$Mo_{12}Bi_aW_bFe_cCo_dNi_eSb_fCs_gMg_hZn_iP_jO_x$

wherein a is 0.1 to 1.5, b is 0 to 4, c is 0.2 to 5.0, d is 0 to 9, e is 0 to 9, f is 0 to 2.0, g is from 0.4 to 1.5, h is 0 to 1.5, I is 0 to 2.0, j is 0 to 0.5 and x is determined by the valences of the other components, c:g=3.3-5.0, c:a=2.0-6.0 and $(3a+3c+2d+2e+g+2h+2i)/(2\times12+2b)$=0.95-1.10.

[0017] The prior art disclosed mixed metal oxide catalysts, which contain molybdenum, bismuth, iron, nickel, cobalt, cesium and other metals for the production of methacrolein. Furthermore, the prior art disclosed certain ranges of amounts of these metals. Some of the prior art disclosed relative ratios of certain components to other components. The effect of the selection of certain components for a mixed metal oxide catalyst compositions for the production of methacrolein and the relative relationship of some of these components to other components has not been investigated in complete detail. However, there is still an need in the art for mixed metal oxidation catalyst compositions, for the production of unsaturated aldehydes, having enhanced relative catalytic activity due to the addition of an amount of molybdenum above an anion to cation molar ratio of 1.0, where the amount is sufficient to ensure that all or substantially all divalent metals are converted to molybdate phases, where the increased molybdate-divalent metal oxide phases correlate with enhanced relative catalytic activity of the catalyst compositions of this invention compared to catalyst compositions not including the additional molybdenum.

SUMMARY ~~OF THE INVENTION~~

[0017a] In one aspect of the present disclosure, there is provided a catalyst for the oxidation of an olefin to an unsaturated aldehyde comprising the mixed metal oxide having the formula (I):

$$Mo_aW_bM_cM'_dM''_eZ_fO_g \quad (I)$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and or mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.0 and 0.4;

c is a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula;

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an M' to M molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[Mo]+2×[W]) to (3×[M] + 2×[M'] + [M'']) or (2×[Mo]+2×[W])/(3×[M] + 2×[M'] + [M'']) or 2(a + b)/(3c + 2d + e).

[0017b] In another aspect of the present disclosure, there is provided a process for the gas phase catalytic oxidation of an olefin to an aldehyde comprising:

contacting an olefin and a molecular oxygen-containing gas to form an unsaturated aldehyde in the presence of a catalyst comprising a mixed metal oxide having the formula (I):

$$Mo_aW_bM_cM'_dM''_eZ_fO_g \quad (I)$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and or mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.0 and 0.4;

c is a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula;

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3**c** + 2**d** + **e**), and

recovering a product stream comprising an aldehyde.

[0017c] In a further aspect of the present disclosure, there is provided a mixed metal oxide having the formula (I):

$$\mathbf{Mo_aW_bM_cM'_dM''_eZ_fO_g} \quad (I)$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and or mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.0 and 0.4;

c is a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula;

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as $(2\times[\mathbf{Mo}]+2\times[\mathbf{W}])$ to $(3\times[\mathbf{M}] + 2\times[\mathbf{M'}] + [\mathbf{M''}])$ or $(2\times[\mathbf{Mo}]+2\times[\mathbf{W}])/(3\times[\mathbf{M}] + 2\times[\mathbf{M'}] + [\mathbf{M''}])$ or $2(\mathbf{a} + \mathbf{b})/(3\mathbf{c} - 2\mathbf{d} + \mathbf{e})$.

