CLAIMS

1. A process for cracking a hydrocarbon-containing feedstock, comprising:

providing a hydrocarbon-containing feedstock to a mixing zone, where the hydrocarbon-containing feedstock is selected to contain at least 20 wt.% hydrocarbons having a boiling point of greater than 538°C as determined in accordance with ASTM Method D5307;

providing at least one metal-containing catalyst to the mixing zone;

continuously or intermittently providing hydrogen to the mixing zone;

continuously or intermittently providing hydrogen sulfide to the mixing zone, where the hydrogen sulfide is provided to the mixing zone at a mole ratio of hydrogen sulfide to hydrogen of at least 0.5:9.5 up to 1:1;

blending the hydrogen, hydrogen sulfide, hydrocarbon-containing feedstock, and the catalyst(s) in the mixing zone at a temperature of from 375°C to 500°C and at a total pressure of from 6.9 MPa to 27.5 MPa—where hydrogen and hydrogen sulfide are provided for mixing such that the combined hydrogen and hydrogen sulfide partial pressures provide at least 60% of the total pressure—to produce:

a) a vapor comprised of hydrocarbons that are vaporizable at the temperature and the pressure within the mixing zone; and

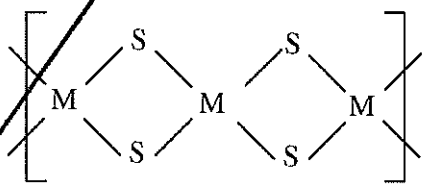
b) a hydrocarbon-depleted feed residuum comprising hydrocarbons that are liquid at the temperature and pressure within the mixing zone;

continuously or intermittently separating at least a portion of the vapor from the mixing zone while retaining in the mixing zone at least a portion of the hydrocarbon-depleted feed residuum within the mixing zone.

2. The process of claim 1 wherein the hydrocarbon-containing feedstock and the hydrocarbon-depleted feed residuum are blended with hydrogen, hydrogen sulfide, and the catalyst(s) in the mixing zone while continuously separating at least a portion of the vapor from the mixing zone.

3. The method of claim 1 or claim 2 wherein any metal-containing catalyst provided to the mixing zone has an acidity as measured by ammonia chemisorption of at most 200 μmol ammonia per gram of catalyst.

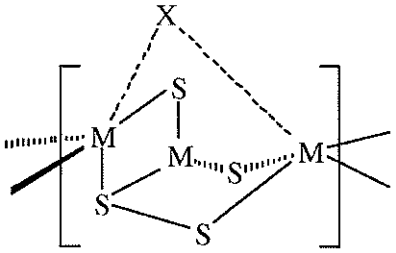
4. The process of claim 1 or any of claims 2-3 wherein the catalyst is comprised of a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi where the second metal comprises a metal selected from the group consisting of Mo, W, V, Sn and Sb, where the second metal is not the same as the first metal, and wherein at least a portion of the material of the catalyst has a structure according to a formula selected from the group consisting of formula (VII), formula (IX), formula (XII), and formula (XIV):



(VII)

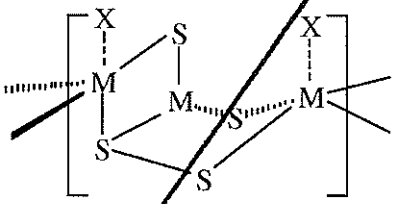
where M is either the first metal or the second metal, and at least one M is the first

metal and at least one M is the second metal;



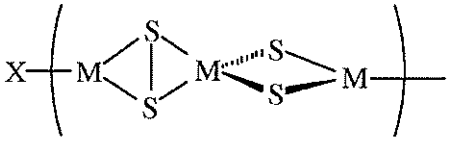
(IX)

where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;



(XII)

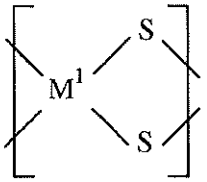
where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;



(XIV)

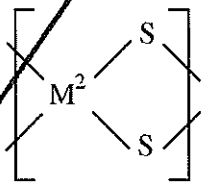
where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3.

