CLAIMS

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

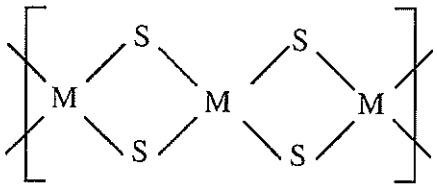
mixing, at a temperature selected from 375°C to 500°C and a total pressure selected from 6.9 MPa to 27.5 MPa,

a) 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;

b) hydrogen;

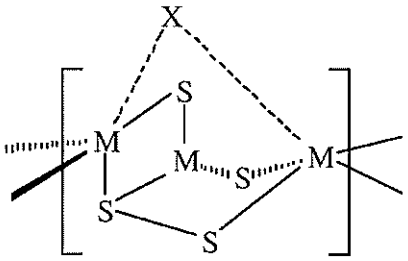
c) hydrogen sulfide, where the hydrogen sulfide is provided for mixing at a mole ratio of hydrogen sulfide to hydrogen of from 0.5:9.5 to 1:1, where the hydrogen and hydrogen sulfide are provided for mixing such that the combined hydrogen and hydrogen sulfide partial pressures provide at least 60% of the total pressure; and

d) a catalyst comprising a material comprised of a first metal and a second metal where the first metal is selected from the group consisting of Cu, Fe, Ni, Co, Bi, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, and Sb, where the second metal is selected from the group consisting of Mo, W, V, Sn, and Sb, where the second metal is different from the first metal, 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 (I), formula (II), formula (III), and formula (IV):



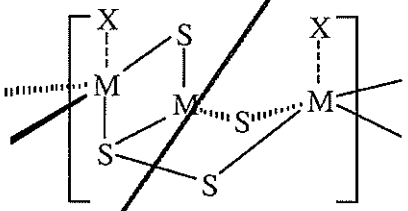
(I)

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;



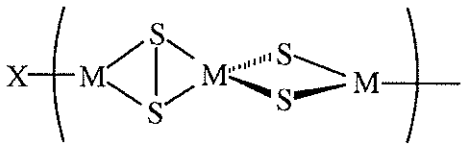
(II)

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;



(III)

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;



(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;

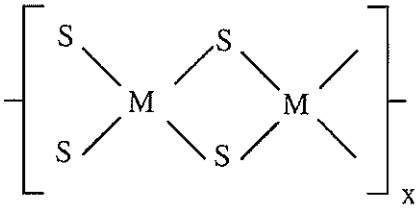
where the hydrocarbon-containing feedstock, catalyst, hydrogen sulfide, and hydrogen form a mixture upon mixing; and

while mixing the mixture at the selected temperature and selected total pressure, separating a vapor comprising a hydrocarbon-containing product from the mixture, where the hydrocarbon-containing product is comprised of one or more hydrocarbon compounds that are liquid at STP.

2. The process of claim 1 further comprising the step of, apart from the mixture, condensing at least a portion of the vapor separated from the mixture to produce a liquid hydrocarbon-containing product separate from the mixture.

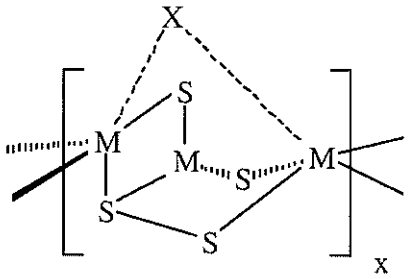
3. The process of claim 1 wherein the vapor separated from mixture is hydroprocessed by contacting the vapor with a hydroprocessing catalyst and hydrogen at a temperature of from 260°C to 425°C and a total pressure of from 3.4 MPa to 27.5 MPa.

