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(54) **USE OF MODIFIED LIGNIN AS A WET END STRENGTH ADDITIVE**

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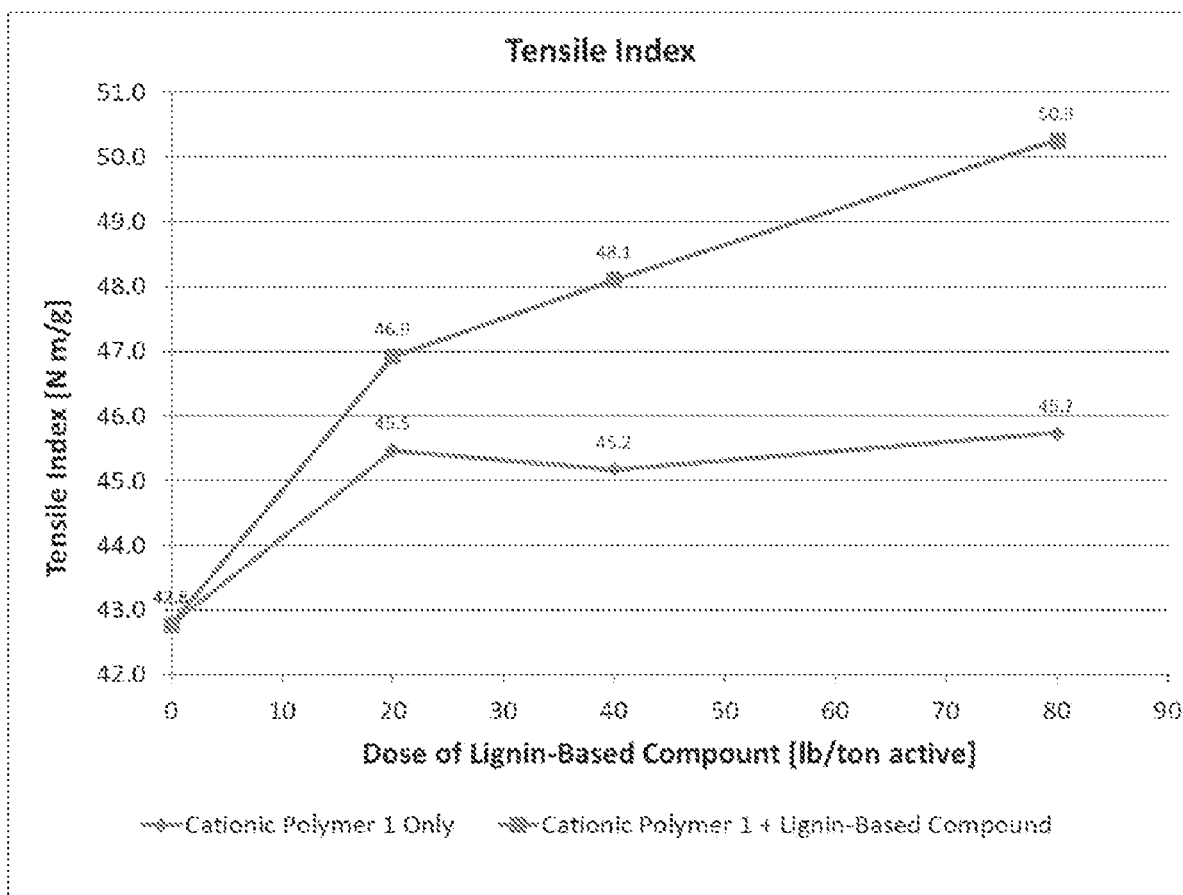
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ABSTRACT

A method of increasing paper strength is provided. The method includes adding a lignin-based compound to a pulp slurry; and adding a cationic polymer to the pulp slurry. When added to a pulp slurry, the combination of a lignin-based compound and a cationic polymer produce a comprehensive paper strength increase.



