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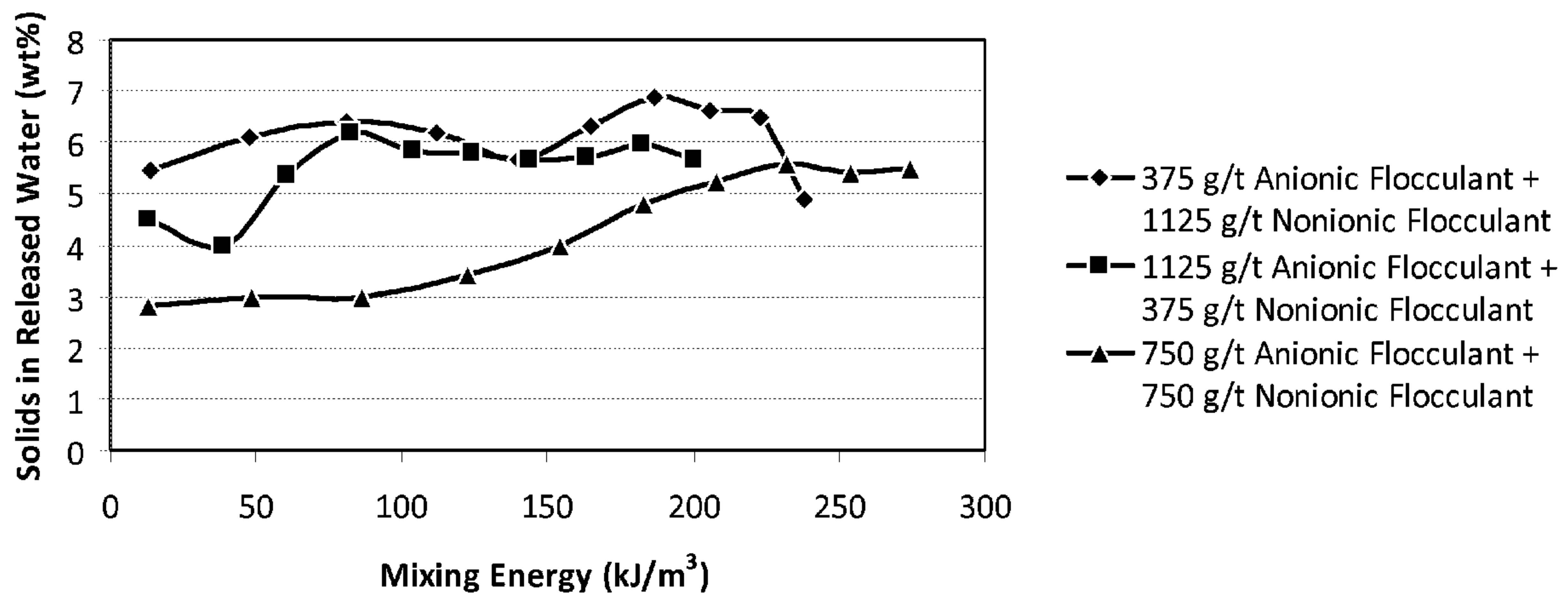
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(54) **Titre : PROCESSUS DE TRAITEMENT DE FLUX DE RESIDUS**
 (54) **Title: PROCESSES FOR TREATING TAILINGS STREAMS**



(57) **Abrégé/Abstract:**

Provided are processes for treating a tailings stream which comprises water and solids, the process comprising: (i) adding one or more anionic polymer flocculants and one or more nonionic polymer flocculants to the tailings stream; (ii) allowing at least a portion of the solids to flocculate; and (iii) separating at least a portion of the flocculated solids from the tailings stream.

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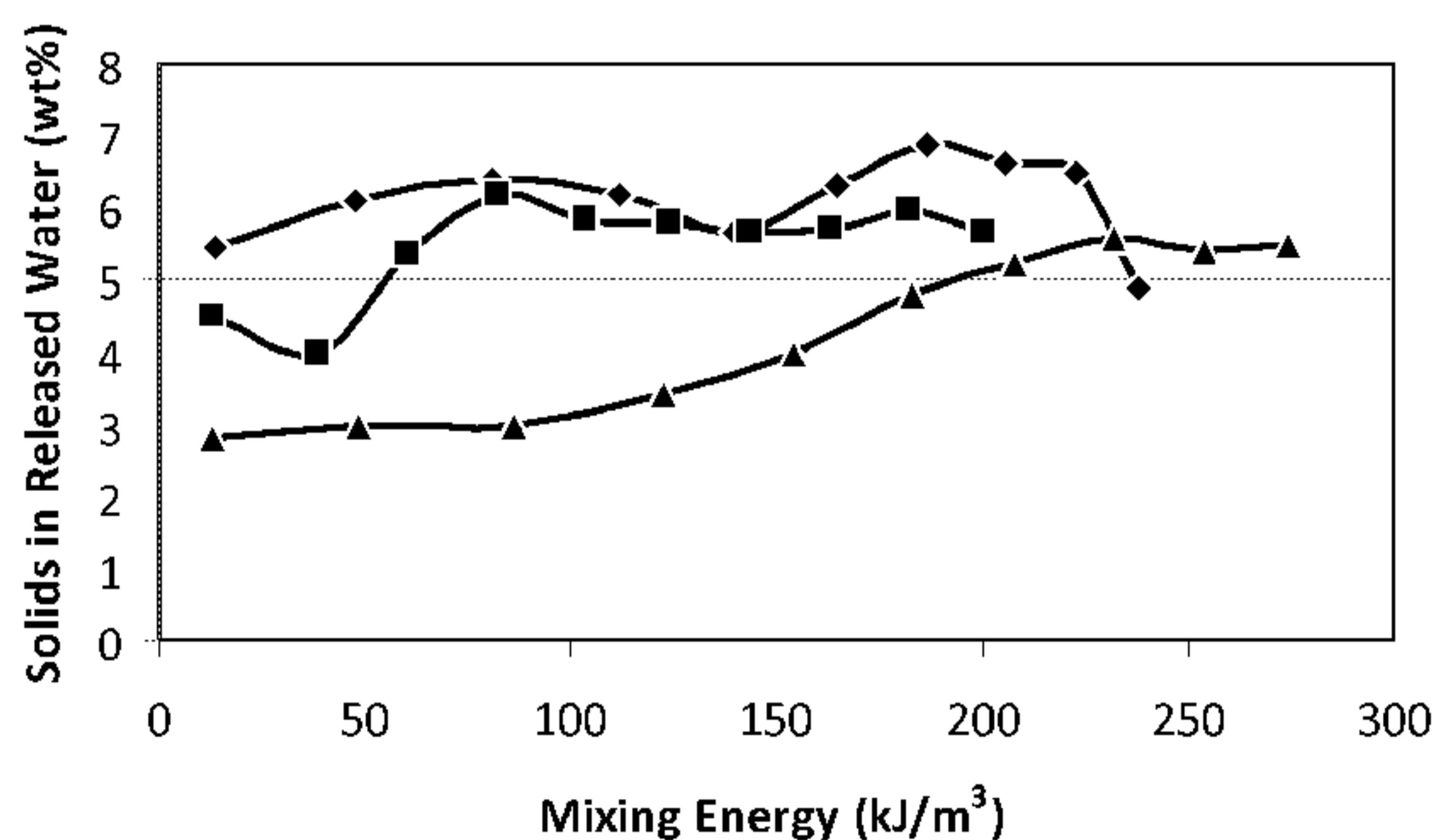


Figure 5

◆ 375 g/t Anionic Flocculant +
1125 g/t Nonionic Flocculant
■ 1125 g/t Anionic Flocculant +
375 g/t Nonionic Flocculant
▲ 750 g/t Anionic Flocculant +
750 g/t Nonionic Flocculant

(57) Abstract: Provided are processes for treating a tailings stream which comprises water and solids, the process comprising: (i) adding one or more anionic polymer flocculants and one or more nonionic polymer flocculants to the tailings stream; (ii) allowing at least a portion of the solids to flocculate; and (iii) separating at least a portion of the flocculated solids from the tailings stream.

PROCESSES FOR TREATING TAILINGS STREAMS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Application No. 61/857,467, filed July 23, 2013.

FIELD OF THE ART

[0002] The present disclosure relates to processes for the treatment of tailings streams from oil sands ore.