4. The process of claim 1 or any of claims 2-3 wherein at least a portion of the material of the catalyst comprised of the first metal and the second metal has a structure according to a formula selected from formula (V), formula (VI), formula (VII), and formula (VIII);



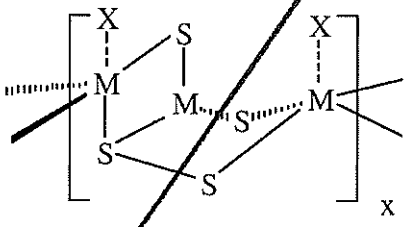
(V)

where M is either the first metal or the second metal, at least one M is the first metal, at least one M is the second metal, and x is at least 2;



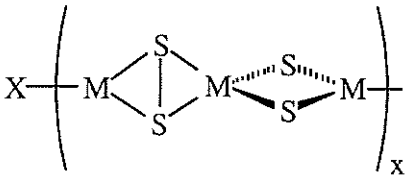
(VI)

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, 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, and x is at least 2;



(VII)

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, 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, and x is at least 2;



(VIII)

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, 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, and x is at least 2.

5. The process of claim 1 or any of claims 2-3 wherein at least a portion of the catalyst is in solid particulate form wherein the portion of the catalyst in solid particulate form has a particle size distribution having a median particle size or a mean particle size of from 50 nm up to 5 μm.

6. The process of claim 1 or any of claims 2-5 wherein the atomic ratio of the first metal to the second metal in the catalyst is at least 1:2, or is greater than 1:2, or is at least 2:3, or is at least 1:1.

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

a) the hydrocarbon-containing feedstock, the catalyst, the hydrogen sulfide, and the hydrogen are mixed by blending the hydrocarbon-containing feedstock, the catalyst, the hydrogen sulfide, and the hydrogen in a mixing zone, where the mixing zone is maintained at a temperature of from 375°C to 500°C under a total pressure of from 6.9 MPa to 27.5 MPa to produce

1) the vapor comprising the hydrocarbon-containing product and

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

b) separating at least a portion of the vapor comprising the hydrocarbon-containing product from the mixing zone while blending the hydrocarbon-depleted feed residuum with the catalyst, hydrogen sulfide, and hydrogen in the mixing zone.

8. The process of claim 7 wherein the hydrocarbon-containing feedstock, the hydrocarbon-depleted feed residuum, and the catalyst define a mixture volume, and the hydrocarbon-containing feedstock is provided for mixing at a rate of at least 350 kg/hr per m^3 of the mixture volume.

9. The process of claim 7 or claim 8 wherein the vapor separated from the mixing zone comprises hydrogen sulfide, and further comprising the steps of separating a gas comprising the hydrogen sulfide from the vapor separated from the mixing zone; and providing the gas comprising hydrogen sulfide to the mixing zone.

10. The process of claim 1 or any of claims 2-9 wherein the hydrogen sulfide is provided to the mixture at a mole ratio of hydrogen sulfide to hydrogen at least 1.5:8.5, or at least 2:8, or at least 2.5:7.5, or at least 3:7, or at least 3.5:6.5, or at least 4:6.

11. The process of claim 1 or any of claims 2-10 wherein the hydrogen sulfide is provided for mixing such that the hydrogen sulfide partial pressure is maintained at a level of at least 5% of the hydrogen partial pressure.

12. The process of claim 1 or any of claims 2-11 wherein the hydrocarbon-containing feedstock contains at least 30 wt.%, or 40 wt.%, or 50 wt.% of hydrocarbons that are liquid at STP and have a boiling point of less than 538°C.

13. The process of claim 1 or any of claims 2-12 wherein the material comprised of the first metal and the second metal comprises at least 50 wt.%, or at least 75 wt.%, or at least 90 wt.%, or at least 95 wt.%, or least 99 wt.%, or 100 wt.% of the catalyst.

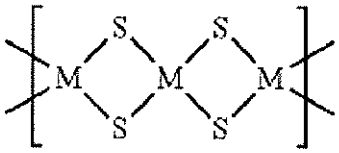
14. The process of claim 1 or any of claims 2-13 wherein the catalyst has an acidity as measured by ammonia chemisorption of at most 200, or at most 100, or at most 50, or at most 25, or at most 10 μmol of ammonia per gram of catalyst.

