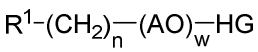
CLAIMS

1. A surfactant defined by Formula I below

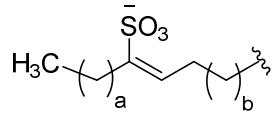


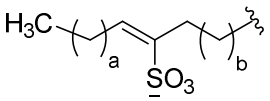
Formula I

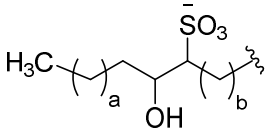
or a salt thereof, wherein

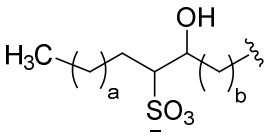
HG represents a head group comprising from 1-3 carboxylate moieties;

R^1 represents a C7-C32 alkyl group substituted with from one to three sulfonate moieties and optionally with from one to three substituents selected from hydroxy and alkoxy, a C7-C32 alkylaryl group substituted with from one to three sulfonate moieties and optionally with from one to three substituents selected from hydroxy and alkoxy, a C7-C32 alkenyl group substituted with from one to three sulfonate moieties and optionally with from one to three substituents selected from hydroxy and alkoxy, or a C7-C32 alkenylaryl group substituted with from one to three sulfonate moieties and optionally with from one to three substituents selected from hydroxy and alkoxy; where R^1 comprises one of the following:









or a salt thereof, wherein

a is an integer from 0 to 32; and

b is an integer from 0 to 32,

with the proviso that the sum of a and b is from 4 to 32;

n is an integer from 1 to 8;

AO represents, individually for each occurrence, an alkyleneoxy group selected from an ethoxy group, a propoxy group, or a butoxy group; and

w is an integer from 1 to 110.

2. The surfactant of claim 1, wherein AO represents, individually for each occurrence, an alkyleneoxy group selected from an ethoxy group or a propoxy group.

3. The surfactant of any of claims 1-2, wherein w is an integer from 20 to 110, such as from 30 to 110, from 40 to 110, from 50 to 110, or from 60 to 110.

4. The surfactant of any of claims 1-3, wherein ε is defined by the formula below

$$\frac{w}{(q+n)} = \varepsilon$$

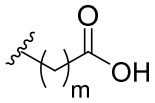
wherein

w and n are as defined above in Formula I; and

q is an integer equal to the number of carbon atoms in R^1; and

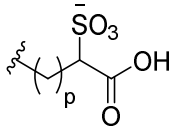
wherein ε is from 0.5 to 6, such as from 1 to 6, from 1.5 to 5, from 2 to 4.5, or from 2 to 4.

5. The surfactant of any of claims 1-4, wherein the head group is defined by the formula below



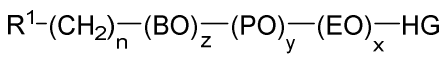
or a salt thereof, where m is an integer from 1 to 6.

6. The surfactant of any of claims 1-4, wherein the head group is defined by the formula below



or a salt thereof, where p is an integer from 1 to 5.

7. The surfactant of any of claims 1-6, wherein the surfactant is defined by Formula IA below



Formula IA

or a salt thereof, wherein

HG represents a head group comprising from 1-3 carboxylate moieties;

n is an integer from 1 to 8;

R^1 represents a C7-C32 alkyl group substituted with from one to three sulfonate moieties and optionally with from one to three substituents selected from hydroxy and alkoxy, a C7-C32 alkylaryl group substituted with from one to three sulfonate moieties and optionally with from one to three substituents selected from hydroxy and alkoxy, a C7-C32 alkenyl group substituted with from one to three sulfonate moieties and optionally with from one to three substituents selected from hydroxy and alkoxy, or a C7-C32 alkenylaryl group substituted with from one to three sulfonate moieties and optionally with from one to three substituents selected from hydroxy and alkoxy;

BO represents a butyleneoxy group;

PO represents a propyleneoxy group;

EO represents an ethyleneoxy group;

x is an integer from 1 to 65;

y is an integer from 0 to 65; and

z is an integer from 0 to 45.

8. The surfactant of claim 7, wherein z is 0.

9. The surfactant of any of claims 7-8, wherein x is from 5 to 50, such as from 10 to 50, from 20 to 45, from 25 to 45, or from 25 to 40.

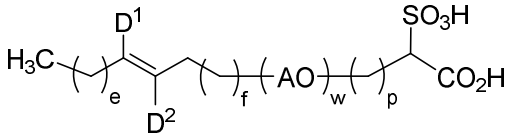
10. The surfactant of any of claims 7-9, wherein y is from 5 to 45, such as from 10 to 40, from 15 to 40, from 15 to 30, or from 15 to 25.

