CLAIMS

1. A bi-modal radial flow reactor comprising:

a cylindrical outer housing surrounding at least five cylindrical, concentric zones, including at least three annulus vapor zones and at least two catalyst zones, wherein the at least two catalyst zones comprise an outer catalyst zone and an inner catalyst zone, and wherein the at least three annulus vapor zones comprise an outer annulus vapor zone, a middle annulus vapor zone, and a central annulus vapor zone, wherein the central annulus vapor zone extends along a centerline of the bi-modal radial flow reactor, and wherein the outer catalyst zone is intercalated with the outer annulus vapor zone and the middle annulus vapor zone, and wherein the inner catalyst zone is intercalated with the middle annulus vapor zone and the central annulus vapor zone;

a manifold comprising piping configured to introduce a feed vertically into a bottom end of each of one or two of the at least three annulus vapor zones, and piping configured to remove a product from an end of each of the one or two remaining of the at least three annulus vapor zones,

wherein each of the at least five cylindrical, concentric zones has a top end and a bottom end; and

(a) wherein each of the at least three annulus vapor zones has an opening at the bottom end thereof, operable as an inlet or an outlet of the bi-modal radial flow reactor; or (b) wherein (i) the middle annulus vapor zone has an opening at the bottom end thereof, operable as a process inlet or process outlet of the bi-modal radial flow reactor, and (ii) the central annulus vapor zone and the outer annulus vapor zone each have an opening at the top end thereof, operable as a process inlet or process outlet of the bi-modal radial flow reactor.

2. The bi-modal radial flow reactor of claim 1, wherein the one or two or the annulus vapor zones comprises the central annulus vapor zone, and wherein the central annulus vapor zone is fluidly connected with piping configured to introduce the feed vertically into a bottom end of the central annulus vapor zone; or wherein the one or two remaining of the at least three annulus vapor zones comprises the central annulus vapor zone, and wherein the central annulus vapor zone is fluidly connected with piping configured to remove the product from an end of the central annulus vapor zone.

3. The bi-modal radial flow reactor of claim 1, wherein the bi-modal radial flow reactor is a fixed bed bi-modal radial flow reactor, wherein the inner catalyst zone and the outer catalyst zone are configured as fixed beds.

4. The bi-modal radial flow reactor of claim 3, wherein the fixed beds are provided by fixed catalyst baskets.

5. The bi-modal radial flow reactor of claim 1, wherein the bi-modal radial flow reactor is a removable catalyst basket bi-modal radial flow reactor, wherein the inner catalyst zone and the outer catalyst zone are configured as removable catalyst baskets, with the inner catalyst zone provided by an inner removable catalyst basket and the outer catalyst zone provided by an outer removable catalyst basket.

6. The bi-modal radial flow reactor of claim 5, wherein the removable catalyst baskets are extractable via a top end of the cylindrical outer housing.

7. The bi-modal radial flow reactor of claim 1, wherein at least one of the at least two catalyst zones contains a reforming catalyst capable of catalyzing the conversion of at least a portion of convertible hydrocarbons in the feed into aromatic hydrocarbons that are present in the product.

8. The bi-modal radial flow reactor of claim 7, wherein the inner catalyst zone comprises a catalyst that is different from a catalyst in the outer catalyst zone in at least one parameter selected from the group consisting of size, shape, composition, and loading.

9. A bi-modal radial flow guard bed reactor comprising:

a cylindrical outer housing surrounding at least five cylindrical, concentric zones, including at least two annulus vapor zones, at least two catalyst zones, and a bed separation zone, wherein the at least two catalyst zones comprise an outer catalyst zone and an inner catalyst zone, wherein the at least two annulus vapor zones comprise an outer annulus vapor zone, and a central annulus vapor zone, wherein the central annulus vapor zone extends along a centerline of the bi-modal radial flow guard bed reactor, and wherein the outer catalyst zone is intercalated with the outer annulus vapor zone and the bed separation zone, and wherein the inner catalyst zone is intercalated with the bed separation zone and the central annulus vapor zone;

a manifold comprising piping configured to introduce a feed vertically into a bottom end of the outer annulus vapor zone, and piping configured to remove a product from an end of the central annulus vapor zone,

wherein each of the at least five cylindrical, concentric zones has a top end and a bottom end; and

wherein the outer annulus vapor zone has an opening at the bottom end thereof, operable as a process inlet or process outlet of the bi-modal radial flow guard bed reactor, and the central annulus vapor zone has an opening at the bottom end thereof, operable as a process inlet or process outlet of the bi-modal radial flow guard bed reactor.