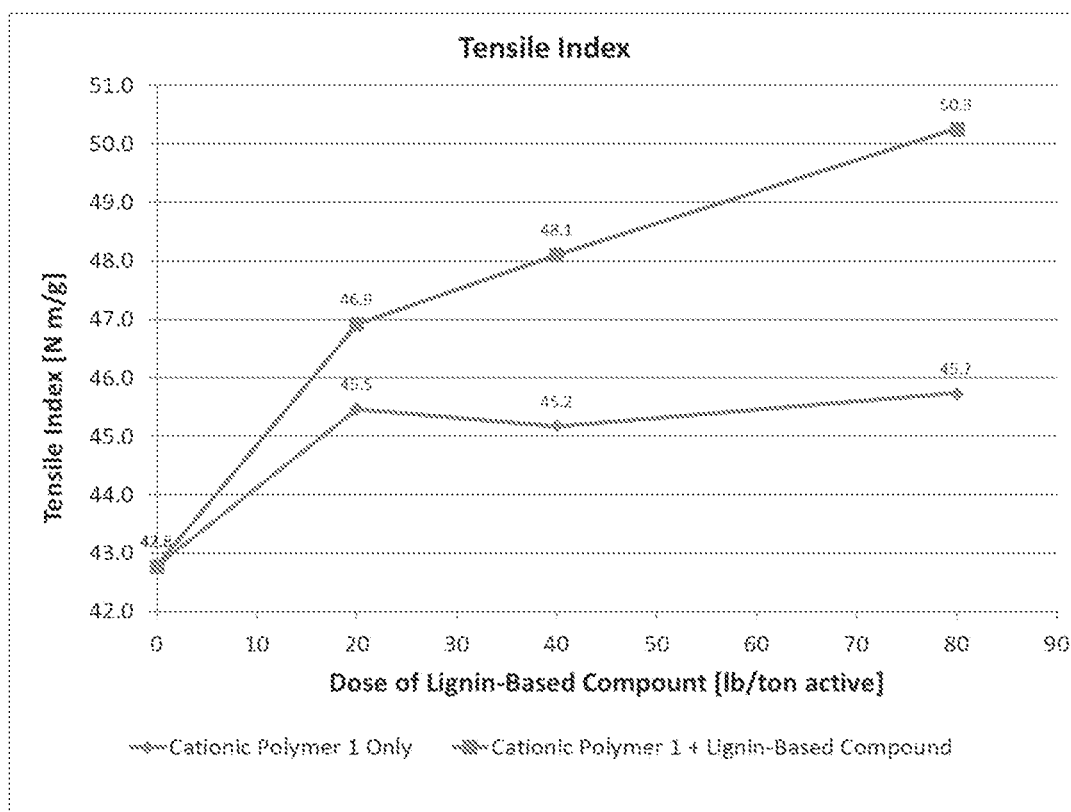


FIG. 1

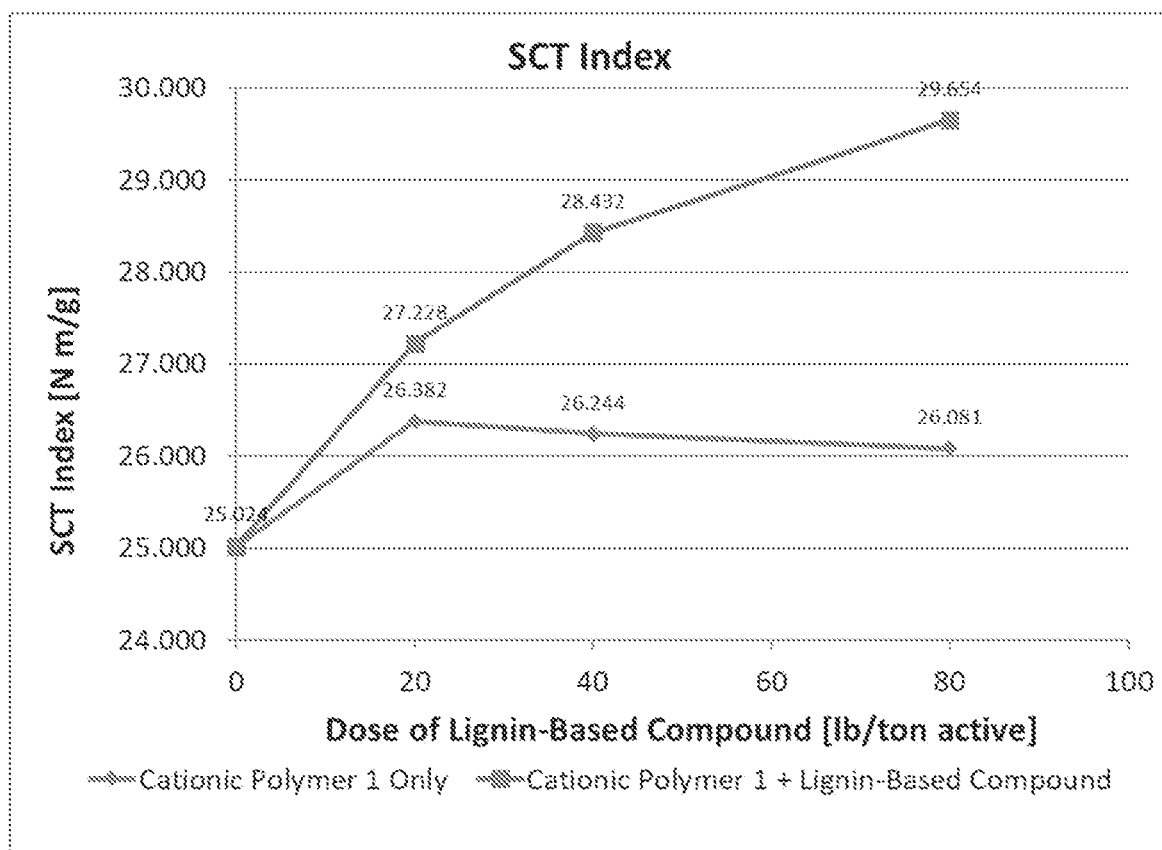


FIG. 2

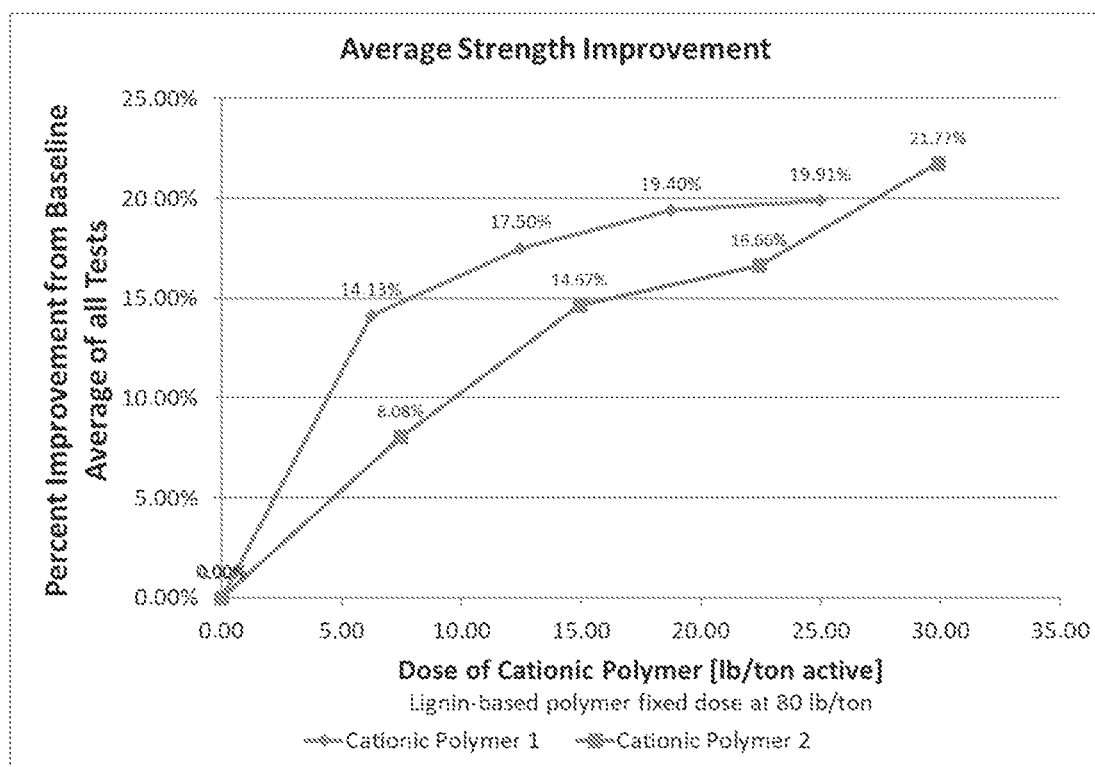


FIG. 3

USE OF MODIFIED LIGNIN AS A WET END STRENGTH ADDITIVE

BACKGROUND

1. Field of the Invention

[0001] The present disclosure generally relates to increasing paper strength. More particularly, the disclosure relates to a composition containing a modified lignin and a method of strengthening paper using the composition.

2. Description of the Related Art

[0002] A typical papermaking process includes the steps of: 1) pulping wood or some other source of papermaking fibers; 2) producing a paper mat from the pulp, the paper mat being an aqueous slurry of cellulosic fiber, which may also contain additives, such as inorganic mineral fillers or pigments; 3) depositing this slurry on a moving papermaking wire or fabric; 4) forming a sheet from the solid components of the slurry by draining the water; 5) pressing and drying the sheet to further remove water, and 6) potentially rewetting the dry sheet by passing it through a size press and further drying it to form a paper product.

[0003] When conducting a papermaking process, a number of concerns need to be taken into account to assure the quality of the final paper product. For example, when draining the water from the slurry, fibers and chemical additives should be retained as much as possible instead of flowing away with the water. Similarly, the final sheet should have adequate wet strength and dry strength. The dry strength of paper generally includes, for example, internal bonds, dry tensile strength, and burst strength.