[0018] Embodiments of this ~~invention~~ disclosure provide highly active catalysts for the production of unsaturated aldehydes and acids from olefins comprising mixed metal oxides including: (1) molybdenum or molybdenum and tungsten; (2) trivalent metals, **M**, selected from the group consisting of trivalent transition metals, trivalent non-transition metals, and mixtures thereof; (3) divalent metals, **M'**, selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof; and (4) monovalent metals, **M"**, selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof, wherein the mixed metal oxides have an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and an **M'** to **M** molar ratio between 1.95 and 2.15. The ACM ratio is defined as

$$(2\times([\mathbf{Mo}]+[\mathbf{W}]))/(3\times[\mathbf{M}]+2\times[\mathbf{M'}]+[\mathbf{M''}]).$$

[0019] Embodiments of this disclosure ~~invention~~ provide highly active molybdenum mixed metal oxide catalyst compositions including at least one compound of the general formula:

$$\mathbf{Mo_aW_bM_cM'_dM''_eZ_fO_g} \quad \text{(I)}$$

where:

M is a trivalent metal (**M**) selected from the group consisting of trivalent transition metals, trivalent non-transition metals, and mixtures thereof;

M' is a divalent metal (**M'**) selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent (**M''**) metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.0 and 0.4;

c is a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula;

wherein the mixed metal oxide has:

Mo is present in an amount sufficient to produce an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio is between 1.95 and 2.15, and

wherein:

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3**c** + 2**d** + **e**).

[0020] Other embodiments of the catalyst include those of formula (II), formula (III), formula (IV), formula (V), and formula (VI), as further described herein. ~~Other aspects of t~~The ~~invention~~ present disclosure also includes processes for catalytic oxidation of olefins to aldehydes using the catalyst of any of the formulas described, as further described herein. ~~Other aspects of t~~The ~~invention~~ present disclosure further includes the mixed metal oxides of any of formula (I), formula (II), formula (III), formula (IV), formula (V), and formula (VI). In each of the embodiments of catalysts,

[0023] In the catalyst compositions of this disclosure~~invention~~, the molybdenum is present completely or substantially completely as molybdate, MoO_4^{2-}, which along with tungsten, if present, in the form of tungstate, WO_4^{2-}, represent the anions in determining the ACM ratio. The catalyst compositions of this disclosure ~~invention~~ are prepared using a total number of moles of molybdate, $[MoO_4^{2-}]_{total}$. The term substantially means that 90% of the molybdenum is in the form of molybdate, preferably, at least 95%, and especially, at least 99%. During catalyst preparation, a portion of $[MoO_4^{2-}]_{total}$ reacts with all or substantially all of the monovalent metals **M"** and trivalent metals **M** in the catalyst compositions, where substantially has an analogous meaning here. The number of moles of molybdate remaining are referred to as the net number of moles of molybdate, $[MoO_4^{2-}]_{net}$. The net number of moles of molybdate represents the moles of molybdate needed to react with the divalent metals, **M'**. The total number of moles of molybdate also includes an additional number of moles of molybdate referred to as the residual number of moles of molybdate, $[MoO_4^{2-}]_{res}$.

[0024] While not intended to being bound by any particular theory, we believe that the residual number of moles of molybdate ensures that all or substantially all the divalent metals **M'** are converted into **M'**-molybdate mixed metal oxides, resulting in an increased amount of these **M'**-molybdate mixed metal oxides in the catalyst compositions. We further believe that the increase in these **M'**-molybdate mixed metal oxides results in the increased relative catalytic activity of the catalyst compositions of this disclosure~~invention~~. Moreover, the inventors have found that a narrow range of $[MoO_4^{2-}]_{res}$ values increases the relative catalytic activity of the catalyst compositions of this disclosure~~invention~~, while values above and below this range decreases relative catalytic activity. Ideally, the residual number of moles of molybdate ranges from greater than or equal to 0.4 to less than 2.0. The term substantially relating to the conversion of **M'** metals means that at least 51% of the **M'** metals are reacted with molybdate to from **M'**-molybdenum mixed metal oxides, preferably, at least 75%, particularly, at least 85%, more particularly, at least 95%, and especially, at least 99%.