BACKGROUND

[0003] Bituminous sands, or oil sands, are a type of unconventional petroleum deposit. The sands contain naturally occurring mixtures of sand, clay, water, and a dense and extremely viscous form of petroleum technically referred to as bitumen (or colloquially "tar" due to its similar appearance, odor, and color). Oil sands are found in large amounts in many countries throughout the world, but are found in extremely large quantities in Canada and Venezuela. Oil sand deposits in northern Alberta in Canada (Athabasca oil sands) contain approximately 1.6 trillion barrels of bitumen, and production from oil sands mining operations is expected to reach 1.5 million barrels of bitumen per day by 2020.

[0004] Oil sands reserves have only recently been considered to be part of the world's oil reserves, as higher oil prices and new technology enable them to be profitably extracted and upgraded to usable products. They are often referred to as unconventional oil or crude bitumen, in order to distinguish the bitumen extracted from oil sands from the free-flowing hydrocarbon mixtures known as crude oil traditionally produced from oil wells.

[0005] Conventional crude oil is normally extracted from the ground by drilling oil wells into a petroleum reservoir, and allowing oil to flow into them under natural reservoir pressure, although artificial lift and techniques such as water flooding and gas injection are usually required to maintain production as reservoir pressure drops toward the end of a field's life. Because extra-heavy oil and bitumen flow very slowly, if at all, toward producing wells under normal reservoir conditions, the sands may be extracted by either strip mining or the oil made to flow into wells by in situ techniques which reduce the viscosity such as by injecting

steam, solvents, and/or hot air into the sands. These processes can use more water and require larger amounts of energy than conventional oil extraction, although many conventional oil fields also require large amounts of water and energy to achieve good rates of production.

[0006] The original process for extraction of bitumen from the sands was developed by Dr. Karl Clark, working with the Alberta Research Council in the 1920s. Today, producers using surface mining processes use a variation of the Clark Hot Water Extraction (CHWE) process. In this process, the ores are mined using open-pit mining techniques. The mined ore is then crushed for size reduction in relatively large tumblers or conditioning drums. Hot water at 40–80 °C is added to the ore, forming a slurry. The formed slurry may be conditioned and transported, for example using a piping system called hydrotransport line, to extraction units, for example to a primary separation vessel (PSV) in which a flotation process is used to recover bitumen as bitumen froth. The hydrotransport line may be configured to condition the oil sands stream while moving it to the extraction unit. The water used for hydrotransport is generally cooler (but still heated) than that in the tumblers or conditioning drums.

[0007] The displacement and liberation of bitumen from the sands is achieved by wetting the surface of the sand grains with an aqueous solution containing a caustic wetting agent, such as sodium hydroxide. The resulting strong surface hydration forces operative at the surface of the sand particles give rise to the displacement of the bitumen by the aqueous phase. For example, sodium hydroxide is added to the slurry to maintain a basic pH, e.g., in the range of 8.0 to 10. This has the effect of dispersing fines (particle size less than 44 µm) and clays from the oil sands and reducing the viscosity of the slurry, thereby reducing the particle size of the minerals in the oil sands.

[0008] Once the bitumen has been displaced and the sand grains are free, the components can be separated. Gravity can cause sand and rock from the slurry to settle to a bottom layer. A portion of the bitumen can float to the top based on the natural hydrophobicity exhibited by the free bituminous droplets at moderate alkaline pH values, and be removed as bitumen froth. An intermediate portion, often referred to as middlings, is relatively viscous and typically contains dispersed clay particles and some trapped bitumen which is not able to rise due to the viscosity. The middlings may then be exposed to froth flotation techniques to recover additional bitumen. (Hot water extraction of bitumen from Utah tar sands, Sepulveda *et al.* S. B. Radding, cd., Symposium on Oil Shale, Tar Sand, and

Related Material - Production and Utilization of Synfuels: Preprints of Papers Presented at San Francisco, California, August 29 - September 3, 1976; vol. 21, no. 6, pp. 110–122 (1976)).

[0009] The recovered bitumen froth generally consists of 60% bitumen, 30% water and 10% solids (sand and clay fines) by weight. The recovered bitumen froth may be cleaned to reject the contained solids and water to meet the requirement of downstream upgrading processes. Depending on the bitumen content in the ore, between 70 and 100% of the bitumen can be recovered using modern hot water extraction techniques from high grade ores.

[0010] Hydrophilic and biwetable ultrafine solids, mainly clays and other charged silicates and metal oxides, tend to form stable colloids in water and exhibit a very slow settling behavior, resulting in tailings ponds that take several years to dewater. The slow settling of fine (<44 μm) and ultrafine clays (<1 μm) and the large demand of water during oil sand extraction process have promoted research and development of new technologies during the last 20 years to modify the water release and to improve settling characteristics of tailings streams. These include process modifications such as variations in pH, salinity and addition of chemical substances. Currently, two technologies commonly used in the oil sands industry are the consolidated tailings (CT) process and the paste technology process. In the CT process, gypsum is used as a coagulant. In the paste technology process polyelectrolytes, generally polyacrylamides of high density, are used as flocculants. Flocculants, or flocculating agents, are chemicals that promote flocculation by causing colloids and other suspended particles in liquids to aggregate, forming a floc. Flocculants are used in water treatment processes to improve the sedimentation or filterability of small particles.

SUMMARY

[0012] Processes for treating a tailings stream which comprises water and solids, comprise: (i) adding one or more anionic polymer flocculants and one or more nonionic polymer flocculants to the tailings stream; (ii) allowing at least a portion of the solids to flocculate; and (iii) separating at least a portion of the flocculated solids from the tailings stream.

[0012a] Various embodiments of the claimed invention pertain to a process for treating a tailings stream which comprises water and solids, the process comprising: (i) adding one or more anionic polymer flocculants having a molecular weight of greater than about 500,000 Daltons and one or more nonionic polymer flocculants having a molecular weight of greater than about 1,000,000 Daltons to the tailings stream; (ii) allowing at least a portion of the solids to flocculate; and (iii) separating at least a portion of the flocculated solids from the tailings stream; wherein a total dosage of the polymer flocculants is about 1000 to about 10000 g/t dry tailings; wherein a ratio of a dosage of the one or more anionic polymer flocculants to the one or more nonionic polymer flocculants is from about 1:1 to about 10:3 by weight; and wherein the tailings stream is produced in a process to extract bitumen from an oil sands ore.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Figure 1 is a graph of the net water release for samples of mature fine tailings streams treated with anionic or nonionic polymer flocculants.

[0014] Figure 2 is a graph of the solids in the released water from samples of mature fine tailings streams treated with anionic or nonionic polymer flocculants.

[0015] Figure 3 is a graph of the flocculated bed solids from samples of mature fine tailings streams treated with anionic or nonionic polymer flocculants.

[0016] Figure 4 is a graph of the net water release for samples of mature fine tailings streams treated with exemplary mixtures of anionic and nonionic polymer flocculants.

[0017] Figure 5 is a graph of the solids in the released water from samples of mature fine tailings streams treated with exemplary mixtures of anionic and nonionic polymer flocculants.

[0018] Figure 6 is a graph of the flocculated bed solids from samples of mature fine tailings streams treated with exemplary mixtures of anionic and nonionic polymer flocculants.

[0019] Figure 7 is a graph of the of the net water release for samples of mature fine tailings streams treated with exemplary mixtures of anionic and nonionic polymer flocculants which shows the effect of the order of addition of the flocculants.

[0020] Figure 8 is a graph of the solids in the released water from samples of mature fine tailings streams treated with exemplary mixtures of anionic and nonionic polymer flocculants which shows the effect of the order of addition of the flocculants.

[0021] Figure 9 is a graph of the flocculated bed solids from samples of mature fine tailings streams treated with exemplary mixtures of anionic and nonionic polymer flocculants which shows the effect of the order of addition of the flocculants.

[0022] Figure 10 is a graph of the centrate solids as a function of flocculant dose and ratio of anionic to nonionic polymer flocculants from samples of mature fine tailings streams treated with anionic flocculants or exemplary mixtures of anionic and nonionic polymer flocculants.

[0023] Figure 11 is a graph of the cake solids as a function of flocculant dose and ratio of anionic to nonionic polymer flocculants from samples of mature fine tailings streams

treated with anionic flocculants or exemplary mixtures of anionic and nonionic polymer flocculants.