[0004] Commonly used dry strength agents include natural polymers, such as cationic starch, carboxymethyl cellulose (CMC) and guar gum, and synthetic polymers, such as polyacrylamide (cationic, anionic and amphoteric), glyoxalated polyacrylamides (GPAMs), and polyvinylamines. In the category of di-aldehyde functionalized polyacrylamide, glyoxalated polyacrylamide (GPAM), prepared from glyoxal and a polyacrylamide backbone, is the most commonly used dry strength agent.

BRIEF SUMMARY

[0005] A method of increasing paper strength is provided. The method includes adding a lignin-based compound to a pulp slurry; and adding a cationic polymer to the pulp slurry.

[0006] In some aspects, the lignin-based compound is soluble in water at a pH of about 4 to about 14.

[0007] In some aspects, the lignin-based compound has a weight average molecular weight of less than about 100,000 g/mol.

[0008] In some aspects, the lignin-based compound has a negative zeta potential.

[0009] In some aspects, the cationic polymer comprises monomers selected from the group consisting of: acrylamide, methacrylamide, diallyldimethylammonium chloride (DADMAC), N-vinylamine, 2-dimethylaminoethyl acrylate (DMAEA), N,N,N-trimethylethanaminium chloride, diallylamine, poly (amidoamine), polyethylenimine, and any combination thereof.

[0010] In some aspects, the cationic polymer is cross-linked epichlorohydrin-dimethylamine, poly (amidoamine), or polyethylenimine.

[0011] In some aspects, the cationic polymer has a weight average molecular weight of about 50,000 Da to about 2,000,000 Da.

[0012] In some aspects, the cationic polymer has a charge density of about 0.1 meq/g to about 15 meq/g.

[0013] In some aspects, the lignin-based compound and the cationic polymer are added to the pulp slurry in a wet end of a papermaking process.