[0025] These compositional characteristics of the catalyst compositions of this disclosure ~~invention~~ may be expressed symbolically as well. Thus, the net number of moles of molybdate may be defined as

$$[MoO_4^{2-}]_{net} = [MoO_4^{2-}]_{total} - ([\mathbf{M}] + [\mathbf{M''}])$$

and the residual number of moles of molybdate may be defined as

$$[MoO_4^{2-}]_{res} = [MoO_4^{2-}]_{net} - [\mathbf{M'}].$$

The catalyst compositions of this disclosure ~~inventions~~ are characterized in that $[MoO_4^{2-}]_{res}$ is greater than or equal to 0.4 and less than 2.0. In other embodiments, $[MoO_4^{2-}]_{res}$ is between 0.5 and 1.5. In other embodiments, $[MoO_4^{2-}]_{res}$ is between 0.75 and 1.25. In other embodiments, $[MoO_4^{2-}]_{res}$ is between 0.8 and 1.0. In other embodiments, $[MoO_4^{2-}]_{res}$ is 0.9. It should be recognized that [Mo] is equal to $[MoO_4^{2-}]$ so that these symbolic representations set forth above may be formulated equally well in terms of [Mo].

[0026] Alternatively, the catalyst compositions of this disclosure ~~invention~~ may be characterized as comprising mixed metal oxides satisfying the following two conditions: (1) an ACM ratio greater than 1.00 and less than 2.00 and (2) an **M'** to **M** molar ratio between 1.95 and 2.15. In other embodiments, catalyst compositions of this disclosure ~~invention~~ may be characterized as comprising mixed metal oxides satisfying the following two conditions: (1) an ACM ratio greater than 1.00 and less than 1.80 and (2) an **M'** to **M** molar ratio between 1.95 and 2.15. In other embodiments, catalyst compositions of this disclosure ~~invention~~ may be characterized as comprising mixed metal oxides satisfying the following two conditions: (1) an ACM ratio greater than 1.00 and less than 1.60 and (2) an **M'** to **M** molar ratio between 1.95 and 2.15. In other embodiments, catalyst compositions of this disclosure ~~invention~~ may be characterized as comprising mixed metal oxides satisfying the following two conditions: (1) an ACM ratio greater than 1.00 and less than 1.40 and (2) an **M'** to **M** molar ratio between 1.95 and 2.15. In other embodiments, catalyst compositions of this disclosure ~~invention~~ may be characterized as comprising mixed metal oxides satisfying the following two conditions: (1) an ACM ratio greater than 1.00 and less than 1.20 and (2) an **M'** to **M** molar ratio between 1.95 and 2.15. In other embodiments, catalyst compositions of this disclosure ~~invention~~ may be characterized as comprising mixed metal oxides satisfying the following two conditions: (1) an ACM ratio greater than or equal to 1.06 and less than 1.20 and (2) an **M'** to **M** molar ratio between 1.95 and 2.15. The ACM ratios and M' and M molar ratios set forth above apply equally well to all mixed metal oxide of formulas (I-VI).

[0027] The fact that catalyst compositions prepared having this additional amount of molybdenum and satisfying these two conditions, correlated with unusually high relative catalytic activities compared to catalyst compositions not including the additional amount of molybdenum and satisfying these two conditions was wholly unexpected. It is known that catalyst compositions having a molar ratio of anions to cations of 1.0 (*i.e.*, an equal molar ratio of metal anions to metal cations = 1.0) have good catalyst performance. Here, we have found that catalyst compositions having an ACM ratio less than 1.0 had diminished relative