10. The bi-modal radial flow guard bed reactor of claim 9, wherein the inner catalyst zone and the outer catalyst zone are configured as removable catalyst baskets, with the inner catalyst zone provided by an inner removable catalyst basket and the outer catalyst zone provided by an outer removable catalyst basket.

11. The bi-modal radial flow guard bed reactor of claim 9, wherein at least one of the at least two catalyst zones contains a catalyst capable of catalyzing the conversion of at least a portion of convertible hydrocarbons in the feed into aromatic hydrocarbons that are present in the product.

12. A bi-modal radial flow reactor comprising:

a cylindrical outer housing surrounding five cylindrical, concentric zones, including three annulus vapor zones and two catalyst zones, wherein the two catalyst zones comprise an outer catalyst zone and an inner catalyst zone, wherein the inner catalyst zone and the outer catalyst zone are configured as removable catalyst baskets, and wherein the three annulus vapor zones comprise an outer annulus vapor zone, a middle annulus vapor zone, and a central annulus vapor zone, wherein the central annulus vapor zone extends along a centerline of the bi-modal radial flow reactor, and wherein the outer catalyst zone is intercalated with the outer annulus vapor zone and the middle annulus vapor zone, and wherein the inner catalyst zone is intercalated with the middle annulus vapor zone and the central annulus vapor zone;

a manifold comprising piping configured to introduce a feed vertically into a bottom end of each of one or two of the three annulus vapor zones, and piping configured to remove a product from an end of each of the one or two remaining of the three annulus vapor zones; and optionally: wherein the one or two or the annulus vapor zones comprises the central annulus vapor zone, and wherein the central annulus vapor zone is fluidly connected with piping configured to introduce the feed vertically into a bottom end of the central annulus vapor zone; or wherein the one or two remaining of the at least three annulus vapor zones comprises the central annulus vapor zone, and wherein the central annulus vapor zone is fluidly connected with piping configured to remove the product from an end of the central annulus vapor zone,

wherein each of the at least five cylindrical, concentric zones has a top end and a bottom end; and (a) wherein each of the at least three annulus vapor zones has an opening at the bottom end thereof, operable as an inlet or an outlet of the bi-modal radial flow reactor; or (b) wherein (i) the middle annulus vapor zone has an opening at the bottom end thereof, operable as a process inlet or process outlet of the bi-modal radial flow reactor, and (ii) the central

annulus vapor zone and the outer annulus vapor zone each have an opening at the top end thereof, operable as a process inlet or process outlet of the bi-modal radial flow reactor.

13. The bi-modal radial flow reactor of claim 12, wherein at least one of the two catalyst zones contains a reforming catalyst capable of catalyzing the conversion of at least a portion of convertible hydrocarbons in the feed into aromatic hydrocarbons that are present in the product.

14. A reactor system comprising a bi-modal radial flow guard bed reactor, at least one removable catalyst basket bi-modal radial flow reactor, and at least one fixed bed bi-modal radial flow reactor, wherein the bi-modal radial flow guard bed reactor is upstream of the at least one removable catalyst basket bi-modal radial flow reactor, and wherein the at least one removable catalyst basket bi-modal radial flow reactor is upstream of the at least one fixed bed bi-modal flow radial reactor,

wherein the at least one removable catalyst basket bi-modal radial flow reactor and the at least one fixed bed bi-modal flow radial flow reactor each comprise:

a cylindrical outer housing surrounding at least five cylindrical, concentric zones, including at least three annulus vapor zones and at least two catalyst zones, wherein the at least two catalyst zones comprise an outer catalyst zone and an inner catalyst zone, and wherein the at least three annulus vapor zones comprise an outer annulus vapor zone, a middle annulus vapor zone, and a central annulus vapor zone, wherein the central annulus vapor zone extends along a centerline of the bi-modal radial flow reactor, and wherein the outer catalyst zone is intercalated with the outer annulus vapor zone and the middle annulus vapor zone, and wherein the inner catalyst zone is intercalated with the middle annulus vapor zone and the central annulus vapor zone; and

wherein the inner catalyst zone and the outer catalyst zone of the fixed bed bi-modal radial flow reactor are configured as fixed beds; and wherein the inner catalyst zone and the outer catalyst zone of the at least one removable catalyst basket bi-modal radial flow reactor are configured as removable catalyst baskets, with the inner catalyst zone provided by an inner removable catalyst basket and the outer catalyst zone provided by an outer removable catalyst basket, and

wherein the bi-modal radial flow guard bed reactor comprises:

a cylindrical outer housing surrounding at least five cylindrical, concentric zones, including at least two annulus vapor zones, at least two catalyst zones, and a bed separation zone, wherein the at least two catalyst zones comprise an outer catalyst zone and an inner catalyst zone, wherein the at least two annulus vapor zones comprise an outer annulus vapor zone, and a central annulus vapor zone, wherein the central annulus vapor zone extends along a centerline of the bi-modal radial flow guard bed reactor, and wherein the outer catalyst zone is intercalated with the outer annulus vapor zone and the bed separation zone, and wherein the inner catalyst zone is intercalated with the bed separation zone and the central annulus vapor zone,

wherein each of the at least five cylindrical, concentric zones has a top end and a bottom end; and

wherein the outer annulus vapor zone has an opening at the bottom end thereof, operable as a process inlet or process outlet of the bi-modal radial flow guard bed reactor, and the central annulus vapor zone has an opening at the bottom end thereof, operable as a process inlet or process outlet of the bi-modal radial flow guard bed reactor.

15. The reactor system of claim 14:

wherein the at least one removable catalyst basket bi-modal radial flow reactor and the at least one fixed bed bi-modal radial flow reactor each further comprise: piping configured to introduce a feed vertically into a bottom end of each of one or two of the at least three annulus vapor zones, and piping configured to remove a product from an end of each of the one or two remaining of the at least three annulus vapor zones; and

wherein the bi-modal radial flow guard bed reactor further comprises: piping configured to introduce a feed vertically into a bottom end of the outer annulus vapor zone, and piping configured to remove a product from an end of the central annulus vapor zone.

16. The reactor system of claim 15, wherein the one or two or the annulus vapor zones comprises the central annulus vapor zone, and wherein the central annulus vapor zone is fluidly connected with piping configured to introduce the feed vertically into a bottom end of the central annulus vapor zone; or wherein the one or two remaining of the at least three annulus vapor zones comprises the central annulus vapor zone, and wherein the central annulus vapor zone is fluidly connected with piping configured to remove the product from an end of the central annulus vapor zone.

17. The reactor system of claim 15, wherein the volume of each of the at least one removable catalyst basket bi-modal radial flow reactor is less than the volume of each of the at least one fixed bed bi-modal radial flow reactors.

18. A bi-modal radial flow reactor comprising:

a cylindrical outer housing surrounding at least five cylindrical, concentric zones, including at least three annulus vapor zones and at least two catalyst zones, wherein the at least two catalyst zones comprise an outer catalyst zone and an inner catalyst zone, and

wherein the at least three annulus vapor zones comprise an outer annulus vapor zone, a middle annulus vapor zone, and a central annulus vapor zone, wherein the central annulus vapor zone extends along a centerline of the bi-modal radial flow reactor, and wherein the outer catalyst zone is intercalated with the outer annulus vapor zone and the middle annulus vapor zone, and wherein the inner catalyst zone is intercalated with the middle annulus vapor zone and the central annulus vapor zone, wherein each of the at least five cylindrical, concentric zones has a top end and a bottom end; and

(a) wherein each of the at least three annulus vapor zones has an opening at the bottom end thereof, operable as an inlet or an outlet of the bi-modal radial flow reactor; or (b) wherein (i) the middle annulus vapor zone has an opening at the bottom end thereof, operable as a process inlet or process outlet of the bi-modal radial flow reactor, and (ii) the central annulus vapor zone and the outer annulus vapor zone each have an opening at the top end thereof, operable as a process inlet or process outlet of the bi-modal radial flow reactor;

a removable head cover fixably coupled to a top of the cylindrical outer housing to seal a top of the bi-modal radial flow reactor; and

a cover plate that covers a top end of the central annulus vapor zone, a top end of the middle annulus vapor zone, or both,

wherein the removable head cover further comprises a pressure plate that serves as the cover plate, and allows for catalyst expansion in the outer catalyst zone, the inner catalyst zone, or both the outer catalyst zone and the inner catalyst zone.

19. The bi-modal radial flow reactor of claim 18, wherein the inner catalyst zone and the outer catalyst zone are configured as catalyst baskets, and wherein the pressure plate allows for catalyst expansion in the catalyst baskets.

20. A bi-modal radial flow reactor comprising:

a cylindrical outer housing surrounding at least five cylindrical, concentric zones, including at least three annulus vapor zones and at least two catalyst zones, wherein the at least two catalyst zones comprise an outer catalyst zone and an inner catalyst zone, and wherein the at least three annulus vapor zones comprise an outer annulus vapor zone, a middle annulus vapor zone, and a central annulus vapor zone, wherein the central annulus vapor zone extends along a centerline of the bi-modal radial flow reactor, and wherein the outer catalyst zone is intercalated with the outer annulus vapor zone and the middle annulus vapor zone, and wherein the inner catalyst zone is intercalated with the middle annulus vapor zone and the central annulus vapor zone, wherein each of the at least five cylindrical, concentric zones has a top end and a bottom end; and