[0014] In some aspects, the lignin-based compound and the cationic polymer are added to the pulp slurry in a whitewater system, pulp stock storage chest, blend chest, machine chest, headbox, saveall chest, or any combination thereof in the papermaking process.

[0015] In some aspects, the lignin-based compound is added to the pulp slurry in an amount ranging from about 10 lb/ton to about 100 lb/ton.

[0016] In some aspects, the cationic polymer is added to the pulp slurry in an amount ranging from about 1 lb/ton to about 30 lb/ton.

[0017] In some aspects, the lignin-based compound is added to the pulp slurry before the cationic polymer is added.

[0018] In some aspects, the lignin-based compound is added to the pulp slurry after the cationic polymer is added.

[0019] In some aspects, the lignin-based compound and the cationic polymer are added to the pulp slurry at a different locations in the wet end.

[0020] The present disclosure also provides a composition, which comprises a lignin-based compound and a cationic polymer.

[0021] Still further, a use of a lignin-based compound and a cationic polymer for strengthening paper is disclosed herein.

[0022] The foregoing has outlined rather broadly the features and technical advantages of the present disclosure in order that the detailed description that follows may be better understood. Additional features and advantages of the disclosure will be described hereinafter that form the subject of the claims of this application. It should be appreciated by those skilled in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other embodiments for carrying out the same purposes of the present disclosure. It should also be realized by those skilled in the art that such equivalent embodiments do not depart from the spirit and scope of the disclosure as set forth in the appended claims.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0023] A detailed description of the invention is hereafter described with specific reference being made to the drawings in which:

[0024] FIG. 1 shows tensile index values measured for sheets that were treated in the wet end with poly (DADMAC) only and a combination of poly (DADMAC) and a lignin-based compound added sequentially.

[0025] FIG. 2 shows SCT index values measured for sheets that were treated in the wet end with poly (DADMAC) only and a combination of poly (DADMAC) and a lignin-based compound added sequentially.

[0026] FIG. 3 shows average strength improvement values for sheets made with a lignin-based compound and varying dosages of a poly (DADMAC) polymer and a crosslinked epichlorohydrin-dimethylamine coagulant.

DETAILED DESCRIPTION

[0027] A method of increasing paper strength is provided. The method includes adding a lignin-based compound to a pulp slurry and adding a cationic polymer to the pulp slurry.

[0028] As used herein, “lignin” refers to a structural component of the cellulose fiber. Lignin is a high molecular weight, cross-linked organic compound that is relatively hydrophobic. In the papermaking process, lignin is typically removed from the cellulose fiber mass and incinerated; its presence in paper can cause several undesirable effects, such as yellowing and a reduction in strength.

[0029] The lignin-based compound can be an enzyme-modified lignin. The enzyme-modified lignin can be a lacase-modified lignin. In some aspects, the lignin-based compound is soluble in water at a pH of about 4 to about 14 for a concentration of about 1 wt % to about 20 wt % of the lignin-based compound at about 25° C. In some aspects, the lignin-based compound is soluble in water at a pH of about 6 to about 9 for a concentration of about 1 wt % to about 20 wt % of the lignin-based compound at about 25° C. In some aspects, the pH is about 6, about 7, about 8, or about 9 for a concentration of about 1 wt % to about 20 wt % of the lignin-based compound at about 25° C. In some aspects, the lignin-based compound is soluble in water at a pH of about 4 to about 14 for a concentration of about 10 wt % to about 20 wt % of the lignin-based compound at about 25° C.

[0030] In some aspects, the lignin-based compound is soluble in water at a pH of about 6 to about 9 for a concentration of about 10 wt % to about 20 wt % of the lignin-based compound at about 25° C. In some aspects, the lignin-based compound is soluble in water at a pH of about 6, about 7, about 8, or about 9 for a concentration of about 10 wt % to about 20 wt % of the lignin-based compound at about 25° C. In some aspects, the lignin-based compound is soluble in water at a pH of about 6, about 7, about 8, or about 9 for a concentration of about 20 wt % of the lignin-based compound at about 25° C.

[0031] In some aspects, the lignin-based compound has a negative zeta potential. The zeta potential of the lignin-based compound can be from about -5 to about -100 mV, from about -30 to about -100 mV, from about -40 to about -80 mV, or from about -50 to about -80 mV. In some aspects, the zeta potential of the lignin-based compound can be from about -60 to about -75 mV.

[0032] The lignin-based compound can have a particle size less than about 10 μm . In some embodiments, the particle size of the lignin-based compound is less than about 500 nm. The particle size of the lignin-based compound can be determined using transmission electron microscopy (TEM), for example.

[0033] In some aspects, the lignin-based compound is free of pulp. In some aspects, the lignin-based compound is not associated with pulp fibers prior to addition to the pulp slurry. In some aspects, the lignin-based compound is free of cellulose. In some aspects, the lignin-based compound is not associated with cellulose prior to addition to the pulp slurry. In some aspects, adding a lignin-based compound to a pulp slurry does not include adding pulp containing lignin to a pulp slurry. In some aspects, the lignin-based compound does not include lignosulfonates.

[0034] Examples of commercially available lignin-based compounds include, but are not limited to, METNIN™ SHIELD.