catalytic activity and selectivity, and similarly, catalyst compositions having an ACM ratio ≥2.0 also had diminished relative catalytic activity and selectivity. However, when the ACM ratio is greater than or equal to 1.06, but less than 2.0 ($1.06 \leq$ ACM ratio < 2.0), then relative catalytic activity is increased dramatically, by as much as 2 to 2.5 times the relative catalytic activity of catalyst compositions not satisfying these two conditions. While not wanting to be bound to a particular theory, the inventors believe that the net and residual number of moles of molybdate result in the conversion of all or substantially all divalent metals, **M'**, into molybdate-divalent mixed metal oxide phases and an increase in the amount of these mixed metal oxide phases in the final catalyst compositions, which results in the unexpected high relative catalytic activity of the catalyst compositions of this disclosure~~invention~~. We have also found that when the ingredients at the indicated ratios are combined with a binder such as a silica binder, then the relative catalytic activity may be even higher. We have further found that when the ingredients at the indicated ratios are combined with a pore forming agent or agents, catalyst compositions having different pore distributions in the final catalyst compositions may be prepared.

[0028] The processes of using the catalyst compositions of this disclosure ~~invention~~ are generally in a gas phase catalytic oxidation of an olefin to an aldehyde. For example, propylene or isobutylene may be oxidized with a molecular oxygen-containing gas in the presence of a catalyst compositions of the present disclosure ~~invention~~ to form a product stream including an aldehyde and an acid such as the unsaturated aldehydes acrolein or methacrolein and the unsaturated acids acrylic acid or methacrylic acid. In certain embodiments, the use of the catalyst compositions of the present disclosure ~~invention~~ is in a process to increase relative catalytic activity to the production of methacrolein and methacrylic acid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] The invention can be better understood with reference to the following detailed description together with the appended illustrative drawings in which like elements are numbered the same:

[0030] **Figure 1** depicts XDR peak intensities of three catalysts: a $Mo_{12}W_{0.3}$ catalyst, a $Mo_{12}W_{0.0}$ catalyst, and a $Mo_{12.3}W_{0.0}$ catalyst, showing different oxide peak intensities including the intensity of the $NiMoO_4$ (phase1)/$CoMoO_4$ (NiMo1/CoMo) mixed oxide phase peaks.

Claims

1. A catalyst for the oxidation of an olefin to an unsaturated aldehyde comprising a mixed metal oxide having the formula (I):

$$Mo_aW_bM_cM'_dM''_eZ_fO_g \quad (I)$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and/or mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.0 and 0.4;

c is a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula;

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3**c** + 2**d** + **e**).

2. The catalyst of claim 1, wherein the **M'** to **M** molar ratio is between 2.00 and 2.10.

3. The catalyst of claim 2, wherein the **M'** to **M** molar ratio is 2.06.

4. The catalyst of claim 1, wherein the ACM ratio is greater than 1.00 and less than 1.80.

5. The catalyst of claim 4, wherein the ACM ratio is greater than 1.00 and less than 1.60.

6. The catalyst of claim 5, wherein the ACM ratio is greater than 1.00 and less than 1.40.

7. The catalyst of claim 6, wherein the ACM ratio is greater than 1.00 and less than 1.20.

8. The catalyst of claim 7, wherein the ACM ratio is greater than or equal to 1.06 and less than 1.20.

9. The catalyst of claim 1, wherein the mixed metal oxide further has a $[Mo]_{res}$ between 0.4 and less than 2.0.

10. The catalyst of claim 9, wherein $[Mo]_{res}$ is 0.9.

11. The catalyst of claim 1, further comprising from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

12. The catalyst of claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (II):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}M'_dM''_eZ_fO_g} \quad \text{(II)}$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent

transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (II) are in their plus three oxidation states,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1**+**c2** + **c3**) + 2**d** + **e**).

13. The catalyst of claim 12, further comprising from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

14. The catalyst of claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (III):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}M'_{d3}M''_eZ_fO_g} \quad \text{(III)}$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2** and **d3** sum to a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (III) are in their plus three oxidation states and Ni and Co in formula (III) are in their plus two oxidation states,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3**) + **e**).

