radicals or dienes to initiate long-chain branching, the branching may become too numerous, thereby causing gelling and reactor fouling. The reincorporation mechanism does not produce much branching, and branching can only occur after the polymer strand is produced, thereby further limiting the amount of branching that can occur.

[0006] An increased amount of long-chain branching (LCB) provides an increase in melt processing properties. Long-chain branched material (e.g., low density polyethylene, LDPE) is added to LLDPE as a processing aid. In general, LDPE has good processing properties but films made from it have poor physical properties such as tear or dart strength. Films made from linear low density polyethylene (LLDPE) have good physical properties such as tear or dart strength but cannot be effectively processed. Blending of some amount of LDPE is required for processing (melt strength, shear thinning) but these reduce the physical properties of LLDPE films. When blending LLDPE and LDPE, researchers are balancing processability and physical properties, while never achieving ideal values for both.

SUMMARY

[0007] Ongoing needs exist to produce a polymer composition having a high melt strength and normal to low viscosity as indicated by the melt index, which provides better processability yet allow the polymers to be formed without fouling in a reactor. Thus, the process and ethylene-based polymers of this disclosure seek to form long-chain branching without causing the ethylene-based polymer to gel or foul reactors.

[0008] This disclosure is directed to ethylene-based polymers. The ethylene-based polymers include a low molecular weight polymer fraction and a high molecular weight polymer fraction. The low molecular weight fraction and the high molecular weight fraction are divided by S_{max} on a molecular weight distribution (MWD) curve determined via absolute gel permeation chromatography. S_{max} is the maximum absolute slope on the higher molecular weight side of the primary peak of the MWD curve, in which the primary peak is the peak of greatest magnitude in the MWD curve.

[0009] The low molecular weight polymer fraction and the high molecular weight polymer fraction of the ethylene-based polymer each includes a Ladder character, L, defined for a given absolute molecular weight (MW) as the fit of the log of the intrinsic viscosity [η] versus the log of the absolute MW (M) curve using the expression, $\log[\eta] = \log(\beta) + \alpha\log(M) - L*\alpha\log(2)$

according to a Mark-Houwink-Sakurada curve, in which log(β) is the intercept and α is the slope. The low molecular weight polymer fraction has an MW below S_{max} and all values of L between −0.35 to 0.35; and the high molecular weight polymer fraction has an MW above S_{max} and a maximum value of L between 0.8 and 1.5.

[0009a] In one aspect, there is provided an ethylene-based polymer comprising: a low molecular weight polymer fraction and a high molecular weight polymer, both derived from polymerized units of ethylene, one or more dienes, and optionally, one or more C_3−C_{12} α-olefins; the low molecular weight fraction and the high molecular weight fraction are divided by S_{max} on a molecular weight distribution (MWD) curve determined via absolute gel permeation chromatography, wherein S_{max} is the maximum absolute slope on the higher molecular weight side of the primary peak of the MWD curve, wherein the primary peak is the peak of greatest magnitude in the MWD curve; wherein the low molecular weight polymer fraction and the high molecular weight polymer fraction each comprise a Ladder character, L, defined for a given absolute molecular weight (MW) as the fit of the log of the intrinsic viscosity [η] versus the log of the absolute MW (M) curve using the expression, $\log[\eta] = \log(\beta) + \alpha\log(M) - L^*\alpha\log(2)$ according to a Mark-Houwink-Sakurada curve, wherein log(β) is the intercept and α is the slope, and wherein the low molecular weight polymer fraction has an MW below S_{max} and all values of L between −0.35 to 0.35; and the high molecular weight polymer fraction has an MW above S_{max} and a maximum value of L between 0.8 and 1.5; wherein the diene is unconjugated, and wherein the diene is acyclic.

BRIEF DESCRIPTION OF FIGURES

[0010] FIG. 1 is a graphical depiction of the molecular weight of a polymer as the number of branching methines per 1000 carbons increase.

[0011] FIG. 2 is a graphical model predicted dependence of the molecular weight distribution (MWD) curve on branching level.

[0012] FIG. 3 is a molecular weight distribution (MWD) curve of a two-catalyst bimodal ethylene-based polymer distribution with and without diene.

[0013] FIG. 4 is a Mark-Houwink-Sakurada plot for a conventionally long-chain branching (LCB) polymer and an LDPE, specifically DOW™ LDPE 662I.

[0014] FIG. 5 is an illustration of an ethylene-based ladder polymer, in which the polymer backbone is depicted as solid lines, and the long chain branches are depicted by dotted lines. This illustration provides a visual depiction of the difference in molecular weights calculated by conventional standard verses absolute weight average molecular weight (MW) for the long-chain branched polymers of this disclosure.