[0035] In some aspects, the weight average molecular weight of the lignin-based compound is less than about 100,000 g/mol. In some aspects, the weight average molecular weight ranges from about 1,000 g/mol to about 100,000 g/mol. For example, the weight average molecular weight may be from about 10,000 g/mol to about 100,000 g/mol, from about 20,000 g/mol to about 100,000 g/mol, from about 30,000 g/mol to about 100,000 g/mol, from about 40,000 g/mol to about 100,000 g/mol, from about 50,000 g/mol to about 100,000 g/mol, from about 60,000 g/mol to about 100,000 g/mol, from about 70,000 g/mol to about 100,000 g/mol, from about 80,000 g/mol to about 100,000 g/mol or from about 90,000 g/mol to about 100,000 g/mol.

[0036] The dosage of the lignin-based compound can be selected to achieve an increase in paper strength. For example, the lignin-based compound can be added to the pulp slurry in an amount ranging from about 10 lb/ton to about 100 lb/ton. In some aspects, the amount of lignin-based compound added to the pulp slurry is about 20 lb/ton to about 80 lb/ton. In some aspects, the amount of lignin-based compound added to the pulp slurry is about 20 lb/ton, about 30 lb/ton, about 40 lb/ton, about 50 lb/ton, about 60 lb/ton, about 70 lb/ton, or about 80 lb/ton.

[0037] The cationic polymers can include other non-ionic co-monomers such as acrylamide, methacrylamide, N,N-dimethylacrylamide, N,N-diethylacrylamide, N-isopropylacrylamide, N-vinylamine, N-vinylmethylacetamide, N-vinyl pyrrolidone, hydroxyethyl methacrylate, hydroxyethyl acrylate, hydroxypropyl acrylate, hydroxypropyl methacrylate, N-t-butylacrylamide, N-methylolacrylamide, vinyl acetate, vinyl alcohol, similar monomers, and combinations thereof. In some aspects, the non-ionic co-monomer is acrylamide or methacrylamide.

[0038] Representative cationic co-monomers may include, for example, dialkylaminoalkyl acrylates and methacrylates and their quaternary or acid salts, including, but not limited to, dimethylaminoethyl acrylate methyl chloride quaternary salt (“DMAEA-MCQ”), dimethylaminoethyl acrylate methyl sulfate quaternary salt, dimethylaminoethyl acrylate benzyl chloride quaternary salt, dimethylaminoethyl acrylate sulfuric acid salt, dimethylaminoethyl acrylate hydrochloric acid salt, dimethylaminoethyl methacrylate methyl chloride quaternary salt, dimethylaminoethyl methacrylate methyl sulfate quaternary salt, dimethylaminoethyl methacrylate benzyl chloride quaternary salt, dimethylaminoethyl methacrylate sulfuric acid salt, dimethylaminoethyl methacrylate hydrochloric acid salt, dialkylaminoalkylacrylamides or methacrylamides and their quaternary or acid salts, such as acrylamidopropyltrimethylammonium chloride, dimethylaminopropyl acrylamide methyl sulfate quaternary salt, dimethylaminopropyl acrylamide sulfuric acid salt, dimethylaminopropyl acrylamide hydrochloric acid salt, methacrylamidopropyltrimethylammonium chloride, dimethylaminopropyl methacrylamide methyl sulfate quaternary salt, dimethylaminopropyl methacrylamide sulfuric acid salt, dimethylaminopropyl methacrylamide hydrochloric acid salt, diethylaminoethylacrylate, diethylaminoethylmethacrylate, diallyldiethylammonium chloride and diallyldimethyl ammonium chloride (“DADMAC”), similar monomers, and combinations thereof. When present, alkyl groups are generally C₁ to C₄ alkyl, substituted or unsubstituted.

[0039] Furthermore, in certain embodiments, the cationic monomers are one or more selected from the group consist-

ing of diallyldimethylammonium chloride (DADMAC), N-vinylamine, 2-dimethylaminoethyl acrylate (DMAEA), N,N,N-trimethylethanaminium chloride, diallylamine, poly (amidoamine), and polyethylenimine.

[0040] Generally, the amine-containing polymers used in accordance with this disclosure may take the form of water-in-oil emulsions, dry powders, dispersions, or aqueous solutions. In certain embodiments, the amine-containing polymers may be prepared via free radical polymerization techniques in water using free radical initiation.

[0041] In some embodiments, the amine-containing polymer is a copolymer formed by diallylamine/substituted diallylamine and (meth) acrylamide, such as a diallylamine-(meth) acrylamide copolymer ("DAA/AcAm"). Moreover, it is also possible to use the mixture of one or more copolymers formed by diallylamine/substituted diallylamine and (meth) acrylamide as the amine-containing polymer.

[0042] In certain aspects, the mole percentage of cationic monomers (e.g., diallylamine) in the cationic polymer, such as diallylamine-(meth) acrylamide copolymer, can be within a range of about 1 to about 99%. The amine-containing polymer may be primarily made up of amine-based monomers, i.e., may comprise more amine-based monomer units than other co-monomer units, such as (meth) acrylamide. In those embodiments, where cost is a deciding factor in terms of composition of the oil-in-water emulsion, the mole percentage of amine-based monomers in the amine-containing polymer may be from about 10% to about 80%, about 15% to about 60% or about 18% to about 40%. In certain embodiments, the amine-containing polymers of the present disclosure are not obtained from Hoffmann degradation and contain no polyethylene amine units.

[0043] In some aspects, the cationic polymer is cross-linked epichlorohydrin-dimethylamine, poly (amidoamine), or polyethylenimine.

