INTEGRATED COAL LIQUEFACTION AND HYDROTREATING PROCESS

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Int. Cl. .............................................. C10g 1/04
Field of Search .................................... 208/8, 143

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ABSTRACT
A hydrotreated liquid product from coal is obtained by a process in which liquefaction and hydrotreating zones are operated at essentially the same moderate pressures (1000–2000 psig). Without prior cooling, all the overhead vapor from the liquefaction reactor is admixed with a portion of light liquid fraction (700°F) recovered from the liquefaction liquid product, giving a hydrotreating feed having a temperature within a predetermined range. The remaining portion of the light liquid fraction of the liquefaction product is fed to the hydrotreating zone at quench points in the hydrotreating zone downstream from the point of introduction for the admixture, thus utilizing the heat of reaction in the hydrotreating zone to heat the remaining liquid portions (which provide quench to the hydrotreating zone).

11 Claims, 1 Drawing Figure
INTEGRATED COAL LIQUEFACTION AND HYDROTREATING PROCESS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the hydrotreating of liquid product produced by liquefying coal, and more particularly, to processes wherein the liquefaction zone, in which coal is liquefied, and the hydrotreating zone, in which liquefied coal is hydrotreated, both are operated at essentially equivalent pressures.

2. Description of the Prior Art

In order to produce a coal liquid product of adequate hydrogen content for use as a fuel product, the liquid product of coal liquefaction is fed to a hydrotreating zone, which generally is operated at substantially different pressures. It is usually necessary to preheat the coal liquid to levels at which hydrotreating occurs before introducing it into the hydrotreating zone. Herefore high furnace duties associated with preheating the feed to the hydrotreating zone have been a highly difficult problem to overcome. One approach for reducing high preheater furnace duty has been to pass substantially all hydrogen gas needed for hydrotreating the coal liquid into the liquefaction reactor in which the coal liquid is produced, stripping off large amounts of liquid from the liquefaction zone and thereby reducing the quantity of liquid to be heated in the preheater. This approach involves its own drawbacks, however, for it increases reactor costs, produces serious heat balance problems, and requires a train of overhead heat exchangers and high pressure vapor liquid separators for separating and recovering hydrogen gases and vourorous and liquid products from the liquefaction zone. Moreover, the required exchanger-separator train is susceptible to stress cracking due to the presence of corrosion precursors (hydrogen sulfide and chloride) in the condensate, which makes the system even more costly. In addition, a preheater is required for the hydrogen treat gas fed to the hydrotreating zone.

SUMMARY OF THE INVENTION

The above-described problems in hydrotreating a liquid liquefaction product are overcome by the present invention. In this invention, all of an overhead vourorous product obtained from a coal liquefaction zone is admixed, without prior cooling, with a portion of a liquid product recovered from the liquefaction zone, thereby heating that portion of the liquid product to a temperature within a predetermined range desired for hydrotreatment of the liquid product. Preferably, hydrogen treat gas, for hydrotreatment of the liquid product, is also heated by admixing it with the vourorous overhead and the light liquid portion, without prior cooling of the vourorous product. The resultant admixture is introduced into a hydrotreating zone having essentially the same pressure as the liquefaction zone. The remaining portion of the liquid product is fed into the hydrotreating zone at a location downstream from the point of introduction for the admixture where the temperature of the hydrotreating zone exceeds the predetermined hydrotreatment temperature by a specified amount, the quantity and temperature of the remaining portion being correlated with the temperature at the location where it is introduced so as to cool the hydrotreating zone downstream from that location to a temperature within the predetermined range for hydrotreatment. The heats of reaction in the hydrotreating zone thus serve to heat the remaining portion of the liquefaction liquid product and such portions conversely provide a liquid quench for the hydrotreating zone. The hydrotreated liquid product is recovered from the effluent of the hydrotreating zone, a hydrogen treat gas preferably also being recovered from the effluent and recycled to admix with the feed to the inlet of the hydrotreating zone, as above described. In the present context, hydrotreating refers to all catalytic hydrofining and hydrogenation reactions conducted at essentially non-cracking temperatures and productive of exothermic heats of reaction.