DETAILED DESCRIPTION

[0024] Disclosed herein are processes for enhancing separation of solids from tailings streams. Exemplary processes utilize blends of anionic polymer and nonionic polymer flocculants to enhance flocculation and separate the solids. By using the exemplary processes, a faster settling rate and a more complete separation of the solids from the water may be achieved, improving process efficiency relative to conventional processes for treating tailings streams. The processes may be used to enhance settling of solids, especially ultrafine solids, in oils sands ore tailings streams. The processes may be readily incorporated into current processing facilities and may provide economic and environmental benefits.

[0025] Exemplary processes for treating a tailings stream which comprises water and solids comprise: (i) adding one or more anionic polymer flocculants and one or more nonionic polymer flocculants to the tailings stream; (ii) allowing at least a portion of the solids to flocculate; and (iii) separating at least a portion of the flocculated solids from the tailings stream. In exemplary embodiments, the addition of the one or more anionic polymer flocculants and one or more nonionic polymer flocculants to the tailings stream results in the formation of flocculated solids.

[0026] The expressions “tailings”, “tailings stream”, “process oil sand tailings”, or “in-process tailings” as used herein refer to tailings that are directly generated as bitumen is extracted from oil sands. Generally, tailings are the discarded materials generated in the course of extracting the valuable material from ore. In tar sand processing, tailings comprise the whole tar sand ore and any net additions of process water thus missing the recovered bitumen. Any tailings fraction obtained from the process, such as tailings from primary separation cell, primary flotation and secondary flotation, process tailings and mature fine tailings or combination thereof, may be treated by the exemplary processes described herein. The tailings may comprise a colloidal sludge suspension containing clay minerals and/or metal oxides/hydroxides. In exemplary embodiments, the tailings stream comprises water and solids.

[0027] Oil sands process tailings contain mineral solids having a variety of particle sizes. Mineral fractions with a particle diameter greater than 44 microns are referred to as “coarse” particles, or “sand.” Mineral fractions with a particle diameter less than 44 microns

are referred to as “fines” and are essentially comprised of silica and silicates and clays that can be easily suspended in the water. Ultrafine solids ($<1\ \mu\text{m}$) may also be present in the tailings stream and are primarily composed of clays. The tailings may include one or more of the coarse particles, fine tailings, or ultrafine solids.

[0028] The tailings can include one or more of any of the tailings streams produced in a process to extract bitumen from an oil sands ore. In exemplary embodiments, the tailings may comprise paraffinic or naphthenic tailings, for example paraffinic froth tailings. The tailings may be combined into a single tailings stream for dewatering or each tailings stream may be dewatered individually.

[0029] In exemplary embodiments, the tailings stream is produced from an oil sands ore and comprises water and solids, for example sand and fines. In exemplary embodiments, the tailings stream comprises at least one of the coarse tailings, fine tailings, and ultrafine tailings. In particular, the processes may be used to treat ultrafine solids. In exemplary embodiments, the tailings stream comprises a fine (particle size $<44\ \mu\text{m}$) content of about 10 to about 100 wt%, about 20 to about 100 wt%, about 30 to about 100 wt%, or about 40 to about 90 wt% of the dry tailings. In exemplary embodiments, the tailings stream contains about 0.01 to about 5 wt% of bitumen. In exemplary embodiments, the oil sands ore tailings stream comprises process tailings.

[0030] As used herein, the terms “polymer,” “polymers,” “polymeric,” and similar terms are used in their ordinary sense as understood by one skilled in the art, and thus may be used herein to refer to or describe a large molecule (or group of such molecules) that contains recurring units. Polymers may be formed in various ways, including by polymerizing monomers and/or by chemically modifying one or more recurring units of a precursor polymer. A polymer may be a “homopolymer” comprising substantially identical recurring units formed by, e.g., polymerizing a particular monomer. A polymer may also be a “copolymer” comprising two or more different recurring units formed by, e.g., copolymerizing two or more different monomers, and/or by chemically modifying one or more recurring units of a precursor polymer. The term “terpolymer” may be used herein to refer to polymers containing three or more different recurring units. A polymer may also be linear, branched or crosslinked.

[0031] In exemplary embodiments, the one or more anionic polymer flocculants include, for example, flocculant-grade homopolymers, copolymers, and terpolymers prepared from monomers. In exemplary embodiments, the one or more anionic polymer flocculants

may be linear, branched, or crosslinked. In exemplary embodiments, the anionic polymer flocculant is a commercially available flocculant. In exemplary embodiments, one or more anionic polymer flocculants may have a molecular weight of greater than about 500,000; about 1,000,000; about 5,000,000; about 10,000,000; about 15,000,000; about 20,000,000; or about 25,000,000 Daltons. In exemplary embodiments, one or more anionic polymer flocculants may have a molecular weight in the range of about 500,000 to about 30,000,000 Daltons, or about 1,000,000 to about 30,000,000 Daltons.

[0032] In exemplary embodiments, the one or more anionic polymer flocculants are prepared by the polymerization of one or more anionic monomers or monomers comprising anionic functionality. In exemplary embodiments, the one or more anionic polymer flocculants are prepared by the polymerization of one or more anionic monomers or monomers comprising anionic functionality combined with nonionic co-monomers. In exemplary embodiments, the one or more anionic polymer flocculants comprise one or more monomers selected from monomers which comprise a carboxylic acid group, a sulfonic acid group or both.

[0033] In exemplary embodiments, the one or more anionic polymer flocculants may comprise monomers selected from the group consisting of acrylic, methacrylic, acrylamido, methacrylamido, vinyl, allyl, ethyl, maleic monomers and the like, all of which may be substituted with a carboxylic acid group, a sulphonic acid group, or both. In exemplary embodiments, monomers which may be substituted with a carboxylic acid group include, for example, acrylic acid, and methacrylic acid. In exemplary embodiments, monomers having a sulphonic function may include, for example, 2-acrylamido-2-methylpropane sulfonic acid (AMPS). In exemplary embodiments, the one or more anionic polymer flocculants is a copolymer comprising monomers of acrylic acid and acrylamide.

[0034] In exemplary embodiments, the one or more anionic polymer flocculants may comprise monomers selected from the group consisting of acrylic acid, methacrylic acid, 2-acrylamido-2-methyl-1-propanesulfonic acid, acrylamidomethylbutanoic acid, maleic acid, fumaric acid, itaconic acid, vinyl sulfonic acid, styrene sulfonic acid, vinyl phosphonic acid, allyl sulfonic acid, allyl phosphonic acid, sulfomethylated acrylamide, phosphonomethylated acrylamide and salts thereof, for example alkali metal, alkaline earth metal and ammonium salts thereof. In exemplary embodiments, the salts are water soluble. In exemplary embodiments, the salt is an alkali metal salt, for example a lithium salt, a sodium salt, a potassium salt, a rubidium salt, or a cesium salt. In exemplary embodiments, the salt is an

alkaline earth metal salt, for example a beryllium salt, a magnesium salt, a calcium salt, a strontium salt or a barium salt.

[0035] In exemplary embodiments, the monomer may be a derivative or salt of a monomer according the embodiments, for example an acrylate salt or salt of acrylic acid such as cation-containing acrylate or multivalent cation-containing acrylate. The cation of such exemplary monomers is for example, lithium, sodium, potassium, rubidium, cesium, beryllium, magnesium, calcium, strontium, barium, iron, aluminum or any suitable cation. In exemplary embodiments, the one or more anionic polymer flocculants may comprise calcium or magnesium-containing copolymer, for example, a copolymer comprising divalent or multivalent acrylate and acrylamido monomers. In exemplary embodiments, the one or more anionic polymer flocculants may comprise calcium or magnesium-containing terpolymer, for example, a terpolymer comprising divalent or multivalent acrylate, acrylamido and AMPS monomers. In exemplary embodiments, the one or more anionic polymer flocculants comprises one or more calcium-containing copolymers or terpolymers. In exemplary embodiments, the one or more anionic polymer flocculants comprises one or more magnesium-containing copolymers or terpolymers.

[0036] In exemplary embodiments, the one or more nonionic polymer flocculants include, for example, flocculant-grade homopolymers, copolymers, and terpolymers prepared from monomers. In exemplary embodiments, the one or more nonionic polymer flocculants may be linear, branched, or crosslinked. In exemplary embodiments, the nonionic polymer flocculant is a commercially available flocculant. In exemplary embodiments, one or more nonionic polymer flocculants may have a molecular weight of greater than about 1,000,000; about 5,000,000; about 10,000,000; about 15,000,000; about 20,000,000; or about 25,000,000 Daltons. In exemplary embodiments, one or more nonionic polymer flocculants may have a molecular weight in the range of about 1,000,000 to about 30,000,000 Daltons.