15. The catalyst of claim 14, further comprising from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

16. The catalyst of claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (IV):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}M'_{d4}M''_eZ_fO_g} \quad \text{(IV)}$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3** and **d4** sum to a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (IV) are in their plus three oxidation states and Ni, Co, and Mg in formula (IV) are in their plus two oxidation states,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as $(2\times[\mathbf{Mo}]+2\times[\mathbf{W}])$ to $(3\times[\mathbf{M}] + 2\times[\mathbf{M'}] + [\mathbf{M''}])$ or $(2\times[\mathbf{Mo}]+2\times[\mathbf{W}])/(3\times[\mathbf{M}] + 2\times[\mathbf{M'}] + [\mathbf{M''}])$ or $2(\mathbf{a} + \mathbf{b})/(3(\mathbf{c1} + \mathbf{c2} + \mathbf{c3}) + 2(\mathbf{d1} + \mathbf{d2} + \mathbf{d3} + \mathbf{d4}) + \mathbf{e})$.

17. The catalyst of claim 16, further comprising from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

18. The catalyst of claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (V):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}Zn_{d4}M'_{d5}Cs_{e1}M''_{e2}Z_fO_g} \quad (V)$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3**, **d4**, and **d5** sum to a number between 5.0 and 8.0;

e1 and e2 sum to a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (V) are in their plus three oxidation states, Ni, Co, Mg and Zn in formula (V) are in their plus two oxidation states and Cs in formula (V) is in its plus one oxidation state,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00, and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3** +**d4** + **d5**) + (**e1** + **e2**)).

19. The catalyst of claim 18, further comprising from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

20. The catalyst of claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (VI):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}Zn_{d4}M'_{d5}Cs_{e1}M''_{e2}Sb_{f1}Z_{f2}O_g} \quad \text{(VI)}$$

where:

M is a trivalent metal selected from the group consisting of bismuth (Bi), trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3**, **d4**, and **d5** sum to a number between 5.0 and 8.0;

e1 and **e2** sum to a number between 0.5 and 1.5;

f1 and **f2** sum to a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (VI) are in their plus three oxidation states, Ni, Co, Mg and Zn in formula (VI) are in their plus two oxidation states and Cs in formula (VI) is in its plus one oxidation state,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3** +**d4** + **d5**) + (**e1** + **e2**)).

21. The catalyst of claim 20, further comprising from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

22. The catalyst of claim 1, wherein the mixed metal oxide further has an enhanced relative XRD peak corresponding to a NiMo (phase 1)/CoMo mixed oxide phase compared to a mixed metal oxide not meeting one or both of the following conditions:

(1) an ACM ratio greater than or equal to 1.06 and less than 1.20 and

(2) an **M'** to **M** molar ratio between 1.95 and 2.15.

23. The catalyst of claim 1, wherein the mixed metal oxide is characterized in that an intensity of a relative XRD peak corresponding to a NiMo (phase 1)/CoMo mixed oxide phase is increased compared to a mixed metal oxide not meeting one or both of the following conditions:

(1) an ACM ratio greater than or equal to 1.06 and less than 1.20 and

(2) an **M'** to **M** molar ratio between 1.95 and 2.15.

24. A process for the gas phase catalytic oxidation of an olefin to an aldehyde comprising:

contacting an olefin and a molecular oxygen-containing gas to form an unsaturated aldehyde in the presence of a catalyst comprising a mixed metal oxide having the formula (I):

$$\mathbf{Mo_aW_bM_cM'_dM''_eZ_fO_g} \quad (I)$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.0 and 0.4;

c is a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5,

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3**c** + 2**d** + **e**), and

recovering a product stream comprising an aldehyde.

25. The process of claim 24, wherein the catalyst further comprises from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

26. The process of claim 24, wherein the catalyst comprises a mixed metal oxide having the formula (II):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}M'_dM''_eZ_fO_g} \quad \text{(II)}$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof,

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof,

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof,

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof,

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5;

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (II) are in their plus three oxidation states,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[W]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[W])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1**+**c2** + **c3**) + 2**d** + **e**).