By operating the liquefaction and hydrotreating zones at essentially the same pressure level, a number of unique and valuable advantages are obtained over the earlier processes. For instance, one advantage, and an object of the invention, is the elimination altogether of preheating furnaces for the liquid product to the hydrotreating zone, and in a preferred form, the further elimination of preheating furnaces for a hydrogen treat gas to the hydrotreating zone. This is possible because all of the overhead vourorous product from the liquefaction zone is used to heat a portion of the liquid feed fed to the inlet of the hydrotreating zone, and preferably, to also heat the hydrogen treat gas fed to the hydrotreating zone.

Another advantage and object of this invention is the elimination of overhead heat exchangers and high pressure liquid separator trains for the effluent from the liquefaction zone. In the present invention, the overhead vourorous product from the liquefaction zone is quenched by a portion of the liquid product recovered from the liquefaction zone, and preferably also by a hydrogen treat stream.

Another advantage and object of the invention is the use of portions of the liquid liquefaction product not fed to the hydrogenation zone inlet to provide quench to the hydrotreating zone, eliminating more expensive and complicated quench systems such as a recycle treat gas quench system.

Yet another advantage and object of this invention results from utilizing all of the vourorous product from the liquefaction zone to heat a portion of the liquid liquefaction product and preferably also recycled treat gas. This is the advantage and objective of minimizing movement of hydrogen gas in general. Since there is no need in the present process to strip as much liquid as possible in order to reduce the heat duty of a liquid preheater for the hydrotreating zone, there is no need for treat gas recycle facilities to be sized to pass all the hydrogen required for liquefaction and hydrogenation to the liquefaction reactor.

A further advantage and objective of the invention, made possible by operating the hydrogenation zone and the liquefaction zone at essentially the same pressures, is a combination of the liquefaction and hydrogenation treat gas recycling systems. This constitutes a significant cost saving feature in treat gas recycle facilities for such a system.

In accordance with this invention, a liquid product boiling above about 200° F. (at atmospheric pressure) and a vourorous product are produced in a coal
liquefaction zone. The vaporous product includes hydrogen gas in concentrations of from about 0.5 to about 12 weight percent, preferably from about 1 to about 4 weight percent thereof. To produce the liquid product and vaporous product, a coal liquefaction zone is charged with coal particles having a size range of about 8 mesh (Tyler) and smaller slurried, at a solvent-to-coal ratio of from about 0.8:1 to about 2:1, in a coal-derived hydrocarbonaceous solvent nominally boiling within the range from about 300°F to about 900°F. The coal feedstock is a solid particulate coal such as a bituminous coal, subbituminous coal, lignite, brown coal, or a mixture thereof. Although it is desirable to grind the coal to a particle size distribution from about 8 mesh and finer, it has been found that the coal suitably liquefies even if particles as large as one-fourth inch on the major dimension are in the slurry. A typical proximate and ultimate analysis of a suitable high volatile bituminous coal is set forth in Table I, which follows:

<table>
<thead>
<tr>
<th>TABLE I Chemical Analysis of Coal Wt. % Dry Analysis</th>
<th>Illinois No. 6 Coal (With 95% Confidence Limit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>68.77 ± 0.22</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5.01 ± 0.03</td>
</tr>
<tr>
<td>Organic Oxygen</td>
<td>9.80</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.13 ± 0.03</td>
</tr>
<tr>
<td>Organic Sulfur</td>
<td>3.13 ± 0.78</td>
</tr>
<tr>
<td>Total Sulfur</td>
<td>4.51 ± 0.1</td>
</tr>
<tr>
<td>Ash</td>
<td>10.23 ± 0.13</td>
</tr>
<tr>
<td>Mineral Matter</td>
<td>11.7 ± 0.1</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>46.63 ± 0.47</td>
</tr>
</tbody>
</table>