[0037] In exemplary embodiments, the one or more nonionic polymer flocculants are prepared by the polymerization of one or more nonionic monomers. In exemplary embodiments, the one or more nonionic polymer flocculants may comprise one or more hydrophobic monomer. In exemplary embodiments, the one or more nonionic polymer flocculants may comprise one or more polar functional groups.

[0038] In exemplary embodiments, the one or more nonionic polymer flocculants may comprise monomers selected from the group consisting of acrylic, methacrylic, acrylamido, methacrylamido, vinyl, allyl, ethyl or maleic monomers and the like, all of which

may be substituted with a side chain selected from, for example, an alkyl, arylalkyl, dialkyl, ethoxyl, and/or hydrophobic group. In exemplary embodiments, the one or more nonionic monomers are selected from the group consisting of: acrylamide, methacrylamide, N-vinyl pyrrolidone, N-vinyl formamide, N,N dimethylacrylamide, N-vinyl acetamide, N-vinylpyridine, N-vinylimidazole, isopropyl acrylamide and polyethelene glycol methacrylate.

[0039] In exemplary embodiments, the total dosage of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants is in the range of about 1 to about 2000, about 500 to about 2000, about 1 to about 5000, or about 1 to about 10,000, grams of dry polymer per ton of dry tailings (g/t). In exemplary embodiments, the total dosage of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants is in the range of about 0.01 to about 0.5, or about 0.1 to about 1, weight percent of dry tailings. In exemplary embodiments, the total dosage of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants is about 0.01, about 0.02, about 0.03, about 0.04, about 0.05, about 0.06, about 0.07, about 0.08, about 0.09, or about 0.1 weight percent of the dry tailings.

[0040] In exemplary embodiments, the one or more anionic polymer flocculants are in an aqueous solution or in an emulsion. In exemplary embodiments, the one or more nonionic polymer flocculants are in an aqueous solution or in an emulsion or inverse emulsion. In exemplary embodiments, the one or more anionic polymer flocculants are in dry form. In exemplary embodiments, the one or more nonionic polymer flocculants are in dry form. In exemplary embodiments, the one or more anionic polymer flocculants and the one or more nonionic flocculant are premixed, for example as a dry blend or in an aqueous solution or emulsion.

[0041] In exemplary embodiments, the one or more anionic polymer flocculants may be added to the tailings stream in dry form, in an emulsion, or in an aqueous solution. In exemplary embodiments, the one or more nonionic polymer flocculants may be added to the tailings stream in dry form, in an emulsion, or in an aqueous solution.

[0042] In the exemplary embodiments, the total dosage of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants can be any dosage that will achieve a necessary or desired result. In other exemplary embodiments, the total dosage of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants added to the tailings stream are in the range of about 100 to about 100,000 grams of the one or more anionic polymer flocculants and the one or more nonionic polymer

flocculants mixture per dry ton (g/t) of dry tailings. In exemplary embodiments, the total dosage of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants is from about 500 to about 10000 g/t, about 1000 to about 10000 g/t, or about 1000 to about 5000 g/t. In exemplary embodiments, the total dosage of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants is about 500 g/t, about 700 g/t, about 1000 g/t, about 1500 g/t, about 2000 g/t, about 2500 g/t, about 3000 g/t, about 3500 g/t, about 4000 g/t, about 45000 g/t, or about 5000 g/t dry tailings.

[0043] In exemplary embodiments, the ratio of dosage of the one or more anionic polymer flocculants to the dosage of the one or more nonionic polymer flocculants can be any dosage that will achieve a necessary or desired result. In exemplary embodiments, the ratio of the dosage of the one or more anionic polymer flocculants to the one or more nonionic polymer flocculants is from about 1:100 to about 100:1, about 1:50 to about 50:1, about 1:25 to about 25:1, about 1:10 to about 10:1, or about 1:2 to about 2:1 by weight. In exemplary embodiments, the ratio of the dosage of the one or more anionic polymer flocculants to the dosage of the one or more nonionic polymer flocculants is about 10:1, 5:1, 3:1, 2:1, 1:1, 1:2, 1:3, 1:5 or 1:10 by weight.

[0044] In exemplary embodiments, the ratio of the dosage of the one or more anionic polymer flocculants to the one or more nonionic polymer flocculants is from about 1:1 to about 100:1, about 1:1 to about 50:1, about 1:1 to about 25:1, about 1:1 to about 10:1, about 1:1 to about 10:3; or about 1:1 to about 2:1 by weight.

[0045] In exemplary embodiments, the one or more nonionic polymer flocculants are added to the tailings stream before the one or more anionic polymer flocculants. In exemplary embodiments, the one or more anionic polymer flocculants are added to the tailings stream before the one or more nonionic polymer flocculants. In exemplary embodiments, the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants are premixed, for example as a dry blend or in an aqueous solution, before being added to a tailings stream. In exemplary embodiments, the one or more anionic polymer flocculants and the one or more nonionic flocculants are added to the tailings stream simultaneously or substantially at the same time.

[0046] In exemplary embodiments, the separation step may be accomplished by any means known to those skilled in the art, including but not limited to centrifuges, hydrocyclones, decantation, filtration, thickeners, or another mechanical separation method.

[0047] In exemplary embodiments, the process may provide enhanced flocculation of solid materials in the tailings, better separation of the solids from water, an increased rate of separation of the solids from the water, and/or may expand the range of operating conditions which can be tolerated while still achieving the desired level of separation of solids from the water within a desired period of time.

[0048] The exemplary processes described herein may provide flocculated beds with higher densities, leading to compact beds that can dewater faster and build yield strength faster than comparable treatments without the addition of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants. In an exemplary embodiment, the processes accelerate dewatering of the tailings stream.

[0049] In exemplary embodiments, the processes may achieve a clarified water phase with about 0.5% to about 3.0% solids within 8 hours. In exemplary embodiments, the processes may achieve a clarified water phase with less than about 0.5% solids within 8 hours. In exemplary embodiments, the processes may achieve a clarified water phase with less than 0.01% solids within 24 hours.

[0050] In exemplary embodiments, the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants can be added prior to and/or during a bitumen extraction process. In exemplary embodiments, the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants are contacted with the oil sands ore at a primary separation step or in a primary separation vessel.

[0051] In exemplary embodiments, the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants may be added in any mixing, conditioning, or separation step in the bitumen extraction process or treatment of oil sand ore tailings stream process. In view of the embodiments described herein, it will be understood that the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants could be added at other points in the bitumen recovery/extraction process as necessary or desired.

[0052] In exemplary embodiments, the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants may be added to the tailings stream before or after desanding. Desanding is a process wherein the tailings are settled for a period of time to form desanded tailings as the supernatant. Desanding can be done also for example by using a hydrocyclone.

[0053] In exemplary embodiments, the processes be used in the presence, or with the addition of, one or more additives. Exemplary additives include but are not limited to coagulants, surfactants, anti-foaming agents, polymers, flocculants, mineral oils, mixture thereof, and other necessary or desired additives. In exemplary embodiments, the additives are in an amount of 0.01 to 50 weight percent based on a total weight of dry ore or tailings. The addition of other additives to the tailings stream may occur at any point in the process as necessary or desired, including simultaneously, before or after the step of adding the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants.

[0054] In exemplary embodiments, the process provides efficient dewatering of the tailings and no other chemicals are necessary as the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants are sufficient.

[0055] According to the exemplary embodiments, the clays in the supernatant, which may be present as a very dilute suspension, can be flocculated and separated from the tailings stream.

[0056] In certain embodiments, the process optionally comprises adding one or more cationic coagulants or cationic flocculants to the tailings stream. The one or more cationic coagulants or flocculants may be added to the tailings stream before, after or at the same time as the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants are added to the tailings stream. In an exemplary embodiment, a cationic coagulant or flocculant may be added to the supernatant. In exemplary embodiments, the cationic flocculant or coagulant is a poly(diallyl dimethyl ammonium chloride) compound; an cpi-polyamine compound; a polymer that contains one or more quaternized ammonium groups, such as acryloyloxyethyltrimethylammonium chloride, methacryloyloxyethyltrimethylammonium chloride, methacrylamidopropyltrimethylammonium chloride, acrylamidopropyltrimethylammonium chloride; or a mixture thereof. In exemplary embodiments, one or more inorganic coagulants may be added to the tailings stream. An inorganic coagulant may, for example, reduce, neutralize or invert electrical repulsions between particles. Exemplary inorganic coagulants include inorganic salts such as aluminum sulfate, ferric chloride, lime, calcium chloride, magnesium chloride, or various commercially available iron or aluminum salts coagulants.