27. The process of claim 26, wherein the catalyst further comprises from 1 to 20 wt.% of a silica binder and from 0.1 to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

28. The process of claim 24, wherein the catalyst comprises a mixed metal oxide having the formula (III):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}M'_{d3}M''_eZ_fO_g} \quad \text{(III)}$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2** and **d3** sum to a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5;

g is a number that completes the valency of the formula;

wherein Bi and Fe in formula (III) are in their plus three oxidation states, Ni, Co, and Mg in formula (III) are in their plus two oxidation states,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15; and

wherein

the ACM ratio is defined as $(2\times[Mo]+2\times[W])$ to $(3\times[\mathbf{M}] + 2\times[\mathbf{M'}] + [\mathbf{M''}])$ or $(2\times[Mo]+2\times[W])/(3\times[\mathbf{M}] + 2\times[\mathbf{M'}] + [\mathbf{M''}])$ or $2(\mathbf{a}+\mathbf{b})/(3(\mathbf{c1}+\mathbf{c2}+\mathbf{c3})+2(\mathbf{d1}+\mathbf{d2}+\mathbf{d3})+\mathbf{e})$.

29. The process of claim 28, wherein the catalyst further comprises from 1 to 20 wt.% of a silica binder and from 0.1 to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

30. The process of claim 24, wherein the catalyst comprises a mixed metal oxide having the formula (IV):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}M'_{d4}M''_eZ_fO_g} \quad \text{(IV)}$$

where:

M is a trivalent metal selected from the group consisting of bismuth (Bi), trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3**, and **d4** sum to a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (IV) are in their plus three oxidation states, Ni, Co, and Mg in formula (IV) are in their plus two oxidation states,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3** +**d4**) + **e**).

31. The process of claim 30, wherein the catalyst further comprises from 1 to 20 wt.% of a silica binder and from 0.1 to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

32. The process of claim 24, wherein the catalyst comprises a mixed metal oxide having the formula (V):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}Zn_{d4}M'_{d5}Cs_{e1}M''_{e2}Z_fO_g} \quad (V)$$

where:

M is a trivalent metal selected from the group consisting of bismuth (Bi), trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3**, **d4**, and **d5** sum to a number between 5.0 and 8.0;

e1 and e2 sum to a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (V) are in their plus three oxidation states, Ni, Co, Mg and Zn in formula (V) are in their plus two oxidation states and Cs in formula (V) is in its plus one oxidation state,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[Mo]+2×[W]) to (3×[M] + 2×[M'] + [M'']) or (2×[Mo]+2×[W])/(3×[M] + 2×[M'] + [M'']) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3** +**d4** + **d5**) + (**e1** + **e2**)).

33. The process of claim 32, wherein the catalyst further comprises from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

34. The process of claim 24, wherein the catalyst comprises a mixed metal oxide having the formula (VI):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}Zn_{d4}M'_{d5}Cs_{e1}M''_{e2}Sb_{f1}Z_{f2}O_g} \quad \text{(VI)}$$

where:

M is a trivalent metal selected from the group consisting of bismuth (Bi), trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and or mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3**, **d4**, and **d5** sum to a number between 5.0 and 8.0;

e1 and **e2** sum to a number between 0.5 and 1.5;

f1 and **f2** sum to a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula,

wherein Bi and Fe in formula (VI) are in their plus three oxidation states, Ni, Co, Mg and Zn in formula (VI) are in their plus two oxidation states and Cs in formula (VI) is in its plus one oxidation

state,

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3** +**d4** + **d5**) + (**e1** + **e2**)).

35. The process of claim 34, wherein the catalyst further comprises from 1 wt.% to 20 wt.% of a silica binder and from 0.1 wt.% to 5 wt.% of a pore former, where the wt.% is based on the total weight of the catalyst.

36. The process of claim 24, wherein the mixed metal oxide further has an enhanced relative XRD peak corresponding to a NiMo (phase 1)/CoMo mixed oxide phase compared to a mixed metal oxide not meeting one or both of the following conditions:

(1) an ACM ratio greater than or equal to 1.06 and less than 1.20 and

(2) an **M'** to **M** molar ratio between 1.95 and 2.15.