Preferably, the coal is dried to remove excess water, either by conventional techniques prior to mixing it with the coal-derived solvent, or preferably by mixing the wet coal with hot solvent to volatilize water in the mixer zone. Moisture in the slurry feed preferably is less than about 2 weight percent. The coal-derived solvent preferably is also a hydrogen-donor solvent, desirably one containing at least 20 weight percent and preferably at least 50 weight percent of compounds which are known to be hydrogen donors at the elevated temperatures used in coal liquefaction reactors, that is, from about 700°F to about 950°F. The hydrogen-donor solvent streams suitably contain one or more hydrogen-donor compounds in admixture with non-donor compounds or with one another, suitably including compounds such as indane, C_{10}-C_{12} tetrahydrochlorinated, C_{13} and C_{14} acenaphthenes, di-, tetra- and octahydroanthracenes, and tetrahydroacenaphthenes and other derivatives of partially saturated aromatic compounds.

In the coal liquefaction process, the solvent stream preferably is a hydrogenated recycle solvent fraction. The composition of such a fraction will vary somewhat, depending upon the source of the coal used as the feedstock to the system, the operating conditions and the overall process, and the conditions used in hydrogenating the solid fraction for recycle after liquefaction. However, a typical description of a hydrogenated recycle solvent fraction will be similar to that shown in Table II.

| TABLE II Solvent Properties Typical Solvent Distillation | Weight Average Boiling Point | Weight Percent Vaporized | Specific Gravity of Fraction |
| --- | --- | --- |
| 400 | 3.35 | 0.9120 |
| 442 | 8.61 | 0.9592 |
| 463 | 9.09 | 0.9729 |
| 488 | 9.09 | 0.9813 |
| 518 | 9.57 | 0.9535 |
| 549 | 9.57 | 1.0115 |
| 568 | 10.05 | 1.0473 |
| 596 | 10.05 | 1.0643 |
| 622 | 10.05 | 1.0613 |
| 674 | 10.04 | 1.0774 |
| 733 | 7.18 | 1.0942 |
| 775 | 3.35 | 1.1069 |

Overall specific gravity = 1.0229
Solvent Elemental Composition

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>90.42</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>8.46</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.68</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.36</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.075</td>
</tr>
</tbody>
</table>

In the liquefaction zone, conditions suitably include a pressure within the range from about 1000 psig to about 2000 psig, preferably from about 1000 psig to about 1500 psig, and a temperature preferably within the range from about 750°F to about 850°F. Liquid residence time in the liquefaction zone is suitably within the range from about 5 to about 60 minutes, preferably from about 10 to about 40 minutes. Hydrogen suitably is passed into the liquefaction zone in amounts of from about 1 to about 6 weight percent (moisture and ash free coal basis), preferably from about 1 to about 3 weight percent, in order to replenish depleted hydrogen donor molecules in the solvent or to provide such molecules in the solvent, if the solvent is not already hydrogenated, by in situ hydrogenation in the liquefaction zone. Conditions in the liquefaction zone are correlated to produce sufficient liquid product to provide quench both for the vapor feed to the hydrogenation zone and for the fluids passing through the hydrogenation zone, at points in the zone, where quench is needed to control hydrogenation temperatures.

The liquid product and the vaporous product produced in liquefaction zone are separately removed from the liquefaction zone and thereafter, a portion of the liquid product is heated to a temperature within a predetermined range suitable for hydrotreating by admixing it with all of the vaporous product, without prior cooling of the vaporous product. The portion of the liquid product which is so heated may be a part of the whole liquid product or a part of a boiling range fraction of the whole liquid product. Preferably, a recycled hydrogen treat gas stream recovered from the effluent of the hydrotreating zone is also heated for passage into the hydrogenation zone by admixing it, as well, with the vaporous product without prior cooling of the vaporous product. The proportions of the portion of liquid product and hydrogen recycle gas, if any, mixed with the total vaporous liquefaction zone product, are adjusted to obtain a temperature within a predetermined
range which is within the range from about 550°F to about 750°F. Suitable for hydrotreating reactions.