[0057] In exemplary embodiments, the processes may be used to dewater the tailings to provide a solid material having any necessary or desired yield strength. In exemplary embodiments, the dewatered tailings may have sufficient yield strength so as to

provide trafficable solids. In exemplary embodiments, the dewatered tailings may possess a yield stress of greater than about 5000 Pa after one year, or a yield stress of greater than about 10000 Pa within five years.

[0058] In the exemplary embodiments, the dewatered solids may be handled or processed in any manner as necessary or desired. In one embodiment, the dewatered solids should be handled in compliance with governmental regulations. In some embodiments, the resultant solids may be disposed of, sent to a tailings pond for additional settling, or when solids are a concentrated source of minerals, the solids may be used as raw materials or feed to produce compounds for commercial products. In the exemplary embodiments, the separated water may be handled or processed in any manner as necessary or desired. In one embodiment, the separated water may be recycled to the process (“recycled water”). For example, the recycled water may be added to the crushed oil sands ore for bitumen extraction. Recycled water may also be added to the process at any point where water is added.

[0059] In exemplary embodiments, the processes may be carried out at broad pH conditions, such as a pH of about 6 to about 12, or about 8.5 to about 10.5. In exemplary embodiments, the pH of the tailings stream is adjusted prior to the addition of the flocculants. In exemplary embodiments, the pH of the tailings stream is not adjusted prior to the addition of the flocculants.

[0060] In the exemplary embodiments, the processes may be carried out at temperature of about 0°C to about 100°C, or about ambient temperature to about 90°C, or about 20°C to about 90°C.

[0061] In one embodiment, the processes produce at least about 20 %, at least about 25 %, about 30 %, about 35 %, about 40 %, or about 50 %, by weight, of bed solids.

[0062] In one embodiment, the processes produce less than about 3 wt%, about 2.5 wt%, about 2 wt%, about 1.5 wt%, about 1 wt%, about 0.5 wt%, or about 0.3 wt% solids in the supernatant.

[0063] In order that the disclosure may be more readily understood, reference is made to the following examples, which are intended to illustrate the invention, but not limit the scope thereof.

EXAMPLES

[0064] Example 1.

[0065] Samples of mature fine tailings and oil sands process-affected water (OSPW) were obtained from a major oil sand producer in Alberta, Canada. The MFT were diluted to 20 wt% with OSPW and treated with a series of flocculant-grade anionic polymer solutions that had been prepared at concentrations of 0.2 wt% in OSPW. The anionic polymer was a copolymer of 30 mol % acrylic acid and 70 mol% acrylamide with an average molecular weight between 1,000,000 and 20,000,000 Daltons.

[0066] Mixing measurements were conducted on an Anton Paar MCR 300 rheometer equipped with an ST 60-2HR-90/188.5 helical impeller. For mixing experiments, an MFT suspension (650 g) was poured into a 1-L beaker, which was then placed under the rheometer and mixed at a constant speed while the torque was measured over time. After 60 seconds of mixing, a flocculant was injected (1500 g/t) at the bottom of the beaker and the changes in torque were followed.

[0067] Flocculant addition took approximately 20 s (the second flocculant was added immediately after the first and each addition lasted about 10 s). Ten seconds later (90 s after the test started; 30 s after beginning flocculant addition) a series of aliquots (16 g on average) were collected at regular intervals and allowed to sediment for 16 hours in glass vials. The net water loss and solids contents of the supernatants and flocculated beds were calculated gravimetrically.

[0068] Mixing energies were calculated from torque vs. time curves according to Equation 1,

$$\varepsilon = 2\pi N \int_0^t (M - M_0) dt \quad (1)$$

[0069] where ε is the mixing energy (J), N the mixing speed (revolutions per second), M the torque (N•m), M_0 the no-load torque (N•m), and t the time (s). The mixing energy is then normalized by the sample volume (700 mL) to obtain the mixing energy per unit volume, typically expressed as kJ/m³.

[0070] Net water release was calculated according to Equation 2,

$$NWR = \frac{W_R - W_A}{W_0} \times 100 \quad (2)$$

[0071] where NWR is the net water release (%), W_0 is the initial mass of water in the sample (g), W_R the mass of water released (g), and W_A the mass of water added when the flocculant solution was dosed into the MFT suspension (g).

[0072] Figures 1 – 3 show the net water release, solids in released water, and flocculated bed solids of MFT treated with 1500 g/t of an anionic flocculant and 1500 g/t of a nonionic flocculant, then allowed to settle. The nonionic flocculant results in more water released and a higher concentration of flocculated bed solids, but the anionic flocculant results in lower solids in the released water.

[0073] When the two polymers are mixed in different proportions and used to treat MFT by gravitational settling, the anionic/nonionic flocculant blend does not perform like a weighted average of its two single components. Instead, the net water release and flocculated bed solids resemble the nonionic single treatment and the solids in the release water resemble the anionic single treatment (see Figures 4-6). Order of addition can also affect performance (see Figures 7 – 9).

[0074] Example 2.

[0075] Samples of mature fine tailings and oil sands process-affected water (OSPW) were obtained from a major oil sand producer in Alberta, Canada. The MFT were diluted to 20 wt% with OSPW, while a series of flocculant-grade anionic polymer solutions were prepared at concentrations of 0.4 wt% in OSPW.

[0076] A 50-g sample of the 20 wt% MFT was added to a 100 mL beaker, followed by 500 g/t of an inorganic coagulant. Next, the anionic and nonionic flocculant were added to the MFT, with the nonionic/anionic ratio and total flocculant dose systematically varied. The sample was mixed, then transferred to a 50 mL centrifuge tube and centrifuged at 3000 rpm for 2 minutes. Finally, the centrate was decanted from the sample and the centrate and bed solids were calculated gravimetrically.

[0077] The results are summarized in Table 1 and illustrated in Figures 10 and 11. Increasing the ratio of nonionic to anionic polymer from 0 to either 0.3 or 1.0 significantly improves the quality of the centrate while not compromising the bed solids. Especially notable is that the nonionic polymer allows the centrate solids to fall to the 1 wt% concentration mark.

[0078] Table 1. Centrifugation of MFT treated with a coagulant, a nonionic flocculant, and an anionic flocculant.

Nonionic Flocculant Dose (g/t)	Anionic Flocculant Dose (g/t)	Total Flocculant Dose (g/t)	Nonionic/Anionic Ratio (wt/wt)	Coagulant Dose (g/t)	Centrate Solids (wt%)	Change in Bed Solids (wt%) from Nonionic/Anionic Ratio = 0
0	500	500	0	500	1.96	-
125	375	500	0.3	500	1.65	-0.10
250	250	500	1	500	2.04	+0.40
0	1000	1000	0	500	1.59	-
250	750	1000	0.3	500	1.11	-0.80
500	500	1000	1	500	1.29	-0.40
0	1500	1500	0	500	1.73	-
375	1125	1500	0.3	500	0.96	-2.70
750	750	1500	1	500	0.94	-1.30
0	2000	2000	0	500	1.62	-
500	1500	2000	0.3	500	1.04	-0.50
1000	1000	2000	1	500	0.73	-0.20

[0079] In the preceding specification, various exemplary embodiments have been described. It will, however, be evident that various modifications and changes may be made thereto, and additional embodiments may be implemented, without departing from the broader scope of the exemplary embodiments as set forth in the claims that follow. The specification and drawings are accordingly to be regarded in an illustrative rather than restrictive sense.

We Claim:

1. A process for treating a tailings stream which comprises water and solids, the process comprising:

(i) adding one or more anionic polymer flocculants having a molecular weight of greater than about 500,000 Daltons and one or more nonionic polymer flocculants having a molecular weight of greater than about 1,000,000 Daltons to the tailings stream;

(ii) allowing at least a portion of the solids to flocculate; and

(iii) separating at least a portion of the flocculated solids from the tailings stream;

wherein a total dosage of the polymer flocculants is about 1000 to about 10000 g/t dry tailings;

wherein a ratio of a dosage of the one or more anionic polymer flocculants to the one or more nonionic polymer flocculants is from about 1:1 to about 10:3 by weight; and

wherein the tailings stream is produced in a process to extract bitumen from an oil sands ore.