11. The surfactant of any of claims 7-10, wherein the ratio of x:(y+z) is from 0.5:1 to 2:1.

12. The surfactant of any of claims 7-10, wherein y is 0 and z is 0.

13. A surfactant mixture comprising:

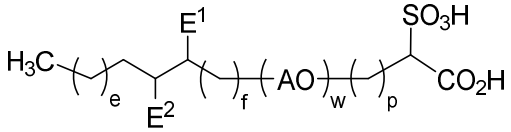
(a) a first surfactant defined by Formula II or a salt thereof;



Formula II

and

(b) a second surfactant defined by Formula III or a salt thereof;



Formula III

wherein

one of D^1 and D^2 is a sulfonate group and one of D^1 and D^2 is hydrogen;

one of E^1 and E^2 is a sulfonate group and one of E^1 and E^2 is hydroxy;

e is an integer from 0 to 32 and f is an integer from 0 to 32, with the proviso that the sum of e and f is from 4 to 32;

AO represents, individually for each occurrence, an alkyleneoxy group selected from an ethoxy group, a propoxy group, or a butoxy group;

w is an integer from 1 to 110; and

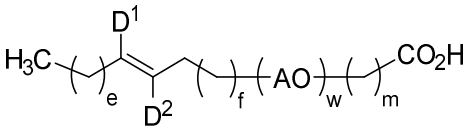
p is an integer from 1 to 5.

14. The mixture of claim 13, wherein the first surfactant is present in an amount of from 1% by weight to 70% by weight, based on the total weight of the surfactant mixture; and

the second surfactant is present in an amount of from 1% by weight to 70% by weight, based on the total weight of the surfactant mixture.

15. The mixture of any of claims 13-14, wherein the surfactant mixture further comprises

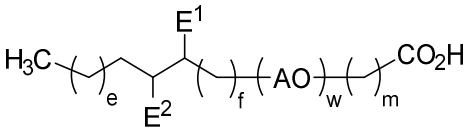
(c) a third surfactant defined by Formula IV or a salt thereof;



Formula IV

and

(d) a fourth surfactant defined by Formula V or a salt thereof;



Formula V

wherein

one of D^1 and D^2 is a sulfonate group and one of D^1 and D^2 is hydrogen;

one of E^1 and E^2 is a sulfonate group and one of E^1 and E^2 is hydroxy;

e is an integer from 0 to 32 and f is an integer from 0 to 32, with the proviso that the sum of e and f is from 4 to 32;

AO represents, individually for each occurrence, an alkyleneoxy group selected from an ethoxy group, a propoxy group, or a butoxy group;

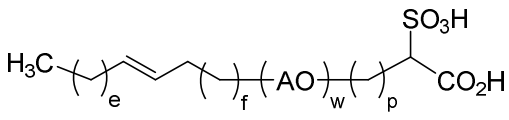
w is an integer from 1 to 110; and

m is an integer from 1 to 6.

16. The mixture of claim 15, wherein the third surfactant is present in an amount of from 1% by weight to 70% by weight, based on the total weight of the surfactant mixture; and

the fourth surfactant is present in an amount of from 1% by weight to 70% by weight, based on the total weight of the surfactant mixture.

17. The mixture of any of claims 13-16, wherein the surfactant mixture further comprises a fifth surfactant defined by Formula VI or a salt thereof



Formula VI

wherein

e is an integer from 0 to 32 and f is an integer from 0 to 32, with the proviso that the sum of e and f is from 4 to 32;

AO represents, individually for each occurrence, an alkyleneoxy group selected from an ethoxy group, a propoxy group, or a butoxy group;

w is an integer from 1 to 110; and

p is an integer from 1 to 5.

18. The mixture of claim 17, wherein the fifth surfactant is present in an amount of from 1% by weight to 70% by weight, based on the total weight of the surfactant mixture.

19. The mixture of any of claims 13-18, wherein AO represents, individually for each occurrence, an alkyleneoxy group selected from an ethoxy group or a propoxy group.

20. The mixture of any of claims 13-19, wherein w is, individually for each occurrence, an integer from 20 to 110, such as from 30 to 110, from 40 to 110, from 50 to 110, or from 60 to 110.

