CLAIMS

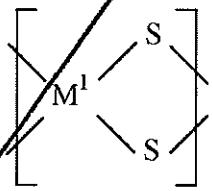
1. A process for cracking a hydrocarbon-containing feedstock, comprising:
continuously or intermittently providing hydrogen to a mixing zone;
providing a metal-containing catalyst to the mixing zone;
selecting a hydrocarbon-containing feedstock containing at least 20 wt.% hydrocarbons having a boiling point of greater than 538°C as determined inaccordance with ASTM Method D5307;
continuously or intermittently providing the hydrocarbon-containing feedstock to the mixing zone at a selected rate and blending the hydrogen, the hydrocarbon-containing feedstock, and the catalyst 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 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,
where the combined volume of the hydrocarbon-depleted feed residuum, the catalyst, and the hydrocarbon-containing feedstock in the mixing zone define a mixture volume in the mixing zone, wherein the rate at which the hydrocarbon-containing feedstock is provided to the mixing zone is selected to be at least 350 kg/hr m^3 of the mixture volume in the mixing zone; and
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 and at least a portion of the catalyst.

2. The process of claim 1 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 separate from the mixing zone.

3. The process of claim 1 wherein the vapor separated from the mixing zone is hydroprocessed by contacting the vapor with a hydroprocessing catalyst and hydrogen at a temperature of from 260°C to 425°C and a total pressure of from 3.4 MPa to 27.5 MPa.

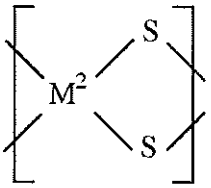
4. The process of claim 1 or any of claims 2-3 further comprising the steps of: providing hydrogen sulfide to the mixing zone and blending the hydrogen sulfide with the hydrocarbon-containing feedstock, the catalyst, and hydrogen in the mixing zone, wherein hydrogen sulfide is provided to the mixing zone at a mole ratio of hydrogen sulfide to hydrogen of at least 0.5:9.5, or at least 1.5:8.5, or at least 2.5:7.5, or at least 3:7, or at least 3.5:6.5, or at least 4:6, up to 1:1, 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.

5. The process of claim 1 or any of claims 2-4 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



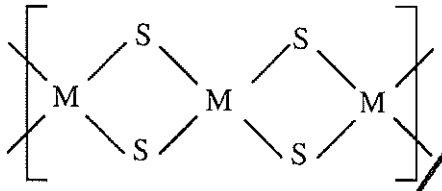
(II)

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.

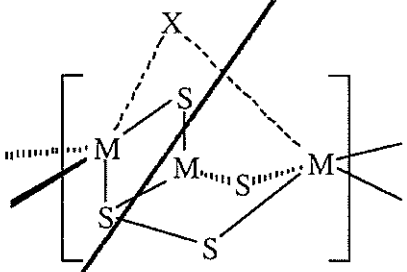
6. The process of claim 1 or any of claims 2-4 wherein the catalyst is comprised of a material comprised of a first metal and a second metal where the first metal

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 (III), formula (IV), formula (V), and formula (VI):



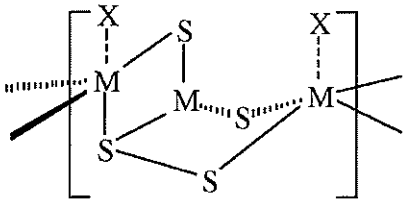
(III)

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;



(IV)

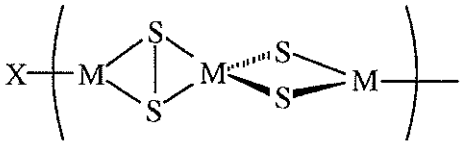
where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;



(V)

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;



(VI)

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.

7. The process of claim 1 or any of claims 2-6 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.

8. The method of claim 1 or any of claims 2-7 wherein any catalyst provided to the mixing zone has an acidity as measured by ammonia chemisorption of at most 200 μmol ammonia per gram of catalyst.

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 that have a boiling point of 538°C or less as determined in accordance with ASTM Method D5307.

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 hydrocarbon-containing feedstock is provided to the mixing zone at a flow rate of at least 400, or at least 500, or at least 600, or at least 700, or at least 800 kg/h per m3 of mixture volume.

12. The process of claim 1 or any of claims 2-11 wherein

the mixing zone is located in reactor;

the reactor has a reactor volume;

the hydrocarbon-containing feedstock and the catalyst initially provided to the mixing zone define 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 12 wherein the vapor separated from the mixing zone is separated from the reactor.