2. The process of claim 1, wherein the one or more anionic polymer flocculants is added before the one or more nonionic polymer flocculants.

3. The process of claim 1, wherein the one or more nonionic polymer flocculants is added before the one or more anionic polymer flocculants.

4. The process of claim 1, wherein the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants are premixed before being added to the tailings stream.

5. The process of claim 4, wherein the premixed flocculants are in a dry blend, in an emulsion or in an aqueous solution.

6. The process of claim 1, 2 or 3, wherein the one or more anionic polymer flocculants are a dry blend, in an emulsion or in an aqueous solution.

7. The process of claim 1, 2 or 3, wherein the one or more nonionic polymer flocculants are a dry blend, in an emulsion or in an aqueous solution.

8. The process of any one of claims 1 to 7, wherein the addition of the one or more anionic flocculants and the one or more nonionic flocculants accelerates the consolidation and/or sedimentation of the flocculated solids in the tailings stream.

9. The process of any one of claims 1 to 8, wherein the ratio of the dosage of the one or more anionic polymer flocculants to the one or more nonionic polymer flocculants is about 1:1 by weight.
10. The process of any one of claims 1 to 9, wherein the total dosage of the one or more anionic polymer flocculants and the one or more nonionic polymer flocculants is about 1000 to about 5000 g/t dry tailings.
11. The process of any one of claims 1 to 10, wherein the separation of the solids from the tailings stream is by centrifuge, hydrocyclone, decantation, filtration, thickening or another mechanical separation.
12. The process of any one of claims 1 to 11, wherein the process further comprises a desanding step.

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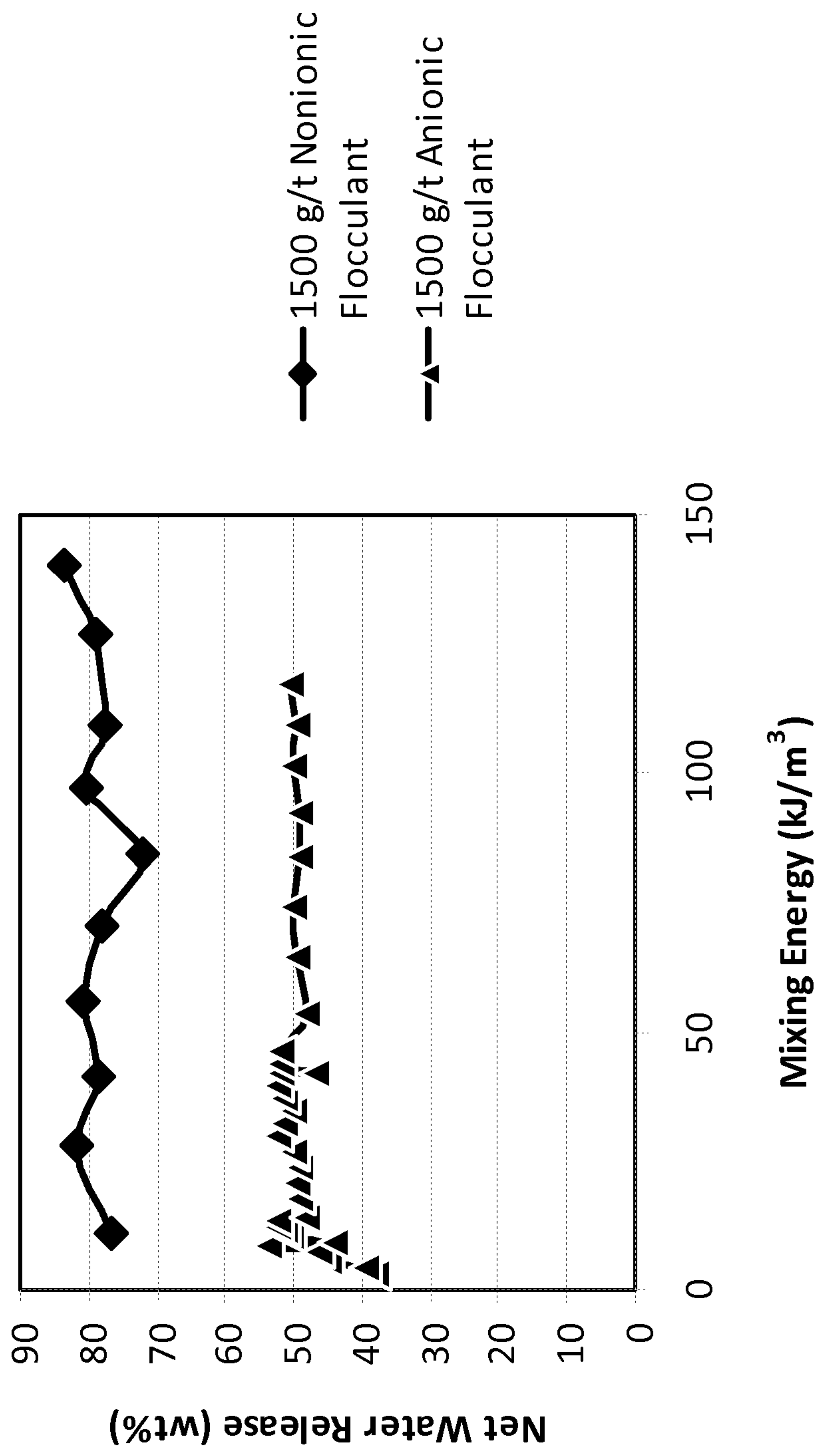


Figure 1

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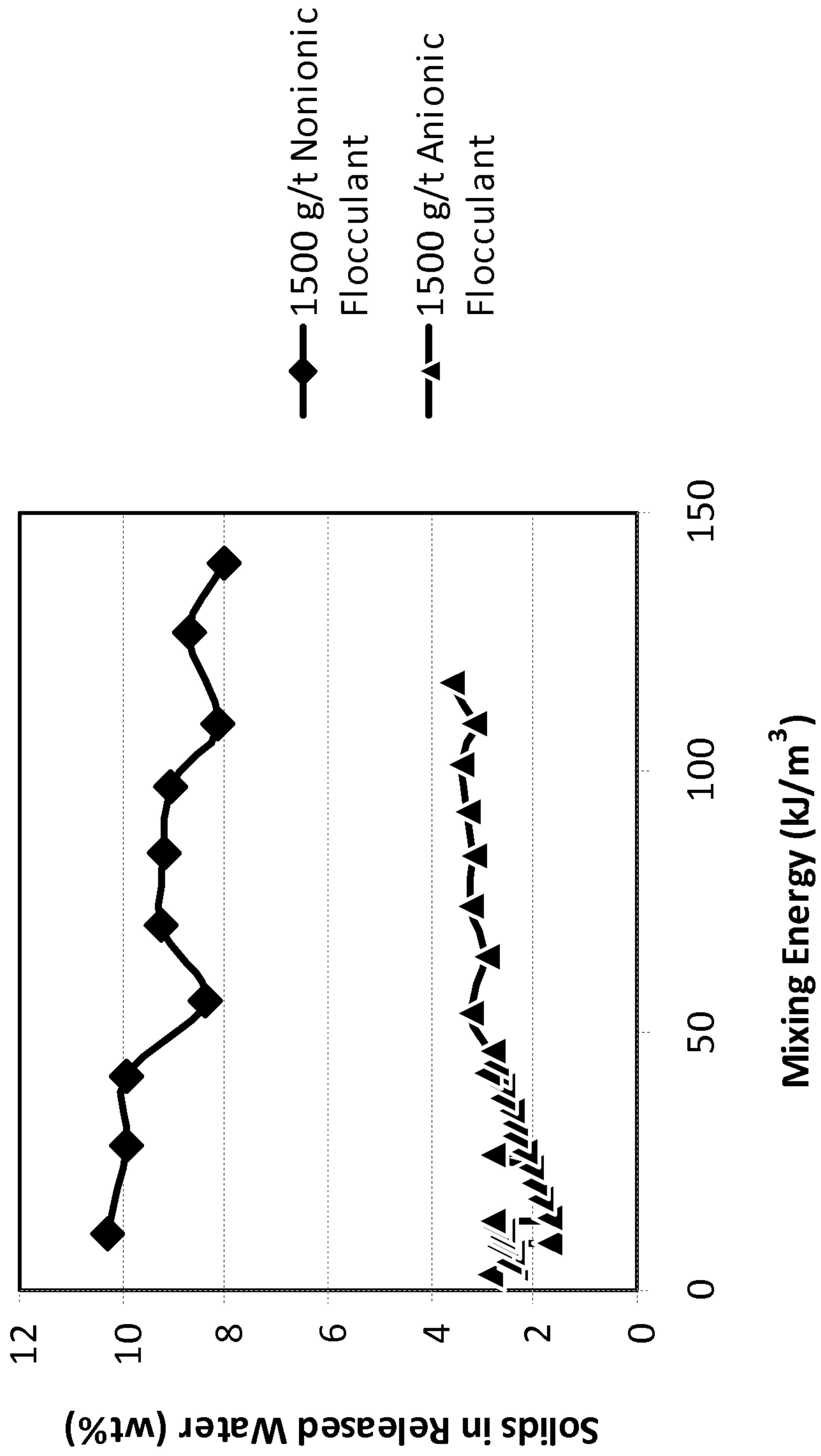