[0015] FIG. 6 is a Mark-Houwink-Sakurada plot, which shows the definition of parameters and variables that characterize the long-chain branched polymers of this disclosure in the Mark-Houwink-Sakurada plot.

[0016] FIG. 7 are Mark-Houwink-Sakurada plots of a series of bimodal ethylene-based polymers where the low MW fraction is produced by a single-chain catalyst and the high MW fraction is produced by the dual-chain catalyst.

[0017] FIG. 8 is a graph showing plots of intrinsic viscosity and the slope of intrinsic viscosity as a function of absolute MW for example 1-11.

[0018] FIG. 9 shows the Ladder character, L, as a function of absolute Mw for example 1-11.

CLAIMS

1. An ethylene-based polymer comprising:

a low molecular weight polymer fraction and a high molecular weight polymer, both derived from polymerized units of ethylene, one or more dienes, and optionally, one or more C_3−C_{12} α-olefins;

the low molecular weight fraction and the high molecular weight fraction are divided by S_{max} on a molecular weight distribution (MWD) curve determined via absolute gel permeation chromatography, wherein S_{max} is the maximum absolute slope on the higher molecular weight side of the primary peak of the MWD curve, wherein the primary peak is the peak of greatest magnitude in the MWD curve;

wherein the low molecular weight polymer fraction and the high molecular weight polymer fraction each comprise a Ladder character, L, defined for a given absolute molecular weight (MW) as the fit of the log of the intrinsic viscosity [η] versus the log of the absolute MW (M) curve using the expression, $\log[\eta] = \log(\beta) + \alpha\log(M) - L^*\alpha\log(2)$ according to a Mark-Houwink-Sakurada curve, wherein log(β) is the intercept and α is the slope, and wherein

the low molecular weight polymer fraction has an MW below S_{max} and all values of L between −0.35 to 0.35; and

the high molecular weight polymer fraction has an MW above S_{max} and a maximum value of L between 0.8 and 1.5;

wherein the diene is unconjugated, and

wherein the diene is acyclic.

2. The ethylene-based polymer of claim 1, wherein the diene comprises 1,4-pentadiene, 1,5-hexadiene, 1,6-heptadiene, 1,7-octadiene, 1,8-nonadiene, 1,9-decadiene, 1,10-undecadiene, 1,11-dodecadiene, dimethyldivinylsilane, dimethyldiallylsilane, dimethylallylvinylsilane.

3. The ethylene-based polymer of claim 1 or 2, wherein the high molecular weight polymer fraction comprises 0.5 to 30 % by weight of the polymer.

4. The ethylene-based polymer of claim 3, wherein the high molecular weight polymer fraction comprises between 1 and 15 % by weight of the polymer.

5. The ethylene-based polymer of any preceding claim, wherein all values L of the low molecular weight polymer fraction are between -0.2 to 0.2.

6. The ethylene-based polymer of any preceding claim, wherein the maximum value of L of the high molecular weight polymer fraction is from 0.9 to 1.1.

7. The ethylene-based polymer of any preceding claim, wherein the ethylene-based polymer has a molecular weight tail quantified by an MWD area metric, A_{TAIL}, and A_{TAIL} is greater than 0.06 as determined by gel permeation chromatography using a triple detector.

8. The ethylene-based polymer of claim 7, wherein A_{TAIL} is greater than 0.08.

9. The ethylene-based polymer of claim 8, wherein A_{TAIL} is greater than 0.10.

10. The ethylene-based polymer of any preceding claim, wherein the ethylene-based polymer has an average g' greater than 0.86, where the average g' is an intrinsic viscosity ratio determined by gel permeation chromatography using a triple detector.

11. The ethylene-based polymer of claim 10, wherein the average g' is greater than 0.88.

12. The ethylene-based polymer of claim 11, wherein the average g' is greater than 0.90.

13. The ethylene-based polymer of any preceding claim, wherein the ethylene-based polymer has a weight averaged molecular weight (M_w) of less than or equal to 250,000 Daltons, as determined by absolute gel permeation chromatography.

14. The ethylene-based polymer of claim 13, wherein the ethylene-based polymer has a weight averaged molecular weight (M_w) of less than or equal to 150,000 Daltons, as determined by absolute gel permeation chromatography.

15. The ethylene-based polymer of claim 14, wherein the ethylene-based polymer has a weight averaged molecular weight (M_w) of less than or equal to 100,000 Daltons, as determined by absolute gel permeation chromatography.

16. The ethylene-based polymer of any preceding claim, wherein the MI is greater than 0.1, wherein MI is the melt index in g/10min according to ASTM D1238.

17. The ethylene-based polymer of claim 16, wherein the MI is greater than 1, wherein MI is the melt index in g/10min according to ASTM D1238.

18. The ethylene-based polymer of claim 17, wherein the MI is greater than 2, wherein MI is the melt index in g/10min according to ASTM D1238.