[0044] The weight average molecular weight of the cationic polymer can range from about 50,000 Da to about 2,000,000 Da. In some aspects, the weight average molecular weight ranges from about 50,000 Da to about 1,000,000 Da. For example, the weight average molecular weight may range from about 50,000 Da to about 900,000 Da, from about 50,000 Da to about 800,000 Da, from about 50,000 Da to about 700,000 Da, from about 50,000 Da to about 600,000 Da, from about 50,000 Da to about 500,000 Da, from about 100,000 Da to about 1,000,000 Da, from about 200,000 Da to about 1,000,000 Da, from about 300,000 Da to about 1,000,000 Da, from about 400,000 Da to about 1,000,000 Da, from about 500,000 Da to about 1,000,000 Da or from about 500,000 Da to about 700,000 Da. In some aspects, the weight average molecular weight is about 1,000,000 Da.

[0045] The charge density of the cationic polymer, measured in milliequivalent (meq) per gram (g), can range from about 0.1 meq/g to about 15 meq/g. In some aspects, the charge density of the cationic polymer can range from about 0.5 meq/g to about 10 meq/g. In some aspects, the charge density of the cationic polymer can range from about 1.0 meq/g to about 10 meq/g. In some aspects, the charge density of the cationic polymer is about 1.0 meq/g, about 2.0 meq/g, about 3.0 meq/g, about 4.0 meq/g, about 4.5 meq/g, about 5.0 meq/g, about 6.0 meq/g, about 7.0 meq/g, about 8.0 meq/g, or about 9.0 meq/g.

[0046] The dosage of the cationic polymer can be selected to achieve an increase in paper strength. For example, the cationic polymer can be added to the pulp slurry in an

amount ranging from about 1 lb/ton to about 30 lb/ton. In some aspects, the cationic polymer can be added to the pulp slurry in an amount ranging from about 1 lb/ton to about 20 lb/ton. In some aspects, the cationic polymer can be added to the pulp slurry in an amount ranging from about 5 lb/ton to about 20 lb/ton. In some aspects, the cationic polymer can be added to the pulp slurry in an amount ranging from about 6 lb/ton to about 18 lb/ton. In some aspects, the cationic polymer can be added to the pulp slurry in an amount ranging from about 8 lb/ton to about 18 lb/ton.

[0047] The lignin-based compound and the cationic polymer can be added to the pulp slurry separately or simultaneously. When added simultaneously, the lignin-based compound and the cationic polymer can be added independently or as part of a single composition. The feeding manner of the lignin-based compound and the cationic polymer includes, but is not limited to, adding the components separately into the pulp slurry in any sequence, or adding into the pulp slurry after premixing the components or co-feeding the components into the pulp slurry. In some aspects, the lignin-based compound is added to the pulp slurry before the cationic polymer is added. In some aspects, the lignin-based compound is added to the pulp slurry after the cationic polymer is added. In some aspects, the lignin-based compound and the cationic polymer are added to the pulp slurry at a different locations in the wet end.

[0048] As used herein, the "wet end" of a papermaking process refers to those parts that involve a slurry of fibers. The wet end does not include portions of the papermaking process commonly referred to as the "dry end" where pulp is formed into paper sheets and dried.

[0049] The lignin-based compound and the cationic polymer are added to the pulp slurry in a wet end of a papermaking process. Specific locations or unit operations in the wet end include, but are not limited to, a whitewater system, pulp stock storage chest, blend chest, machine chest, headbox, or saveall chest.

[0050] In some aspects, a composition is provided that includes a lignin-based compound as described herein and a cationic polymer as described herein. In some aspects, the composition can consist essentially of the lignin-based compound and the cationic polymer.

[0051] The transitional phrase "consisting essentially of" limits the scope of a claim to the specified elements, components, ingredients and/or steps, as well as those that do not materially affect the basic and novel characteristic(s) of the claimed invention. A basic and novel characteristic of the combination of the lignin-based compound and the cationic polymer is the unexpected increase in paper strength seen when the compounds are added to the paper slurry in the wet end. Examples of how paper strength can be measure are provided in the examples.

[0052] In some aspects, the composition consists of the lignin-based compound and the cationic polymer. In some aspects, the composition consists of the lignin-based compound, the cationic polymer, and a solvent. The solvent can be water, for example.

EXAMPLES

Example 1

[0053] A lignin-based compound was dosed at about 20, about 40, and about 80 lb/ton actives and a polyDADMAC polymer (about 5.1 meq/g; weight average MW about 5,000

to about 500,000 g/mol) was dosed at about 4.5, about 8.5 and about 17 lb/ton active. Enough polyDADMAC polymer was added to achieve a net cationic system charge. The polyDADMAC polymer was added first followed by the lignin-based compound to a 0.9 wt % solution of fiber (recycled board) in water. Each component was allowed to mix for about 10 seconds in the fiber slurry before mixing was stopped and a handsheet was made. The handsheets were conditioned at about 23° C. and about 50% relative humidity and the strength of the resulting handsheets was measured. Specifically, the tensile and short-span compression (SCT) of the sheets were measured and the results are shown in FIGS. 1 and 2. From this data, the lignin-based compound was retained on the fiber surface and strength improved significantly as a result. Table 1 shows the cationic polymers tested.