5. The process of claim 1 any of claims 2-3 wherein the catalyst is comprised of a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi, where the second metal comprises a metal selected from the group consisting of Mo, W, V, Sn, and Sb, where the second metal is not the same as the first metal, and wherein the material is comprised of at least three linked chain elements, the chain elements comprising a first chain element including the first metal and having a structure according to formula (I) and a second chain element including the second metal and having a structure according to formula (II)



(I)

where M^1 is the first metal



(II)

where M^2 is the second metal

where at least one chain element in the material is a first chain element and at least one chain element in the material is a second chain element, and where chain elements in the material are linked by bonds between the two sulfur atoms of a chain element and the metal of an adjacent chain element.

6. The method of claim 1 or any of claims 2-5 wherein the catalyst is a solid particulate material having a particle size distribution having a median particle size or a mean particle size of from 50 nm to 5 μm.

7. The process of claim 1 or any of claims 2-6 further comprising the steps of : separating a stream containing liquids and solids from the mixing zone; separating solids from the stream containing liquids and solids to produce a liquid stream and a solid material; and providing the liquid stream to the mixing zone.

8. The process of claim 1 or any of claims 2-7 wherein the hydrogen sulfide is provided to the mixing zone at a mole ratio of hydrogen sulfide to hydrogen of at least 1:10, or at least 1:5, or at least 1:4, or at least 3:10, or at least 3.5 to 10, or at least 2:5.

9. The process of claim 1 or any of claims 2-8 wherein the hydrocarbon-containing feedstock contains at least 30 wt.%, or least 40 wt.%, or at least 50 wt.% of hydrocarbons having a boiling point of 538°C or less as determined in accordance with ASTM Method D2887.

10. The process of claim 1 or any of claims 2-9 wherein the temperature in the mixing zone is selected and controlled to be at least 430°C or at least 450°C.

11. The process of claim 1 or any of claims 2-10 wherein the combined volume of the hydrocarbon-depleted feed residuum, the catalyst(s), and the hydrocarbon-containing feedstock in the mixing zone defines a mixture volume in the mixing zone, and the hydrocarbon-containing feedstock is provided to the mixing zone at a rate selected to be at least 350, or at least 400, or at least 500, or at least 600, or at least 700, or at least 800, or at least 900, or at least 1000 kg/hr m^3 of the mixture volume in the mixing zone.

12. The process of claim 11 wherein the mixing zone is located in a reactor;
the reactor has a reactor volume;
the combined volume of the hydrocarbon-containing feedstock and the catalyst(s) initially provided to the mixing zone defines an initial mixture volume, where the initial mixture volume is from 5% to 97% of the reactor volume;
and where the mixture volume of the catalyst, the hydrocarbon-depleted feed residuum, and the hydrocarbon-containing feed is maintained at a level of from 10% to 1940% of the initial mixture volume.

13. The process of claim 1 or any of claims 2-12 wherein the hydrocarbon-depleted feed residuum contains less than 0.02 grams of substances insoluble in toluene as determined in accordance with ASTM Method D4072, excluding the catalyst, per gram of hydrocarbon-containing feedstock provided to the mixing zone.

14. The process of claim 1 or any of claims 2-13 further comprising the step of, apart from the mixing zone, condensing at least a portion of the vapor separated from the mixing zone to produce a liquid hydrocarbon-containing product.

We claim:

1. A process for cracking a hydrocarbon-containing feedstock, comprising: providing a hydrocarbon-containing feedstock to a mixing zone, where the hydrocarbon-containing feedstock is selected to contain at least 20 wt. % hydrocarbons having a boiling point of greater than 538° C. as determined in accordance with ASTM Method D5307; providing at least one metal-containing catalyst to the mixing zone; continuously or intermittently providing hydrogen to the mixing zone; continuously or intermittently providing hydrogen sulfide to the mixing zone, where the hydrogen sulfide is provided to the mixing zone at a mole ratio of hydrogen sulfide to hydrogen of at least 0.5:9.5 up to 1:1; blending the hydrogen, hydrogen sulfide, hydrocarbon-containing feedstock, and the catalyst(s) in the mixing zone at a temperature of from 375° C. to 500° C. and at a total pressure of from 6.9 MPa to 27.5 MPa—where hydrogen and hydrogen sulfide are provided for mixing such that the combined hydrogen and hydrogen sulfide partial pressures provide at least 60% of the total pressure—to produce: a) a vapor comprised of hydrocarbons that are vaporizable at the temperature and the pressure within the mixing zone; and b) a hydrocarbon-depleted feed residuum comprising hydrocarbons that are liquid at the temperature and pressure within the mixing zone; continuously or intermittently separating at least a portion of the vapor from the mixing zone while retaining in the mixing zone at least a portion of the hydrocarbon-depleted feed residuum within the mixing zone, wherein the vapor separated from the mixing zone comprises at most 5 wt. % solids and liquids at the temperature at which the vapor is separated from the mixing zone; and apart from the mixing zone, condensing a liquid hydrocarbon-containing product that contains at least 90% of the atomic carbon initially contained in the hydrocarbon-containing feedstock and that contains less than 5 wt. % hydrocarbons having a boiling point of at least 538° C. as determined in accordance with ASTM Method D5307 from at least a portion of the vapor separated from the mixing zone.

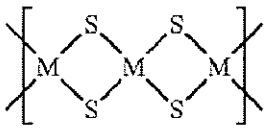
2. The process of claim 1 wherein the hydrocarbon-containing feedstock and the hydrocarbon-depleted feed residuum are blended with hydrogen, hydrogen sulfide, and the catalyst(s) in the mixing zone while continuously separating at least a portion of the vapor from the mixing zone.

3. The method of claim 1 wherein any metal-containing catalyst provided to the mixing zone has an acidity as measured by ammonia chemisorption of at most 200 mmol ammonia per gram of catalyst.

4. The process of claim 1 wherein the catalyst comprises a metal of Column 6, 14, or of the Periodic Table or a compound containing a metal of Column(s) 6, 14, or 15 of the Periodic Table and a metal of Column(s) 3 or 7-15 of the Periodic Table or a compound containing a metal of Column(s) 3 or 7-15 of the Periodic Table.

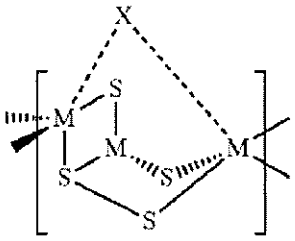
5. The process of claim 1 wherein the catalyst is comprised of a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi where the second metal comprises a metal selected from the group consisting of Mo, W, V, Sn and Sb, where the second metal is not the same as the first metal, and wherein at least a portion of the material of the catalyst has a structure according to a formula selected from the group consisting of formula (VII), formula (IX), formula (XII), and formula (XIV):

(VII)



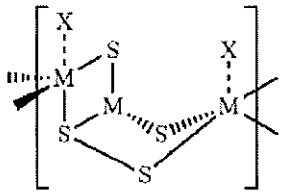
where M is either the first metal or the second metal, and at least one M is the first metal and at least one M is the second metal;

(IX)



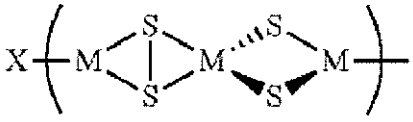
where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;

(XII)



where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;

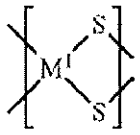
(XIV)



where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3.

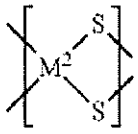
6. The process of claim 1 wherein the catalyst is comprised of a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi, where the second metal comprises a metal selected from the group consisting of Mo, W, V, Sn, and Sb, where the second metal is not the same as the first metal, and wherein the material is comprised of at least three linked chain elements, the chain elements comprising a first chain element including the first metal and having a structure according to formula (I) and a second chain element including the second metal and having a structure according to formula (II)

(I)



where M^1 is the first metal

(II)



where M^2 is the second metal

where at least one chain element in the material is a first chain element and at least one chain element in the material is a second chain element, and where chain elements in the material are linked by bonds between the two sulfur atoms of a chain element and the metal of an adjacent chain element.