Figure 2

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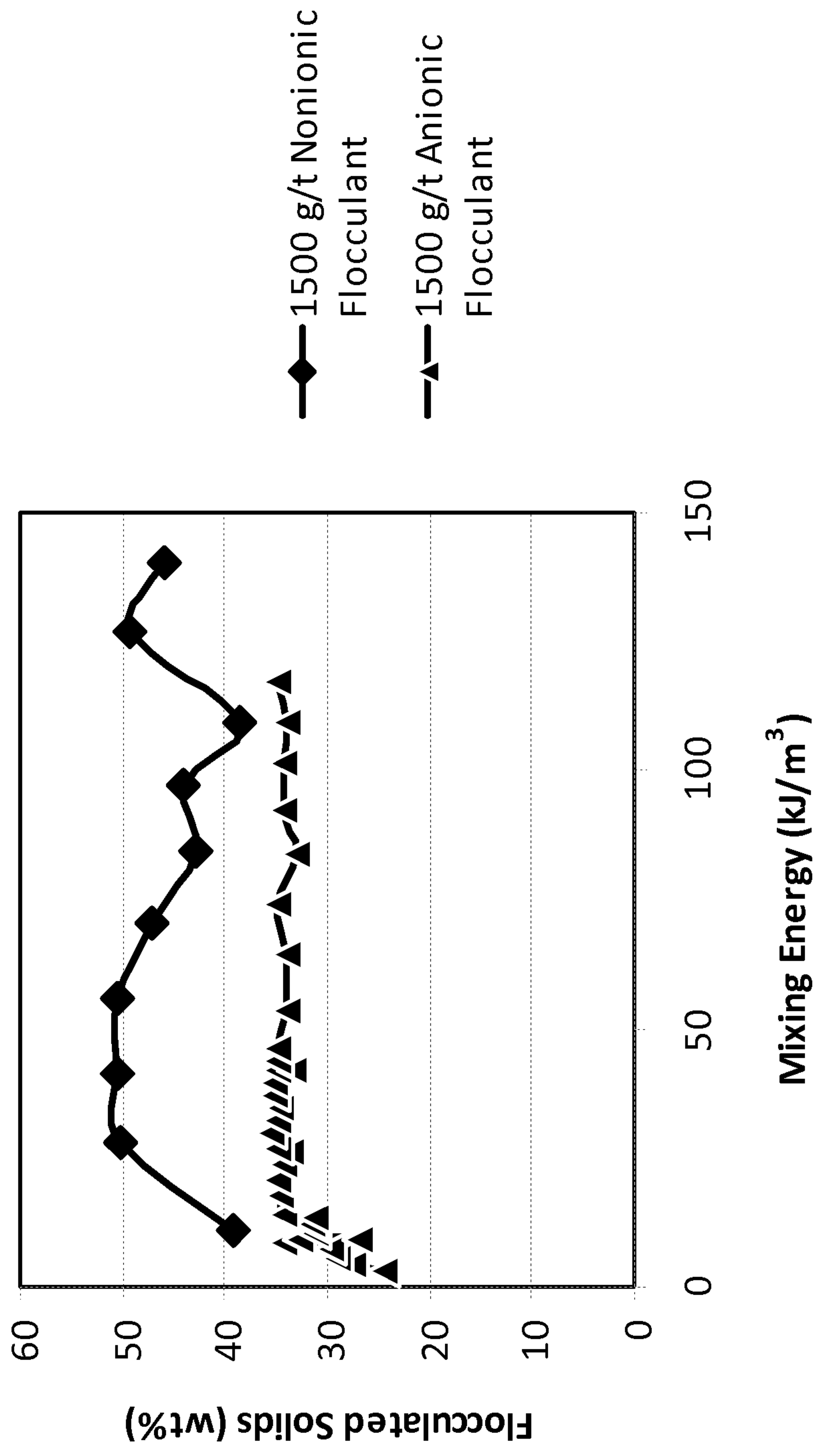


Figure 3

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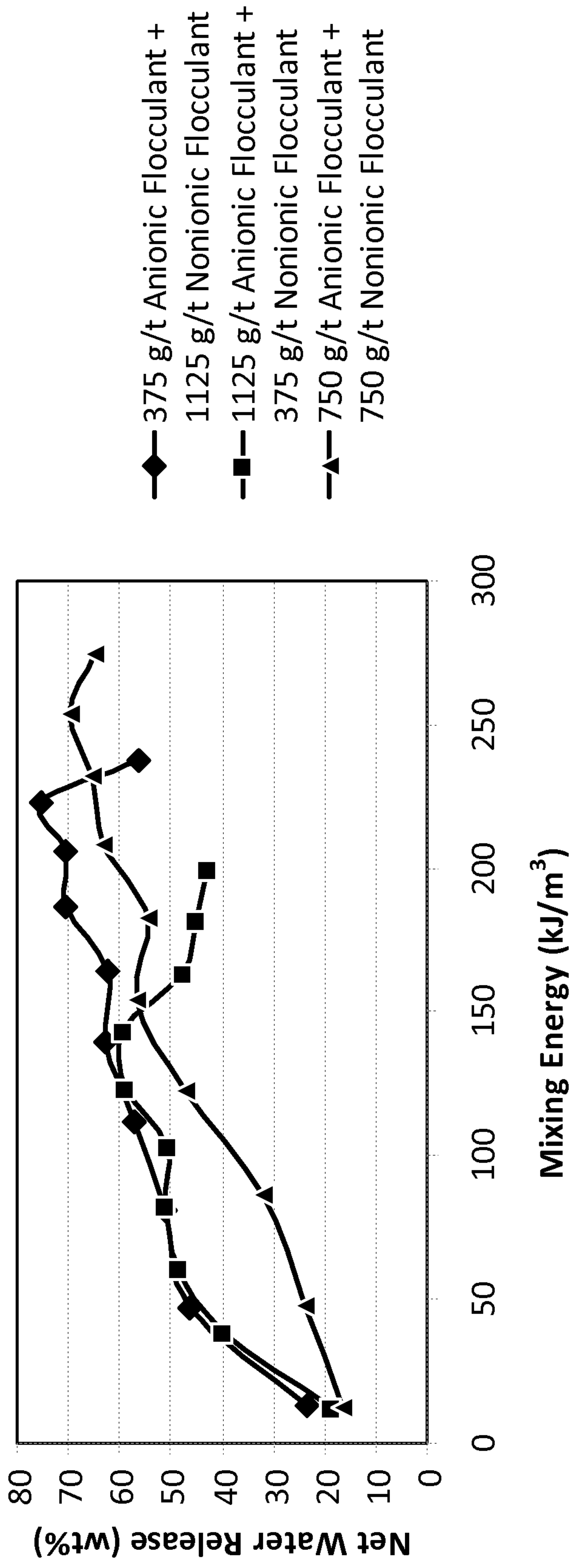