(a) wherein each of the at least three annulus vapor zones has an opening at the bottom end thereof, operable as an inlet or an outlet of the bi-modal radial flow reactor; or (b) wherein (i) the middle annulus vapor zone has an opening at the bottom end thereof, operable as a process inlet or process outlet of the bi-modal radial flow reactor, and (ii) the central annulus vapor zone and the outer annulus vapor zone each have an opening at the top end thereof, operable as a process inlet or process outlet of the bi-modal radial flow reactor; and

a removable head cover fixably coupled to a top of the cylindrical outer housing to seal a top of the bi-modal radial flow reactor, wherein the removable head cover further comprises a pressure cover plate that aligns with a top of the central annulus vapor zone when the bi-modal radial flow reactor is closed, a pressure cover plate that aligns with a top of the middle annulus vapor zone when the bi-modal radial flow reactor is closed, or a pressure cover plate that aligns with the top of the central annulus vapor zone and the top of the middle annulus vapor zone when the bi-modal radial flow reactor is closed.

21. The bi-modal radial flow reactor of claim 20, wherein the bi-modal radial flow reactor is a fixed bed bi-modal radial flow reactor, wherein the inner catalyst zone and the outer catalyst zone are configured as fixed beds.

22. The bi-modal radial flow reactor of claim 21, wherein the fixed beds are provided by fixed catalyst baskets.

23. The bi-modal radial flow reactor of claim 22, wherein the fixed catalyst baskets are delineated by one or more material selected from the group consisting of V wires and mesh screens.

24. The bi-modal radial flow reactor of claim 20 further comprising at least one port fluidly connected with a bottom end of at least one of the at least two catalyst zones, whereby catalyst can be removed therefrom.

25. The bi-modal radial flow reactor of claim 20, wherein the bi-modal radial flow reactor is a removable basket bi-modal radial flow reactor, wherein the inner catalyst zone and the outer catalyst zone are configured as removable baskets, with the inner catalyst zone provided by an inner catalyst basket and the outer catalyst zone provided by an outer catalyst basket.

26. The bi-modal radial flow reactor of claim 25, wherein the removable baskets provide a reduction of at least 10% in a turnaround time for catalyst change-out relative to a comparably sized, conventional radial flow reactor with a fixed catalyst bed.

27. The bi-modal radial flow reactor of claim 25, wherein the removable baskets are extractable via a top end of the cylindrical outer housing.

28. The bi-modal radial flow reactor of claim 20, wherein the outer catalyst zone, the inner catalyst zone, or both the outer catalyst zone and the inner catalyst zone have a diameter in the range of from 0.5 foot (0.15 m) to 2 feet (0.61 m), a height of from 5 feet (1.52 m) to 50 feet (15.24 m), or both.

29. The bi-modal radial flow reactor of claim 20 further comprising a manifold configured to introduce a feed vertically into a bottom end of each of one or two of the at least three void vapor zones, and extract a product from a bottom end of each of the one or two remaining of the at least three void vapor zones.

30. The bi-modal radial flow reactor of claim 29, wherein the manifold is operable to reverse the flow such that the feed can be introduced into the remaining one or two of the at least three void vapor zones, and the product can be extracted from the one or two of the at least three void vapor zones.

31. The bi-modal radial flow reactor of claim 20, wherein at least one of the at least two catalyst zones contains a catalyst.

32. The bi-modal radial flow reactor of claim 31, wherein the catalyst is capable of catalyzing an endothermic reaction.

33. The bi-modal radial flow reactor of claim 32, wherein the catalyst is a reforming catalyst capable of catalyzing the conversion of at least a portion of convertible hydrocarbons in the feed into aromatic hydrocarbons that are extracted with the product.

34. The bi-modal radial flow reactor of claim 33, wherein the bi-modal radial flow reactor provides a longer run time prior to catalyst change-out relative to a conventional, uni-modal radial flow reforming reactor operated to provide equivalent selectivity, and/or wherein the bi-modal radial flow reactor is operable at a lower end of run inlet temperature relative to a conventional, uni-modal radial flow reforming reactor operated to provide equivalent selectivity.

35. The bi-modal radial flow reactor of claim 31, wherein the inner catalyst zone comprises a catalyst that is different from a catalyst in the outer catalyst zone in at least one parameter selected from the group consisting of size, shape, composition, and loading.

36. The bi-modal radial flow reactor of claim 33, wherein the reforming catalyst comprises at least one Group VIII metal and a zeolitic support.

37. The bi-modal radial flow reactor of claim 20, wherein the outer catalyst zone comprises an iron trap media.