We claim:

1. A process for cracking a hydrocarbon-containing feedstock, comprising: continuously or intermittently providing hydrogen to a mixing zone; providing a metal-containing catalyst to the mixing zone; selecting a hydrocarbon-containing feedstock containing at least 20 wt. % hydrocarbons having a boiling point of greater than 538° C. as determined in accordance with ASTM Method D5307; continuously or intermittently providing the hydrocarbon-containing feedstock to the mixing zone at a selected rate and blending the hydrogen, the hydrocarbon-containing feedstock, and the catalyst 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 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, where the combined volume of the hydrocarbon-depleted feed residuum, the catalyst, and the hydrocarbon-containing feedstock in the mixing zone define a mixture volume in the mixing zone, wherein the rate at which the hydrocarbon-containing feedstock is provided to the mixing zone is selected to be at least 350 kg/hr per m^3 of the mixture volume in the mixing zone; and 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 and at least a portion of the catalyst, 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.

2. The process of claim 1 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 separate from the mixing zone.

3. The process of claim 2 wherein the hydrocarbon-containing product condensed from the vapor separated from the mixing zone contains less than 3 wt. % hydrocarbons having a boiling point of greater than 538° C. as determined in accordance with ASTM Method D5307 and at most 0.5 wt. coke as determined in accordance with ASTM Method D4072, and contains at least 80% of the atomic carbon initially contained in the hydrocarbon-containing feedstock provided to the mixing zone.

4. The process of claim 2 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.

5. The process of claim 2 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.

6. The process of claim 2 wherein the hydrocarbon-containing product contains at most 0.001 wt. % vanadium and at most 0.001 wt. % nickel.

7. The process of claim 1 wherein the vapor separated from the mixing zone is hydroprocessed by contacting the vapor with a hydroprocessing catalyst and hydrogen at a temperature of from 260° C. to 425° C. and a total pressure of from 3.4 MPa to 27.5 MPa.

8. The process of claim 1 wherein the hydrocarbon-depleted feed residuum is blended with hydrogen and the catalyst in the mixing zone while separating at least a portion of the vapor from the mixing zone.

9. The process of claim 8 wherein the hydrocarbon-containing feedstock and the hydrocarbon-depleted feed residuum are blended with hydrogen and the catalyst in the mixing zone while separating at least a portion of the vapor from the mixing zone.

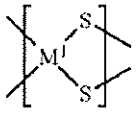
10. The process of claim 1 wherein the hydrocarbon-containing feedstock is continuously provided to the mixing zone, the hydrogen is continuously provided to the mixing zone, at least a portion of the vapor is continuously separated from the mixing zone, and the hydrocarbon-containing feedstock, the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

11. The process of claim 1 further comprising the steps of: providing hydrogen sulfide to the mixing zone and blending the hydrogen sulfide with the hydrocarbon-containing feedstock, the catalyst, and hydrogen in the mixing zone, wherein 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, 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.

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

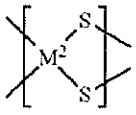
13. The process of claim 1 wherein the catalyst is comprised of a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi, where the second metal 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)



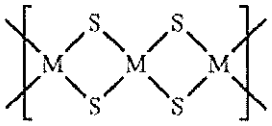
where M^2 is the second metal

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.

14. 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

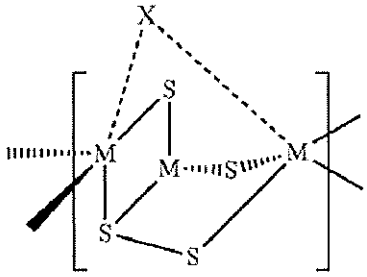
metal, and wherein at least a portion of the material of the catalyst has a structure according to a formula selected from the group consisting of formula (VII), formula (IX), formula (XII), and formula (XIV):

(VII)



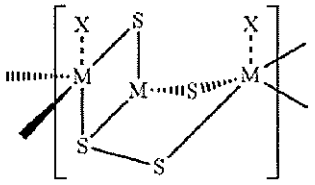
where M is either the first metal or the second metal, and at least one M is the first metal and at least one M is the second metal;

(IX)



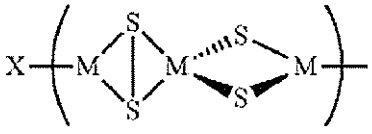
where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;

(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.

15. The process of claim 1 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.

16. The method of claim 1 wherein any catalyst provided to the mixing zone has an acidity as measured by

ammonia chemisorption of at most 200 μmol ammonia per gram of catalyst.

17. 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.

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

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

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.

21. The process of claim 1 wherein the hydrocarbon-containing feedstock is provided to the mixing zone at a flow rate of at least 400 kg/h per m^3 of mixture volume.

22. The process of claim 1 wherein: the mixing zone is located in reactor; the reactor has a reactor volume; the hydrocarbon-containing feedstock and the catalyst initially provided to the mixing zone define an initial mixture volume, where the initial mixture volume is from 5% to 97% of the reactor volume; 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.

23. The process of claim 22 wherein the vapor separated from the mixing zone is separated from the reactor.