In the hydrotreating zone, into which the admixture is fed, pressure is maintained essentially the same as in the liquefaction zone. Depending on the particular hydrotreating reaction employed, space velocities, hydrogen treat rate and hydrotreating temperatures will vary. In general, temperatures in the hydrotreating zone are suitably within the range from about 550° to 750°F, space velocity within the hydrotreating zone is suitably within the range from about 0.3 to 2 w/hr/w, and hydrogen treat rates are suitably within the range from about 1,000 to about 12,000 SCF/B. Preferably the hydrotreating zone is a solvent hydrogenation zone in which the mean hydrogenation temperature is within the range from about 650° to about 700°F, liquid hourly space velocity is within the range from about 1 to about 2 w/hr/w and hydrogen treat rates are within the range from about 3,000 to about 8,000 SCF/B.

Hydrotreating temperatures are maintained at a predetermined range within the aforesaid range of from about 550° to about 750° by introduction of the remainder of the liquid liquefaction product into the hydrotreating zone at one or more locations downstream from point of introduction of the admixture where the temperature of the hydrotreating zone exceeds the predetermined range of temperatures by a specified maximum within the range from about 5° to about 75°. The quantity and temperature of the remaining liquid liquefaction portion is correlated with the temperature at the one or more locations to quench the temperature in the hydrotreating zone downstream from the one or more locations to within the predetermined range to be maintained in the zone. The range of temperatures chosen for hydrotreatment, and to a lesser degree the other hydrotreating conditions, will affect the maximum temperature which can be permitted in the hydrotreating zone without runaway reaction or undue shortening of catalyst life. Where hydrotreatment is effected with a generally low range of temperatures, e.g., about 550° to about 650° F., it may when a liquid product of relatively low or moderate specific gravity and low sulfur and nitrogen content is being hydrotreated (typical for subbituminous and lower rank Western coals), it may be suitably specified that the remaining portion of the liquid product is to be introduced at the one or more locations in the hydrotreating zone where the temperature is as much as 75° F. greater than 650° F. But where the hydrotreating temperatures are in a higher range, e.g., from about 700° to about 750° F., it may be for hydrotreating of liquid product of heavier, high sulfur and nitrogen content coal typical of Eastern bituminous coal, the maximum temperature rise above that range suitably may be no more than 25° F.

The hydrotreating catalysts employed in the hydrotreatment are of conventional nature. Without being limited to any particular catalyst, these catalysts will typically comprise an alumina or silica-alumina support carrying one or more iron group metals and one or more metals of Group VI-B of the Periodic Table in the form of the oxides or sulfides. In particular, combination of one or more Group VI-B metal oxides or sulfides with one or more Group VIII metal oxides or sulfides are preferred. For example, typical catalyst metal combinations contemplated are oxides and/or sulfides of cobalt-molybdenum, nickel-tungsten, nickel-molybdenum-tungsten, cobalt-nickel-molybdenum, nickel-molybdenum, etc. As a typical example, one catalyst will comprise a high metal-content sulfided cobalt-molybdenum-alumina catalyst containing about 1 to 10 weight percent cobalt oxide and about 5 to 40 weight percent molybdenum oxide, especially about 2 to 5 weight percent cobalt and about 10 to 30 weight percent molybdenum. It will be understood that other oxides and sulfides will be useful, such as those of iron, nickel, chromium, tungsten, etc. The preparation of these catalysts is now well known in the art. The active metals can be added to the relatively inert carrier by impregnation from aqueous solutions followed by drying and calcining to activate the composition. Suitable carriers include, for example, activated alumina, activated alumina-silica, zirconia, titania, etc., and mixtures thereof. Activated clays, such as bauxite, bentonite and montmorillonite, may also be employed.

The invention will be better understood by the detailed description of a preferred embodiment of it, as depicted in the attached drawing, and by provision thereof of an example making use of the process described in the preferred embodiment.