7. The method of claim 1 wherein the metal-containing catalyst is a solid particulate material having a particle size distribution having a median particle size or a mean particle size of from 50 nm to 5 μm.

8. The process of claim 1 further comprising the steps of: separating a stream containing liquids and solids from the mixing zone; separating solids from the stream containing liquids and solids to produce a liquid stream and a solid material; and providing the liquid stream to the mixing zone.

9. The process of claim 1 wherein the hydrogen sulfide is provided to the mixing zone at a mole ratio of hydrogen sulfide to hydrogen of at least 1:10.

10. The process of claim 1 wherein the hydrocarbon-containing feedstock is continuously provided to the mixing zone, hydrogen is continuously provided to the mixing zone, hydrogen sulfide is continuously provided to the mixing zone, at least a portion of the vapor is continuously separated from the mixing zone, and the hydrocarbon-containing feedstock, the hydrocarbon-depleted feed residuum, hydrogen, hydrogen sulfide, and the catalyst are blended in the mixing zone for a period of at least 45 hours.

11. The process of claim 1 wherein the hydrocarbon-containing feedstock contains at least 30 wt. % of hydrocarbons having a boiling point of greater than 538° C. as determined in accordance with ASTM Method D5307.

12. The process of claim 1 wherein the hydrocarbon-containing feedstock contains at least 30 wt. %, of hydrocarbons having a boiling point of 538° C. or less as determined in accordance with ASTM Method D5307.

13. The process of claim 1 wherein the temperature in the mixing zone is selected and controlled to be at least 430° C.

14. The process of claim 1 wherein the hydrocarbon-containing product condensed from the vapor separated from the mixing zone contains at most 1 wt. % coke as determined in accordance with ASTM Method 4072.

15. The process of claim 1 wherein the hydrocarbon-containing product condensed from the vapor separated

from the mixing zone contains at least 40% of the atomic sulfur present in the hydrocarbon-containing feedstock wherein at least 40 wt. % of the sulfur is contained in hydrocarbon compounds having a carbon number of 17 or less as determined by two-dimensional GC-GC sulfur chemiluminscence.

16. The process of claim 1 wherein the hydrocarbon-containing product condensed from the vapor separated from the mixing zone contains at least 40% of the atomic nitrogen present in the hydrocarbon-containing feedstock wherein at least 30 wt. % of the nitrogen in the hydrocarbon composition is contained in nitrogen-containing hydrocarbon compounds having a carbon number of 17 or less.

17. The process of claim 1 wherein the hydrocarbon-containing product contains at most 0.001 wt. % vanadium and at most 0.001 wt. % nickel.

18. The process of claim 1 wherein the combined volume of the hydrocarbon-depleted feed residuum, the catalyst(s), and the hydrocarbon-containing feedstock in the mixing zone defines a mixture volume in the mixing zone, and the hydrocarbon-containing feedstock is provided to the mixing zone at a rate selected to be at least 350 kg/hr per m^3 of the mixture volume in the mixing zone.

19. The process of claim 18 wherein the mixing zone is located in a reactor; the reactor has a reactor volume; the combined volume of the hydrocarbon-containing feedstock and the catalyst(s) initially provided to the mixing zone defines an initial mixture volume, where the initial mixture volume is from 5% to 97% of the reactor volume; and where the mixture volume of the catalyst, the hydrocarbon-depleted feed residuum, and the hydrocarbon-containing feed is maintained at a level of from 10% to 1940% of the initial mixture volume.

20. The process of claim 1 wherein the hydrocarbon-depleted feed residuum contains less than 0.02 grams of substances insoluble in toluene as determined in accordance with ASTM Method D4072, excluding the catalyst, per gram of hydrocarbon-containing feedstock provided to the mixing zone.