15. The process of claim 1 or any of claims 2-14 wherein the material of the catalyst comprised of the first metal and the second metal contains less than 0.5 wt.% of non-sulfur-containing ligands.

We claim:

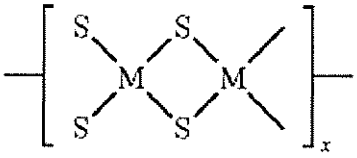
1. A process for hydrocracking a hydrocarbon-containing feedstock, comprising: mixing, at a temperature selected from 375° C. to 500° C. and a total pressure selected from 6.9 MPa to 27.5 MPa, a) a hydrocarbon-containing feedstock containing at least 20 wt. % hydrocarbons having a boiling point of greater than 538° C. as determined in accordance with ASTM Method D5307; b) hydrogen; c) hydrogen sulfide, where the hydrogen sulfide is provided for mixing at a mole ratio of hydrogen sulfide to hydrogen of from 0.5:9.5 to 1:1, where the 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; and d) a catalyst comprising a material comprised of a first metal and a second metal where the first metal is selected from the group consisting of Cu, Fe, Ni, Co, Bi, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, and Sb, where the second metal is selected from the group consisting of Mo, W, V, Sn, and Sb, where the second metal is different from the first metal, 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 (I), formula (VI), formula (VII), and formula (VIII):

(I)



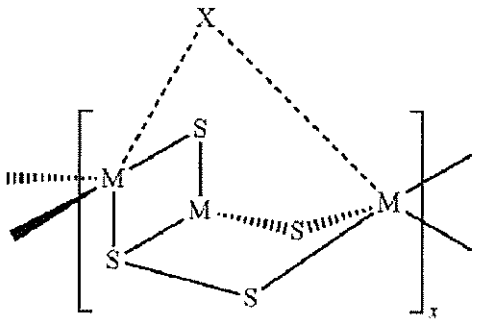
where M is either the first metal or the second metal, and at least one M is the first metal and at least one M is the second metal and at least a portion of the material of the catalyst having a structure of formula (I) has a structure according formula (V):

(V)



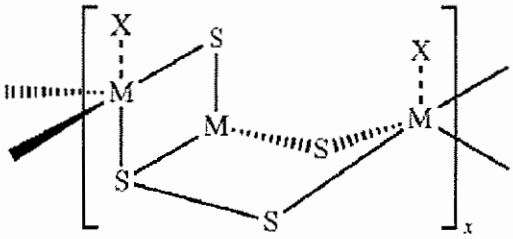
where M is either the first metal or the second metal, at least one M is the first metal, at least one M is the second metal, and x is at least 2;

(VI)



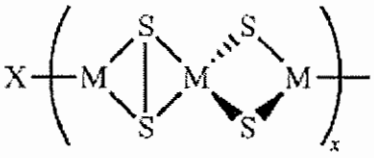
where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3, and x is at least 2;

(VII)



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, and x is at least 2;

(VIII)



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, T, ClO_4, and NO_3, and x is at least 2; where the hydrocarbon-containing feedstock, catalyst, hydrogen sulfide, and hydrogen form a mixture upon mixing; and while mixing the mixture at the selected temperature and selected total pressure, separating a vapor comprising a hydrocarbon-containing product from the mixture, where the hydrocarbon-containing product is comprised of one Or more hydrocarbon compounds that are liquid at STP.

2. The process of claim 1 further comprising the step of, apart from the mixture, condensing at least a portion of the vapor separated from the mixture to produce a liquid hydrocarbon-containing product separate from the mixture.

3. The process of claim 1 wherein at least a portion of the catalyst is in solid particulate form.

4. The process of claim 3 wherein the portion of the catalyst in solid particulate form has a particle size distribution having a median particle size or a mean particle size of from 50 nm up to 5 μm.