DESCRIPTION OF THE DRAWING

The drawing is a schematic flow diagram of an integrated liquefaction-hydrogenation process for producing a recycle solvent for a coal liquefaction reactor.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A slurry of particulate coal (8 mesh Tyler and smaller) in a hydrogen-donor solvent at a solvent/coal ratio within the range from about 0.8:1 to about 2:1 and preheated to a temperature within the range from about 750° F. to about 850° F. is introduced by way of line 10 and admixed with a preheated hydrogen recycle stream introduced by way of line 12 to produce a slurry feed stream having from about 1 to about 6 weight percent of hydrogen (MAF coal basis). The slurry feed stream is introduced into a liquefaction reactor 14 maintained at liquefaction conditions including a pressure within the range from about 1000 psig to about 2000 psig, e.g., about 1800 psig, and a temperature within the range from about 750° F. to about 850° F. Liquid residence time within the reactor 14 is suitably within the range from about 10 to about 40 minutes. A vaporous product is removed overhead from liquefaction 14 by way of line 16, and suitably includes from about 0.5 to about 4 weight percent hydrogen. A liquid product is separately removed from the liquefaction reactor by way of line 18 and conducted into a low pressure, temperature reduction gas-liquid separation zone 19 for separation of flue gas constituents, primarily C2-C6 hydrocarbons and hydrogen gases, removed by way of line 20, from C3 and heavier liquid products, recovered by way of line 22. The liquid products in line 22 are then alternatively conducted either into a fractionator 24 or a fluid coker 26. Fluid coker 26 is preferably operated with a dense phase bed of coke particles maintained in fluidized state by steam and by evolution of vapor volatilization and cracking of the
feed stream, as known in the art. Within fluid coker 26, the liquid product hydrocarbons undergo thermal cracking to produce vaporeous coker products which pass upwardly through a cyclone separator, for returning coke particles back to the fluidized bed, and into a coker fractionator conventionally located above the fluid coker and integrated therewith. In the coker fractionator, the vaporeous coker products are liquefied and distillate according to boiling point, producing a light coker fractionator stream boiling below 700° F., recovered by way of line 28, and a heavy coker fractionator stream boiling from about 700° F. to about 1000° F., recovered by way of line 30. Coker fractionator bottoms, including char, is removed from coker 26 by way of line 32 for gasification or other end use. Alternatively, if coking is unnecessary, line 22 is conducted directly to fractionator 24. Accordingly, fractionator 24 is operated to produce a gas stream boiling up to about 400° F. for recovery by way of line 34. Fractionator 24 suitably fractionates the liquid product into a light fraction boiling from about 400° F. to about 700° F., for recovery by way of line 36, as well as a heavy fraction boiling from about 700° F. to about 1000° F., recovered by way of line 38. A bottom fraction from the fractionator is withdrawn for further use such as gasification. A desired fraction of the liquid product is removed from the fractionating zone by way of line 42 for ultimate hydro treating, either the 400°–700° F. fraction from line 36, the 700°–1000° F. fraction from line 38, or a 400°–1000° F. fraction provided by combining lines 36 and 38 through line 40. If fluid coker 26 is used, the desired fraction is conveyed from lines 28 or 30, or both of them. The liquid product fraction in line 42 is split into two or more portions, as by suitable proportioning valve apparatus (not illustrated), and a first portion, at a temperature, for example, of about 300° F., is admixed with all or the vaporeous liquefaction product from line 16 having, say, a temperature of about 800° F., thereby producing an admixture in line 48 with a resultant temperature within a range from about 650° F. to about 750° F. suitable for hydrogenation, in the case of the 400°/700° F. fraction, preferably from about 650° F. to about 700° F. As illustrated, the admixture is also preferably constituted with a recycle hydrogen treat gas stream introduced by way of line 46 without prior preheating passage through a preheater furnace, the quantity of the first liquid portion from line 42 being adjusted with the quantity of the recycle stream to provide the desired temperature range consistent with the feed rates of each which is wanted.