[0054] The lignin-based compound tested in these examples had a zeta potential at a pH of about 7.6 of about -66.6 mV, a zeta potential at a pH of about 9.6 of about -66.8 mV, a particle size of about 9.9 nm as measured by dynamic light scattering, and a pH, in neat form, of about 9.2.

TABLE 1

Cationic Polymers			
Cationic polymer	Chemistry	Charge density meq/g	Molecular weight range Dalton
1	polyDADMAC	about 5.1	Less than about 500,000
2	Crosslinked EPI-DMA polymer	about 4.3	about 500,000-700,000
3	Polyvinylamine	about 9.2	about 300,000
4	DMAEA.MCQ-Acrylamide copolymer (10 mol % DMAEA)	about 1.0	about 1 × 10 ⁶
5	Diallylamine-acrylamide copolymer (35 mol % DAA)	about 4.4	about 1 × 10 ⁶

Example 2

[0055] Further studies were carried out to assess the impact of other cationic polymers. An EPI-DMA polymer

(about 4.3 meq/g; weight average MW about 500,000 to about 700,000 Da; cationic polymer 2) was compared to the polyDADMAC polymer (cationic polymer 1). In this study, the dosage of lignin-based compound was fixed at about 80 lb/ton active. The dosage of cationic polymer 1 ranged from about 6.25, about 12.50, about 18.75, and about 25.00 lb/ton active, while the dosage of cationic polymer 2 was set to about 7.48, about 14.95, about 22.43, and about 29.90 lb/ton active. While the dosages of the two polymers were different, these particular dosages were selected so that the total system charge would be the same (cationic polymer 1 and 2 have slightly different charge densities). The cationic poly-

mers and lignin-based compound were added in sequence as described previously and handsheets were made and tested for tensile, burst, SCT, and ring crush strength. These results are shown in Table 2 and the average strength improvement is shown in FIG. 3. The percentages reported for Tensile, Burst, SCT, RCT, and Avg are percent change compared to blank.

TABLE 2

Dose of lignin-based compound	Cationic polymer	Dose of Cat. polymer	Tensile	Burst	SCT	RCT	Avg.
80	1	6.3	18.18	14.64	9.57	8.53	14.13
80	1	12.5	14.47	26.30	11.74	14.12	17.50
80	1	18.8	20.81	19.84	17.54	14.46	19.40
80	1	25.0	17.74	27.85	14.13	18.91	19.91
80	2	7.5	9.36	10.24	4.65	7.65	8.08
80	2	15.0	12.74	21.50	9.76	13.50	14.67
80	2	22.4	16.97	20.55	12.46	15.17	16.66
80	2	29.9	19.24	31.35	14.70	15.10	21.77

[0056] From this data, it appears that both cationic polymers 1 and 2 can be used to retain the lignin-based compound and improve strength. The optimal cationic polymer dosage, however, is slightly different between the two products.

[0057] A further study was carried out to assess the use of a different cationic polymer as a retention aid for the lignin-based compound. In this case, a high-charge low-molecular weight polyvinylamine (PVAM) was used (cationic polymer 3). The properties of this polymer are shown in Table 3. The dosage of the PVAM polymer was set to about 18 lb/ton actives to maintain a total system charge of about +0.25 meq. The strength performance results are presented in Table 4. These data show that the PVAM/lignin-based compound combination can improve strength by over about 30% from the baseline. This is a significant result, in that typical strength aids can usually provide a 10-15% strength increase.

TABLE 3

Cationic polymer	% Hydrolysis (by NMR)	IV (dL/g)	Est./Approx. Mw (kDa)	% Solids (Moisture Balance)	% Actives (Calculated)	Charge Density (meq/g) pH 6, Colloid titration
3	90.1	~1	300	20.0%	9.4%	9.1671

TABLE 4

Dose of lignin-based compound	Cationic polymer	Dose of Cat. polymer	Tensile	Burst	SCT	RCT	Avg.
60	3	10.0	21.61	43.36	30.08	27.79	31.68

Example 3

[0058] Another study was carried out to assess the ability of two commercial strength products, cationic polymers 4

and 5, to retain the lignin-based compound and increase strength. A secondary goal of this study was to vary the amount of cationic polymer 3 to assess the optimal PVAM dosage. Cationic polymers 4 and 5 were each dosed at about 8 lb/ton active, while the PVAM dosage was set to about 6, about 12, and about 18 lb/ton actives. The lignin-based compound dosage was fixed at about 60 lb/ton active. The results from this study are shown in Table 5. While using cationic polymer 4 or cationic polymer 5 can improve strength, the strength improvement is much lower than what is provided by the PVAM (cationic polymer 3). The PVAM dosage also significantly impacts strength, and a marked change in performance is observed at each PVAM dose. Here again, the average strength gain obtained using the high dose of the PVAM with the lignin-based compound is about 30%, consistent with previous work.

TABLE 5

Dose of lignin-based compound	Cationic polymer	Dose of Cat. polymer	Tensile	Burst	SCT	RCT	Avg.
60	3	6.0	5.17	6.08	7.04	10.89	6.10
60	3	12.0	11.59	14.49	20.16	20.77	15.41
60	3	18.0	28.85	30.02	27.68	28.60	28.85
60	4	8.0	17.71	19.72	13.87	10.88	17.10
60	5	8.0	15.16	12.62	11.51	10.55	13.10

[0059] These results show that the lignin-based compound can be retained on the fiber surface using the appropriate retention system using polymers with cationic charge density and molecular weight lower than the average of the commercial strength aids. In this inventive process, lignin, typically regarded as a waste component of cellulose, can be used in the wet end of the paper machine to generate significant levels of strength, double that of a typical wet end strength aid.