5. The process of claim 1 wherein the hydrocarbon-containing product separated from the mixture contains: less than 4 wt. % hydrocarbons having a boiling point of greater than 538° C. as determined in accordance with ASTM Method D5307, less than 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.

6. The process of claim 1 wherein the atomic ratio of the first metal to the second metal in the catalyst is greater than 1:2.

7. The process of claim 1 wherein: a) the hydrocarbon-containing feedstock, the catalyst, the hydrogen sulfide, and the hydrogen are mixed by blending the hydrocarbon-containing feedstock, the catalyst, the hydrogen

sulfide, and the hydrogen in a mixing zone, where the mixing zone is maintained at a temperature of from 375° C. to 500° C. under a total pressure of from 6.9 MPa to 27.5 MPa to produce 1) the vapor comprising the hydrocarbon-containing product and 2) a hydrocarbon-depleted feed residuum comprising hydrocarbons that are liquid at the temperature and pressure within the mixing zone; b) separating at least a portion of the vapor comprising the hydrocarbon-containing product from the mixing zone while blending the hydrocarbon-depleted feed residuum with the catalyst, hydrogen sulfide, and hydrogen in the mixing zone.

8. The process of claim 7 wherein the hydrocarbon-containing feedstock, the hydrocarbon-depleted feed residuum, and the catalyst define a mixture volume, and the hydrocarbon-containing feedstock is provided for mixing at a rate of at least 350 kg/hr per m^3 of the mixture volume.

9. The process of claim 7 wherein the vapor separated from the mixing zone comprises hydrogen sulfide, and further comprising the steps of separating a gas comprising the hydrogen sulfide from the vapor separated from the mixing zone; and providing the gas comprising hydrogen sulfide to the mixing zone.

10. The process of claim 7 wherein the hydrocarbon-depleted feed residuum produced by blending the hydrocarbon-containing feedstock, the catalyst, hydrogen sulfide, and hydrogen in the mixing zone contains less than 0.03 grams of hydrocarbons that are insoluble in toluene as determined in accordance with ASTM Method D4072 per gram of hydrocarbon-containing feedstock provided to the mixing zone,

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

12. The process of claim 1 wherein the hydrogen sulfide is provided for mixing such that the hydrogen sulfide partial pressure is maintained at a level of at least 5% of the hydrogen partial pressure.

13. The process of claim 1 wherein the hydrocarbon-containing feedstock contains at least 30 wt. % of hydrocarbons that are liquid at STP and have a boiling point of less than 538° C.

14. The process of claim 1 wherein the material comprised of the first metal and the second metal comprises at least 50 wt. % of the catalyst.

15. The process of claim 1 wherein the hydrocarbon-containing product separated from the mixture contains at least 40% of the atomic sulfur present in the hydrocarbon-containing feedstock.

16. The process of claim 1 wherein the hydrocarbon-containing product separated from the mixture contains at least 40% of the atomic nitrogen present in the hydrocarbon-containing feedstock.

17. The process of claim 1 wherein the first metal is selected from copper or iron and the second metal is molybdenum.

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

19. The process of claim 1 wherein the catalyst has an acidity as measured by ammonia chemisorption of at most 200 μmol of ammonia per gram of catalyst.

20. The process of claim 1 wherein the material of the catalyst comprised of the first metal and the second metal is a polymer.

21. The process of claim 1 wherein the material of the catalyst comprised of the first metal and the second metal contains less than 0.5 wt. % of non-sulfur-containing ligands.

22. The process of claim 1 wherein the hydrocarbon-containing feedstock is mixed with the hydrogen sulfide, the hydrogen, and the catalyst at a temperature of at least 430° C.

23. The process of claim 2 wherein the catalyst has a BET surface area of from 50 m^2/g to 500 m^2/g.

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

25. The process of claim 1 wherein the vapor separated from mixture 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.