The admixture in line 48 is then introduced into solvent hydrogenation reactor 50, which is maintained at essentially the same operating pressure as in liquefaction reactor 14. Hydrogenation conditions within reactor 50 further include the aforesaid temperature within the range from about 650° F. to about 750° F., a hydrogen treat rate within the range from about 400° F. to about 12,000 SCF/B and an overall liquid hourly space velocity within the range from about 0.3 to about 2 w/hr/l. A remaining portion of the liquid product fraction recovered from fractionator 24 (or fluid coker 26) is introduced into the solvent liquefaction zone 50 by line 52 (and if necessary, by line 54) at least at one location downstream from the inlet to the hydrogenation reactor where the temperature of the hydrogenation reactor exceeds the 650°–750° F. range by a specified maximum within the range from about 5° F. to about 75° F., e.g., at most 75° F. for the 650°–700° F. hydrotreating range used for the 400°/700° F. fraction. The quantity and temperature of the remaining portion or portions of the fraction used are correlated with the temperature at the location in the solvent hydrogenation reactor where such portion or portions are introduced so as to cool the hydrogenation reactor downstream from said such locations to a temperature within the range from about 650° F. to about 750° F., or 650°–700° in the case where the 400°/700° F. fraction is used.

The effluent from the hydrogenation reactor 50 is removed by way of line 56 and conducted into a high pressure temperature reducing gas liquid separator 58, for separation of a gaseous hydrogen stream 60 from hydrocarbon vapors and liquids in line 59. The hydrogen gas in line 60 is carried into a conventional scrubber 62 in which, suitably, a monoethanol amine water solution is introduced, by way of 64, for countercurrently contacting upflowing hydrogen gas, sour water being removed by way of line 66 for ammonia recovery. The scrubbed hydrogen gas is removed from scrubber 62 by way of line 68, purged by way of line 70, and made up with fresh hydrogen by way of line 72, suitably to 80 percent hydrogen, for compression in centrifugal compressor 74. The hydrogen recycle gas from compressor 74 is then, in part, admixed with the gaseous liquefaction product 16 and the liquid liquefaction product fraction in line 42, as already described, and the remaining portion of the hydrogen recycle stream is recycled by way of line 76 to line 12 for introduction into liquefaction reactor 14 with the coal slurry from line 10.

The hydrocarbonaceous vapors and liquids recovered from separator 58 by way of line 59 are introduced into a low pressure vapor liquid separator 78, from which C3–C6 fuel gas constituents are removed overhead by way of line 80, C6 and heavier liquid hydrocarbon constituents being removed by way of line 82 and introduced into stripper 86 with liquid hydrocarbons recovered from scrubber 62 by way of line 69. In stripper 86, hydrocarbons boiling below about 400° F. are stripped overhead, and heavier boiling fractions are recovered by way of line 90, either for recycle as hydrogen-donor solvent in making up the coal slurry introduced by way of line 10, or for product use by way of line 94, or for both such purposes.

The advantages of this invention will be apparent from this embodiment of it. No preheating furnaces are necessary for the liquid fraction or the recycle hydrogen treat stream passed into solvent hydrogenation reactor 50. Heat for the hydrogen treat stream and the portion of the liquid fraction passed into the reactor is provided by the vaporeous product recovered from the liquefaction zone. The other portions of the liquid fraction are heated, while simultaneously quenching the catalyst beds in reactor 50, by injection into the reactor downstream from the inlet. This quench replaces the more costly recycle treat gas quench. By not cooling the vaporeous product, heat exchangers and separation vessels for it are eliminated. Moreover, operation of the liquefaction and
hydrogenation zones at substantially the same temperature permits a cost saving combination of the treat gas recycling systems of the two zones. Finally, elimination of feed preheat furnaces reduces the need for higher hydrogen throughputs in the liquefaction reactor, reducing hydrogen hauling equipment and liquefaction reactor costs.