[0060] All of the compositions and methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While this invention may be embodied in many different forms, there are described in detail herein specific preferred embodiments of the invention. The present disclosure is an exemplification of the principles of the invention and is not intended to limit the invention to the particular embodiments illustrated. In addition, unless expressly stated to the contrary, use of the term “a” is intended to include “at least one” or “one or more.” For example, “a polymer” is intended to include “at least one polymer” or “one or more polymers.”

[0061] Any ranges given either in absolute terms or in approximate terms are intended to encompass both, and any definitions used herein are intended to be clarifying and not limiting. Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in their respective testing measurements. Moreover, all ranges disclosed herein are to be understood to encompass any and all subranges (including all fractional and whole values) subsumed therein.

[0062] Any composition disclosed herein may comprise, consist of, or consist essentially of any element, component

and/or ingredient disclosed herein or any combination of two or more of the elements, components or ingredients disclosed herein.

[0063] Any method disclosed herein may comprise, consist of, or consist essentially of any method step disclosed herein or any combination of two or more of the method steps disclosed herein.

[0064] The transitional phrase “comprising,” which is synonymous with “including,” “containing,” or “characterized by,” is inclusive or open-ended and does not exclude additional, un-recited elements, components, ingredients and/or method steps.

[0065] The transitional phrase “consisting of” excludes any element, component, ingredient, and/or method step not specified in the claim.

[0066] Unless specified otherwise, all molecular weights referred to herein are weight average molecular weights and all viscosities were measured at 25° C. with neat (not diluted) polymers.

[0067] As used herein, the term “about” refers to the cited value being within the errors arising from the standard deviation found in their respective testing measurements, and if those errors cannot be determined, then “about” may refer to, for example, within 5% of the cited value.

[0068] Furthermore, the invention encompasses any and all possible combinations of some or all of the various embodiments described herein. It should also be understood that various changes and modifications to the presently preferred embodiments described herein will be apparent to those skilled in the art. Such changes and modifications can be made without departing from the spirit and scope of the invention and without diminishing its intended advantages. It is therefore intended that such changes and modifications be covered by the appended claims.

1. A method of increasing paper strength, comprising: adding a lignin-based compound to a pulp slurry; and adding a cationic polymer to the pulp slurry.
2. The method of claim 1, wherein the lignin-based compound is soluble in water at a pH of about 4 to about 14 at a concentration of about 1 wt % to about 20 wt % of the lignin-based compound at about 25° C.
3. The method of claim 1, wherein the lignin-based compound has a weight average molecular weight of less than about 100,000 g/mol.
4. The method of claim 1, wherein the lignin-based compound has a negative zeta potential.
5. The method of claim 1, wherein the lignin-based compound is free of pulp.
6. The method of claim 1, wherein the cationic polymer comprises monomers selected from the group consisting of: acrylamide, methacrylamide, diallyldimethylammonium chloride (DADMAC), N-vinylamine, 2-dimethylaminoethyl acrylate (DMAEA), N,N,N-trimethylethanaminium chloride, diallylamine, poly (amidoamine), polyethylenimine, and any combination thereof.
7. The method of claim 1, wherein the cationic polymer is crosslinked epichlorohydrin-dimethylamine, poly (amidoamine), or polyethylenimine.
8. The method of claim 1, wherein the cationic polymer has a weight average molecular weight of about 50,000 Da to about 2,000,000 Da.
9. The method of claim 1, wherein the cationic polymer has a charge density of about 0.1 meq/g to about 15 meq/g.

10. The method of claim 1, wherein the lignin-based compound and the cationic polymer are added to the pulp slurry in a wet end of a papermaking process.

11. The method of claim 1, wherein the lignin-based compound and the cationic polymer are added to the pulp slurry in a whitewater system, pulp stock storage chest, blend chest, machine chest, headbox, saveall chest, or any combination thereof in the papermaking process.

12. The method of claim 1, wherein the lignin-based compound is added to the pulp slurry in an amount ranging from about 10 lb/ton to about 100 lb/ton.

13. The method of claim 1, wherein the cationic polymer is added to the pulp slurry in an amount ranging from about 1 lb/ton to about 30 lb/ton.

14. The method of claim 1, wherein the lignin-based compound is added to the pulp slurry before the cationic polymer is added.

15. The method of claim 1, wherein the lignin-based compound is added to the pulp slurry after the cationic polymer is added.

16. The method of claim 1, wherein the lignin-based compound and the cationic polymer are added to the pulp slurry at different locations in the wet end.

17. A composition, comprising:

a lignin-based compound; and

a cationic polymer.

18. The composition of claim 17, wherein the lignin-based compound has a weight average molecular weight of less than about 100,000 g/mol and a negative zeta potential.

19. (canceled)

20. The composition of claim 17, wherein the cationic polymer is crosslinked epichlorohydrin-dimethylamine, poly (amidoamine), or polyethylenimine.

21. The composition of claim 17, wherein the composition is free of pulp.

22. (canceled)

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