21. The mixture of any of claims 13-20, wherein the sum of e and f is from 8 to 22.

22. An aqueous composition comprising water and a surfactant defined by any of claims 1-12.

23. The composition of claim 19, wherein the composition comprises a surfactant mixture defined by any of claims 13-21.

24. The composition of any of claims 22-23, wherein the composition further comprises one or more co-surfactants, wherein the one or more co-surfactants comprise an anionic surfactant, a non-ionic surfactant, a cationic surfactant, a zwitterionic surfactant, or any combination thereof;

wherein the anionic surfactant comprises a sulfonate, a disulfonate, a sulfate, a disulfate, a sulfosuccinate, a disulfosuccinate, a carboxylate, a dicarboxylate, or any combination thereof,

wherein the anionic surfactant comprises one of the following:

a branched or unbranched C6-C32:PO(0-65):EO(0-100)-carboxylate;

a C8-C30 alkyl benzene sulfonate (ABS);

a sulfosuccinate surfactant;

a surfactant defined by the formula below

$$R^1—R^2—R^3$$

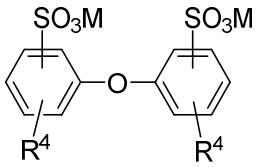
wherein

R^1 comprises a branched or unbranched, saturated or unsaturated, cyclic or non-cyclic, hydrophobic carbon chain having 6-32 carbon atoms and an oxygen atom linking R^1 and R^2;

R^2 comprises an alkoxylated chain comprising at least one oxide group selected from the group consisting of ethylene oxide, propylene oxide, butylene oxide, and any combination thereof; and

R^3 comprises a branched or unbranched hydrocarbon chain comprising 2-12 carbon atoms and from 2 to 5 carboxylate groups;

a surfactant defined by the formula below



wherein

R^4 is, individually for each occurrence, a branched or unbranched, saturated or unsaturated, cyclic or non-cyclic, hydrophobic carbon chain having 6-32 carbon atoms; and

M represents a counterion;

or any combination thereof;

wherein the non-ionic surfactant comprises a branched or unbranched C6-C32:PO(0-65):EO(0-100), such as a branched or unbranched C6-C30:PO(30-40):EO(25-35), a branched or unbranched C6-C12:PO(30-40):EO(25-35), or a branched or unbranched C6-C30:EO(8-30).

25. A method for treating a subterranean formation, the method comprising

introducing an aqueous fluid comprising water and a surfactant defined by any of claims 1-12 through a wellbore into the subterranean formation.

26. The method of claim 25, wherein the composition comprises a surfactant mixture defined by any of claims 13-21.

27. The method of any of claims 25-26, wherein the aqueous fluid comprises a composition defined by any of claims 22-24.

28. The method of any of claims 25-27, wherein the method comprises a method for stimulating the subterranean formation that comprises:

(a) injecting the aqueous fluid through the wellbore into the subterranean formation;

(b) allowing the aqueous fluid to imbibe into a rock matrix of the subterranean formation for a period of time; and

(c) producing fluids from the subterranean formation through the wellbore.

29. The method of any of claims 25-27, wherein the method comprises a method for fracturing the subterranean formation that comprises:

(a) injecting the aqueous fluid into the subterranean formation through the wellbore at a sufficient pressure to create or extend at least one fracture in a rock matrix of the subterranean formation in fluid communication with the wellbore.

30. The method of claim 25-27, wherein the wellbore comprises an injection wellbore, and wherein the method comprises a method for hydrocarbon recovery that comprises:

(a) injecting the aqueous fluid through the injection wellbore into the subterranean formation; and

(b) producing fluids from a production wellbore spaced apart from the injection wellbore a predetermined distance and in fluid communication with the subterranean formation;

wherein injection of the aqueous fluid increases a flow of hydrocarbons to the production wellbore.

31. A method of making a polyanionic surfactant of any one of claims 1-12 or a mixture of any one of claims 13-21, the method comprising:

alkoxylating an unsaturated alcohol having from 8 to 36 carbons to form an alkyleneoxy-tipped unsaturated alcohol;

reacting the alkyleneoxy-tipped unsaturated alcohol to form an unsaturated alkoxylated carboxylate; and

sulfonating the unsaturated alkoxylated carboxylate to form the polyanionic surfactant.

32. The method of claim 31, wherein reacting the alkyleneoxy-tipped unsaturated alcohol comprises oxidizing the alkyleneoxy-tipped unsaturated alcohol to form the unsaturated alkoxylated carboxylate.

33. The method of claim 31, wherein reacting the alkyleneoxy-tipped unsaturated alcohol comprises carboxyalkylation of the alkyleneoxy-tipped unsaturated alcohol to form the unsaturated alkoxylated carboxylate.