The following example will more particularly illustrate the invention.

Example

A slurry of Illinois No. 6 coal (9.52 weight percent ash) at a solvent-to-coal ratio of 1:2 and preheated to 800° F. is admixed at a feed rate of 3,511 thousand pounds/hour with a hydrogen treat recycle stream compressed to 1885 psig and subsequently heated to 634° F. in amounts of 462 thousand SCF/SD (80 percent hydrogen), providing a hydrogen treat rate in the liquefaction zone of 5.2 weight percent on a dry coal basis. Conditions in the liquefaction zone include a mean temperature of about 825° F., a mean pressure of about 1810 psig, and a liquid residence time of about 36 minutes, hydrogen uptake in the zone being about 1.57 weight percent on a dry coal basis. About 519 thousand SCF/SD of vaporous product comprising 49 weight percent of hydrogen is recovered from the liquefaction reactor, at a temperature of 838° F. and a pressure of about 1790 psig. The vaporous liquefaction product is admixed with about 38.6 thousand barrels/SD of a 400/700° F. liquid product fraction at a temperature of 285° F. and about 200 million SCF/SD of 80 percent hydrogen recycle gas at a temperature of 300° F. to produce an admixture feed to the solvent hydrogenation reactor having a temperature of about 700° F. The hydrogenation catalyst is conventional cobalt molybdate on a silica-alumina bed. Total treat gas purity to the hydrogenation reactor is 66.7 mol percent hydrogen for a treat gas rate of 4730 SCF/B. The liquefaction product fraction at 285° F. is fed at the rate of 20 thousand B/SD to the solvent hydrogenation reactor as quench at locations downstream from the reactor inlet where bed temperature rises to 50° F. above the inlet temperature. Reactor inlet temperatures at the start of the run are 662° F. and at the end of the run are 739° F., the bed ΔT being 22° F. and the temperature increase rate per day being 0.43° F. Reactor inlet pressure is 1790 psig and overall liquid hourly space velocity is 4.0 whr/l. Hydrogen consumption in the solvent hydrogenation reactor is 630 SCF/B, about 1.18 weight percent on a dry coal basis.

Having described in full our invention, in which coal liquefaction and coal liquid hydrodronating zones are operated at essentially equivalent temperatures and wherein one portion of the liquid product from the liquefaction reactor is heated by means of the vapor product from the liquefaction reactor for feed to a hydrodronating zone, the other portion of the liquid product being fed to the hydrodronating zone for quench of the zone, various changes and modifications of the invention will now occur to those skilled in the art.

Insofar as these changes and modifications are equivalent ways of achieving the ends of this invention within the spirit and scope of the appended claims, they are deemed within the invention, we claim:

1. A process for producing hydrotreated liquid product from coal, which comprises:

subjecting a slurry of coal particles in a hydrogen-donor solvent to coal liquefaction in the presence of hydrogen for a sufficient period of time and at a sufficient temperature to form a liquid product and a vaporous product;

admitting all of said vaporous product with a portion of said liquid product, without prior cooling of said vaporous product, to obtain an admixture having a temperature within a predetermined range;

introducing said admixture into a hydrogenation zone having essentially the same pressure as said liquefaction zone;

introducing a second portion of said liquid product into said hydrogenation zone at a location downstream from the point of introduction of said admixture where the temperature of said hydrogenation zone exceeds said predetermined range by a specified minimum, the quantity and temperature of said second portion being correlated with the temperature at said location as to cool the hydrogenation zone downstream of said location to a temperature within a predetermined range; and

recovering a hydrotreated liquid product from said hydrogenation zone.

2. The process of claim 1 in which said predetermined range is within the range from about 550° F. to about 750° F. and said specified minimum is within the range from about 5° F. to about 75° F.

3. The process of claim 2 in which said predetermined range is from about 650° F. to about 700° F.

4. The process of claim 1 in which the pressure in said liquefaction and hydrogenation zones is within the range from about 1000 psig to about 2000 psig.