37. The process of claim 24, wherein the mixed metal oxide is characterized in that an intensity of a relative XRD peak corresponding to a NiMo (phase 1)/CoMo mixed oxide phase is increased compared to a mixed metal oxide not meeting one or both of the following conditions:

(1) an ACM ratio greater than or equal to 1.06 and less than 1.20 and

(2) an **M'** to **M** molar ratio between 1.95 and 2.15.

38. A mixed metal oxide having the formula (I):

$$\mathbf{Mo_aW_bM_cM'_dM''_eZ_fO_g} \quad (I)$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent

transition metals, divalent non-transition metals, and or mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.0 and 0.4;

c is a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula;

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3**c** + 2**d** + **e**).

CLAIMS

1. A mixed metal oxide having the formula (I):

$$\mathbf{Mo_aW_bM_cM'_dM''_eZ_fO_g} \quad (I)$$

where:

M is a trivalent metal selected from the group consisting of trivalent transition metals, trivalent non-transition metals and mixtures thereof;

M' is a divalent metal selected from the group consisting of alkaline earth metals, divalent transition metals, divalent non-transition metals, and or mixtures thereof;

M'' is a monovalent metal selected from the group consisting of alkali metals, monovalent transition metals, and mixtures thereof;

Z is an element in the form of an oxide when added to a pre-catalyst preparation and is selected from the group consisting of cerium, antimony, phosphorus, boron, sulfur, silicon, aluminum, titanium, tellurium, vanadium, zirconium, niobium, and mixtures thereof;

a is a number between 12.3 and 14.0;

b is a number between 0.0 and 0.4;

c is a number between 2.0 and 4.0;

d is a number between 5.0 and 8.0;

e is a number between 0.5 and 1.5;

f is a number between 0.5 and 1.5; and

g is a number that completes the valency of the formula;

wherein the mixed metal oxide has:

an anion to cation molar (ACM) ratio greater than 1.00 and less than 2.00; and

an **M'** to **M** molar ratio is between 1.95 and 2.15, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3**c** + 2**d** + **e**).

2. The catalyst of Claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (II):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}M'_dM''_eZ_fO_g} \quad \text{(II)}$$

where:

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

wherein Bi and Fe in formula (II) are in their plus three oxidation states, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1**+**c2** + **c3**) + 2**d** + **e**).

3. The catalyst of Claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (III):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}M'_{d3}M''_eZ_fO_g} \quad \text{(III)}$$

where:

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2** and **d3** sum to a number between 5.0 and 8.0;

wherein Bi and Fe in formula (III) are in their plus three oxidation states and Ni and Co in formula (III) are in their plus two oxidation states, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3**) + **e**).

4. The catalyst of Claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (IV):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}M'_{d4}M''_eZ_fO_g} \quad \text{(IV)}$$

where:

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3** and **d4** sum to a number between 5.0 and 8.0;

wherein Bi and Fe in formula (IV) are in their plus three oxidation states and Ni, Co, and Mg in formula (IV) are in their plus two oxidation states, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3** +**d4**) + **e**).

5. The catalyst of Claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (V):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}Zn_{d4}M'_{d5}Cs_{e1}M''_{e2}Z_fO_g} \quad \text{(V)}$$

where:

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3**, **d4**, and **d5** sum to a number between 5.0 and 8.0;

e1 and e2 sum to a number between 0.5 and 1.5;

wherein Bi and Fe in formula (V) are in their plus three oxidation states, Ni, Co, Mg and Zn in formula (V) are in their plus two oxidation states and Cs in formula (V) is in its plus one oxidation state,

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3** +**d4** + **d5**) + (**e1** + **e2**)).

