle which will still permit solids to be conveyed and discharged therefrom.

4. The heat exchanger according to claim 1 wherein said means for heating or cooling comprises a fluid flow through conduits immersed in said liquid pool, said fluid absorbing or rejecting heat externally to said liquid pool.

5. The heat exchanger according to claim 1 wherein said means for heating or cooling comprises a stream withdrawn from the liquid pool, pumped through an external heat source or heat sink, and returned to the liquid pool.

6. The heat exchanger according to claim 1 wherein the wall comprises a plurality of walls disposed so as to form a substantially continuous conveying path.

7. The heat exchanger according to claim 1 wherein said liquid pool comprises a plurality of liquids.

8. The heat exchanger according to claim 1 comprising a plurality of liquid pools.
9. The heat exchanger according to claim 1 wherein said reservoir contains a plurality of partitions which divide the liquid pool into liquid columns which are in a pressure balance with one another.

10. The heat exchanger according to claim 1 wherein said reservoir is totally enclosed and gas-tight and said wall is enclosed within said reservoir.

11. The heat exchanger according to claim 1 wherein the means for imparting oscillatory motion to said wall communicates with the wall by connecting means.

12. The heat exchanger according to claim 11 wherein at least one of the connecting means contains a rod slidably mounted within a resilient bushing comprised of a rubber-like material.

13. The heat exchange according to claim 1 wherein the solids are carbon-containing solids.
14. A liquid to solids heat exchanger comprising:
(a) a liquid pool within a reservoir;
(b) means for heating or cooling said liquid pool;
(c) at least one wall for supporting the solids, said wall having a top surface and a bottom surface, a duct communicating with and disposed beneath said bottom surface such that the bottom surface forms a closure for one end of the duct, the other end of the duct being immersed in said liquid pool such that the bottom surface but not the top surface is in contact with the liquid pool and the level of the liquid pool within the duct is at a higher elevation than the level of the liquid pool outside the duct; and
(d) means for imparting an oscillatory motion to said wall thereby causing any solids present on said top surface to be conveyed along the top surface while exchanging heat with the liquid pool.

15. The heat exchanger according to claim 14 wherein said means for heating or cooling comprises a fluid flow through conduits immersed in said liquid pool, said fluid absorbing or rejecting heat externally to said liquid pool.
16. The heat exchanger according to claim 14 wherein said means for heating or cooling comprises a stream withdrawn from the liquid pool, pumped through an external heat source or heat sink, and returned to the liquid pool.

17. The heat exchanger according to claim 14 wherein the wall comprises a plurality of walls disposed so as to form a substantially continuous conveying path.

18. The heat exchanger according to claim 17 wherein the walls are disposed in substantially one plane.

19. The heat exchanger according to claim 14 wherein said liquid pool comprises a plurality of liquids.

20. The heat exchanger according to claim 14 comprising a plurality of liquid pools.

21. The heat exchanger according to claim 14 wherein said reservoir contains a plurality of partitions which divide the liquid pool into liquid columns which are in a pressure balance with one another.
22. The heat exchanger according to claim 14 wherein said reservoir is totally enclosed and gas-tight and said wall is enclosed within said reservoir.

23. The heat exchanger according to claim 14 wherein the means for imparting oscillatory motion to said wall communicates with the wall by connecting means.

24. The heat exchanger according to claim 23 wherein at least one of the connecting means contains a rod slidably mounted within a resilient bushing comprised of a rubber-like material.

25. The heat exchanger according to claim 14 wherein the solids are carbon-containing solids.
# INTERNATIONAL SEARCH REPORT

**International Application No.** PCT/US88/00582

## I. CLASSIFICATION OF SUBJECT MATTER
According to International Patent Classification (IPC) or to both National Classification and IPC

- **IPC (4)**: F28F 5/00
- **U.S. CL.**: 165/84

## II. FIELDS SEARCHED

### Classification System

| U.S. | 165/84, 86, 120 432/83, 134 62/378, 380 |

### Minimum Documentation Searched

- **Documentation Searched other than Minimum Documentation**: to the extent that such documents are included in the fields searched.

## III. DOCUMENTS CONSIDERED TO BE RELEVANT

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- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art  
- "A" document member of the same patent family

## IV. CERTIFICATION

- **Date of the Actual Completion of the International Search**: 23 May 1988
- **Date of Mailing of this International Search Report**: 17 JUN 1988

**International Searching Authority**: ISA/US

**Signature of Authorized Officer**: [Signature]

Albert W. Davis Jr.