5. The process of claim 1 in which all of said vaporous product is admixed with a stream of hydrogen treat gas and a portion of said liquid product, without prior cooling of said vaporous product, to obtain an admixture having a temperature within said predetermined range.

6. A process for producing a hydrogenated liquid product from coal, which comprises:

in a coal liquefaction zone, liquefying coal slurried in a hydrogen-donor solvent in admixture with from about 1 to about 6 weight percent hydrogen, under liquefaction conditions, to produce a vaporous product, containing from about 1 to about 12 weight percent hydrogen, and a liquid product, including a fraction boiling within the range from about 300° F. to about 700° F.;

removing said vaporous product and said liquid product separately from said liquefaction zone;

recovering said fraction from said liquid product and splitting said fraction into a plurality of portions;

admixing all of said vaporous product with a first portion of said fraction without prior cooling of said vaporous product, to produce an admixture having a temperature in a predetermined range within the range from about 550° F. to about 750° F.;

introducing said admixture at said temperature into a hydrogenation zone having essentially the same pressure as said liquefaction zone;

introducing a second portion of said fraction into said hydrogenation zone at a location downstream from the inlet for said admixture where the tem-
perature of the hydrogenation zone exceeds said temperature within said predetermined range by a
specified temperature within the range from about 5°F. to about 75°F., the quantity and temperature
of said second portion being correlated with the temperature at said location so as to cool the
hydrogenation zone downstream from said location to a temperature within said predetermined
range;
removing the effluent from said hydrogenation zone;
and
recovering the hydrotreated liquid product from said effluent.
7. The process of claim 6 further comprising:
recovering a hydrogen treat gas from said effluent, and admixing said vaporeous product with said
hydrogen treat gas and said first portion of said fraction, without prior cooling of said vaporeous
product, to obtain said admixture having a temperature within said predetermined range.
8. The process of claim 6 in which the pressure in said liquefaction and hydrogenation zones is within the
range from about 1000 psig to about 2000 psig.
9. The process of claim 8 in which said liquefaction conditions further include a temperature within the
range from about 750°F. to about 850°F. and a liquid residence time of from about 5 to about 60 minutes.
10. The process of claim 5 in which said predetermined range is from about 650°F. to about 700°F.
11. A process for producing a hydrogenerated liquid product from coal, which comprises:
in a coal liquefaction zone, liquefying coal slurried in a hydrogen-donor solvent in admixture from about
1 to about 6 weight percent hydrogen, under liquefaction conditions including a pressure within
the range from about 1000 psig to about 2000 psig, a temperature within the range from about 750°F.
to about 850°F., and a liquid residence time of from about 5 to about 60 minutes, to produce a
vaporous product containing from about 1 to about 12 weight percent hydrogen, and a liquid
product including a fraction boiling within the range from about 300°F. to about 700°F.;
removing said vaporous product and said liquid product separately from said liquefaction zone,
recovering said fraction from said liquid product and splitting said fraction into a plurality of portions;
admixing all of said vaporous product with a recycle stream of hydrogen treat gas and a first portion of
said fraction, without prior cooling of said vaporous product, to obtain an admixture having a temperature
within a predetermined range from about 650°F. to about 700°F.;
introducing said admixture at said temperature into a hydrogenation zone having essentially the same
pressure as said liquefaction zone;
introducing a second portion of said fraction into said hydrogenation zone at a location downstream
from the point of introduction of said admixture where the temperature of the hydrogenation zone
exceeds said temperature within said predetermined range by a specified maximum within the
range from about 5°F. to about 75°F., the quantity and temperature of said second portion being
 correlated with the temperature at said location so as to cool the hydrogenation zone downstream
from said location to a temperature within said predetermined range;
removing the effluent from said hydrogenation zone;
recovering the hydrotreated liquid product and the hydrogen treat gas from said effluent; and
recycling the hydrogen treat gas for admixture with said vaporous product.

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