6. The catalyst of Claim 1, wherein the catalyst comprises a mixed metal oxide having the formula (VI):

$$\mathbf{Mo_aW_bBi_{c1}Fe_{c2}M_{c3}Ni_{d1}Co_{d2}Mg_{d3}Zn_{d4}M'_{d5}Cs_{e1}M''_{e2}Sb_{f1}Z_{f2}O_g} \quad \text{(VI)}$$

where:

b is a number between 0.2 and 0.4;

c1, **c2** and **c3** sum to a number between 2.0 and 4.0;

d1, **d2**, **d3**, **d4**, and **d5** sum to a number between 5.0 and 8.0;

e1 and **e2** sum to a number between 0.5 and 1.5;

f1 and **f2** sum to a number between 0.5 and 1.5; and

wherein Bi and Fe in formula (VI) are in their plus three oxidation states, Ni, Co, Mg, and Zn in formula (VI) are in their plus two oxidation states and Cs in formula (VI) is in its plus one oxidation state, and

wherein

the ACM ratio is defined as (2×[**Mo**]+2×[**W**]) to (3×[**M**] + 2×[**M'**] + [**M''**]) or (2×[**Mo**]+2×[**W**])/(3×[**M**] + 2×[**M'**] + [**M''**]) or 2(**a** + **b**)/(3(**c1** + **c2** + **c3**) + 2(**d1** + **d2** + **d3** +**d4** + **d5**) + (**e1** + **e2**)).

7. The catalyst of any of Claims 1 – 6, wherein the **M'** to **M** molar ratio is between 2.00 and 2.10.

8. The catalyst of any of Claims 1 – 7, wherein the **M'** to **M** molar ratio is 2.06.

9. The catalyst of any of Claims 1 – 8, wherein the ACM ratio is greater than 1.00 and less than 1.80.

10. The catalyst of any of Claims 1 – 9, wherein the ACM ratio is greater than 1.00 and less than 1.60.

11. The catalyst of any of Claims 1 – 10, wherein the ACM ratio is greater than 1.00 and less than 1.40.

12. The catalyst of any of Claims 1 – 11, wherein the ACM ratio is greater than 1.00 and less than 1.20.

13. The catalyst of any of Claims 1 – 12, wherein the ACM ratio is greater than or equal to 1.06 and less than 1.20.

14. The catalyst of any of Claims 1 – 13, wherein the mixed metal oxide further has a $[Mo]_{res}$ between 0.4 and less than 2.0.

15. The catalyst of any of Claims 1 – 14, wherein $[Mo]_{res}$ is 0.9.

16. The catalyst of any of Claims 1 – 15, further comprising 1 wt% to 20 wt% of a silica binder and 0.1 wt% to 5 wt% of a pore former, where the wt% is based on the total weight of the catalyst.

17. The catalyst of any of Claims 1 – 16, wherein the mixed metal oxide further has an enhanced relative XRD peak corresponding to a NiMo (phase 1)/CoMo mixed oxide phase compared to a mixed metal oxide not meeting one or both of the following conditions:

(1) an ACM ratio greater than or equal to 1.06 and less than 1.20 and

(2) an **M'** to **M** molar ratio between 1.95 and 2.15.

18. The catalyst of any of Claims 1 – 17, wherein the mixed metal oxide is characterized in that an intensity of a relative XRD peak corresponding to a NiMo (phase 1)/CoMo mixed oxide phase is increased compared to a mixed metal oxide not meeting one or both of the following conditions:

(1) an ACM ratio greater than or equal to 1.06 and less than 1.20 and

(2) an **M'** to **M** molar ratio between 1.95 and 2.15.

19. A catalyst for the oxidation of an olefin to an unsaturated aldehyde comprising the mixed metal oxide of any of Claims 1 – 18.

20. A process for the gas phase catalytic oxidation of an olefin to an aldehyde comprising:

contacting an olefin and a molecular oxygen-containing gas to form an unsaturated aldehyde in the presence of a catalyst comprising the mixed metal oxide of any of Claims 1 – 18; and

recovering a product stream comprising an aldehyde.