Figure 4

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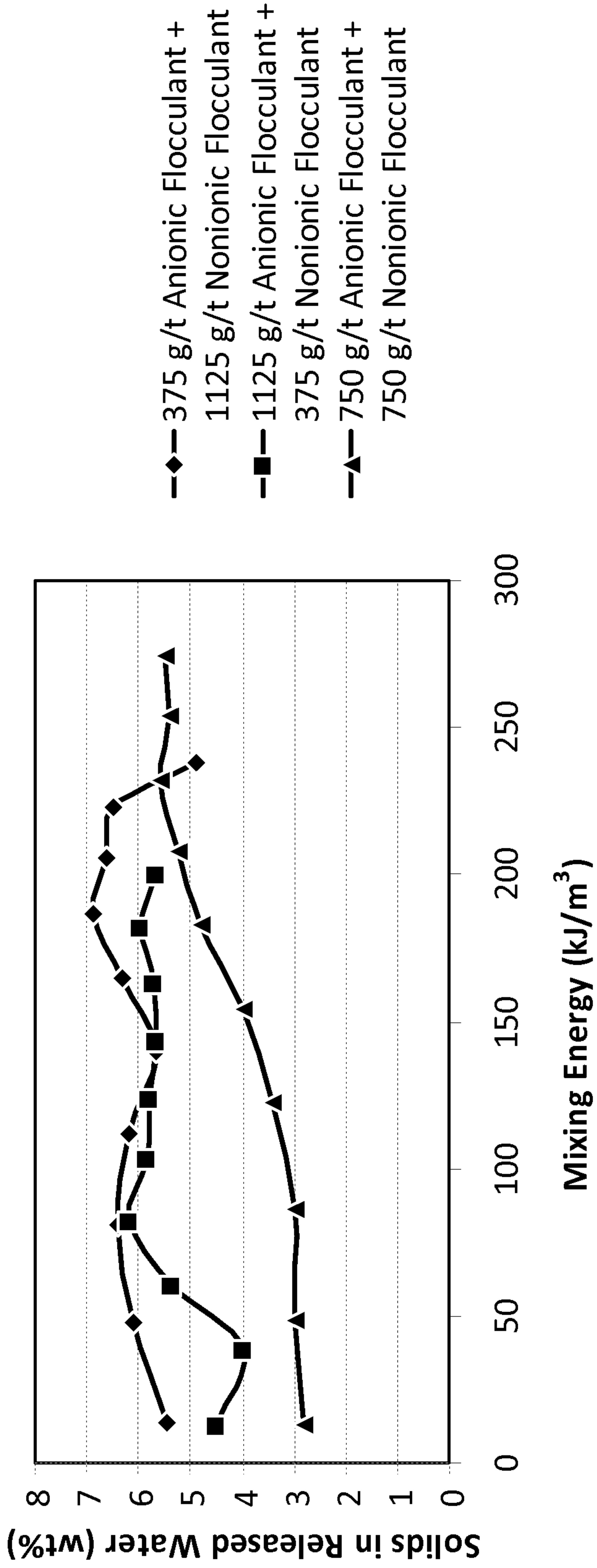


Figure 5

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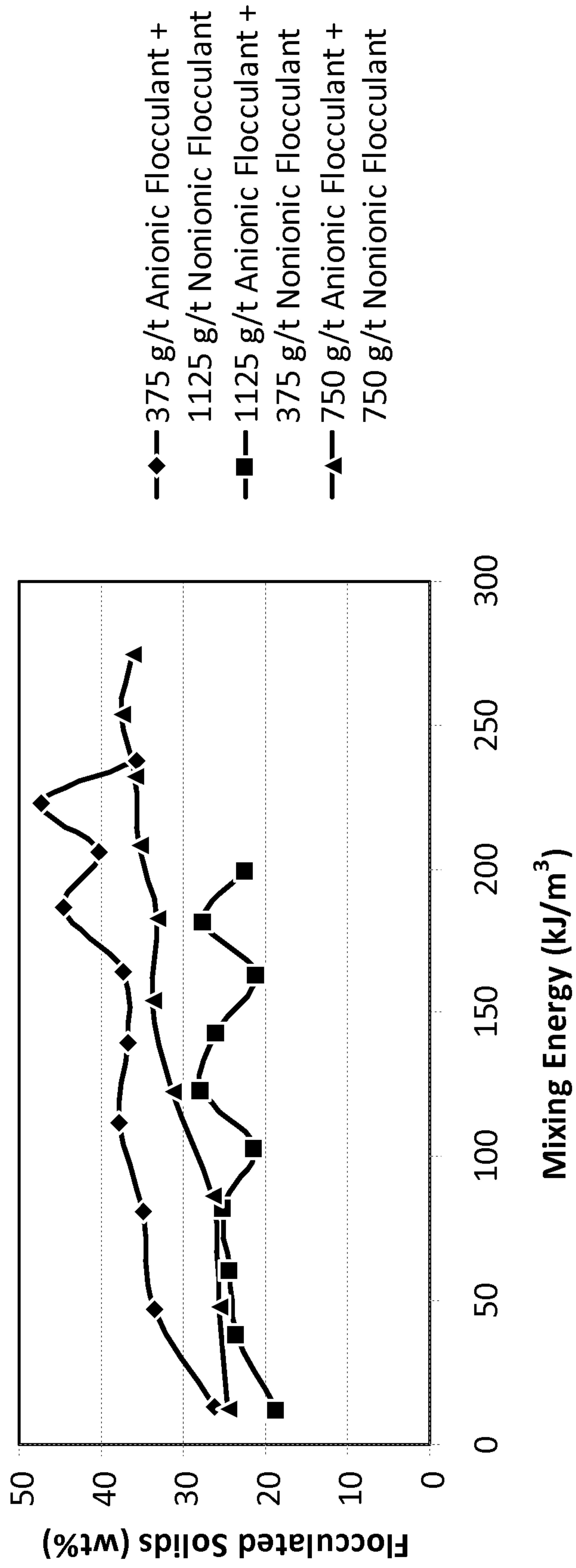


Figure 6

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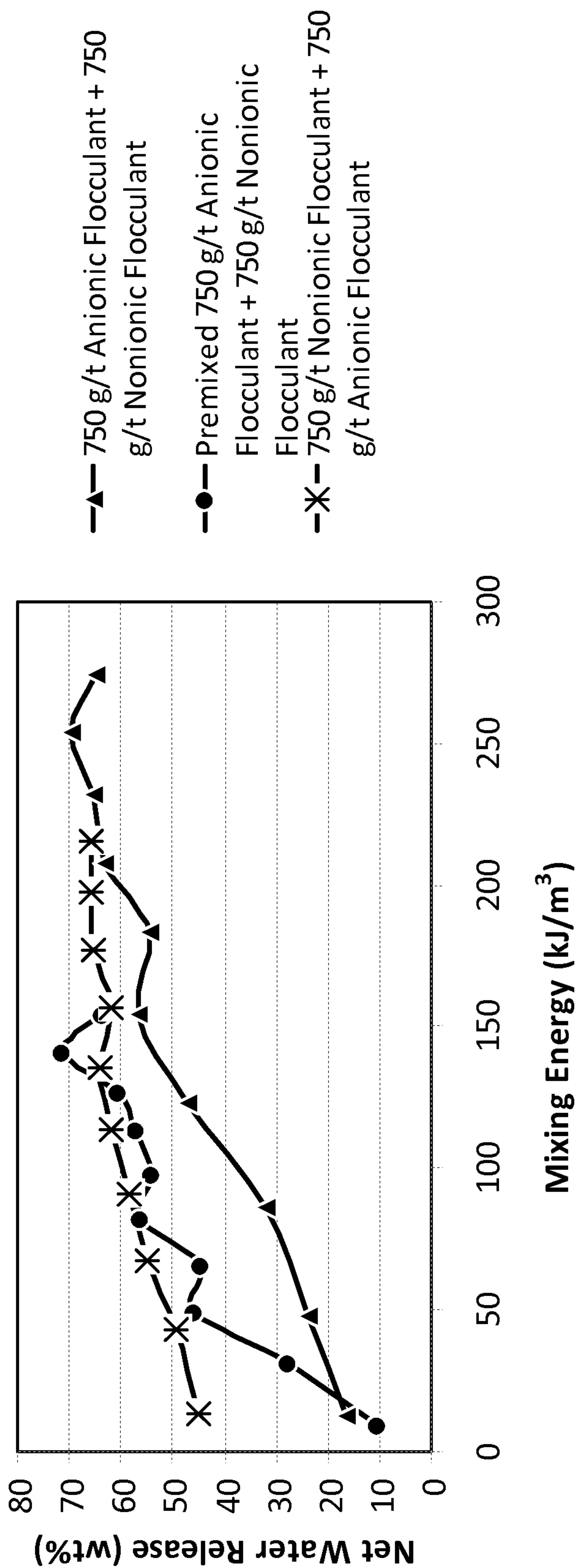


Figure 7

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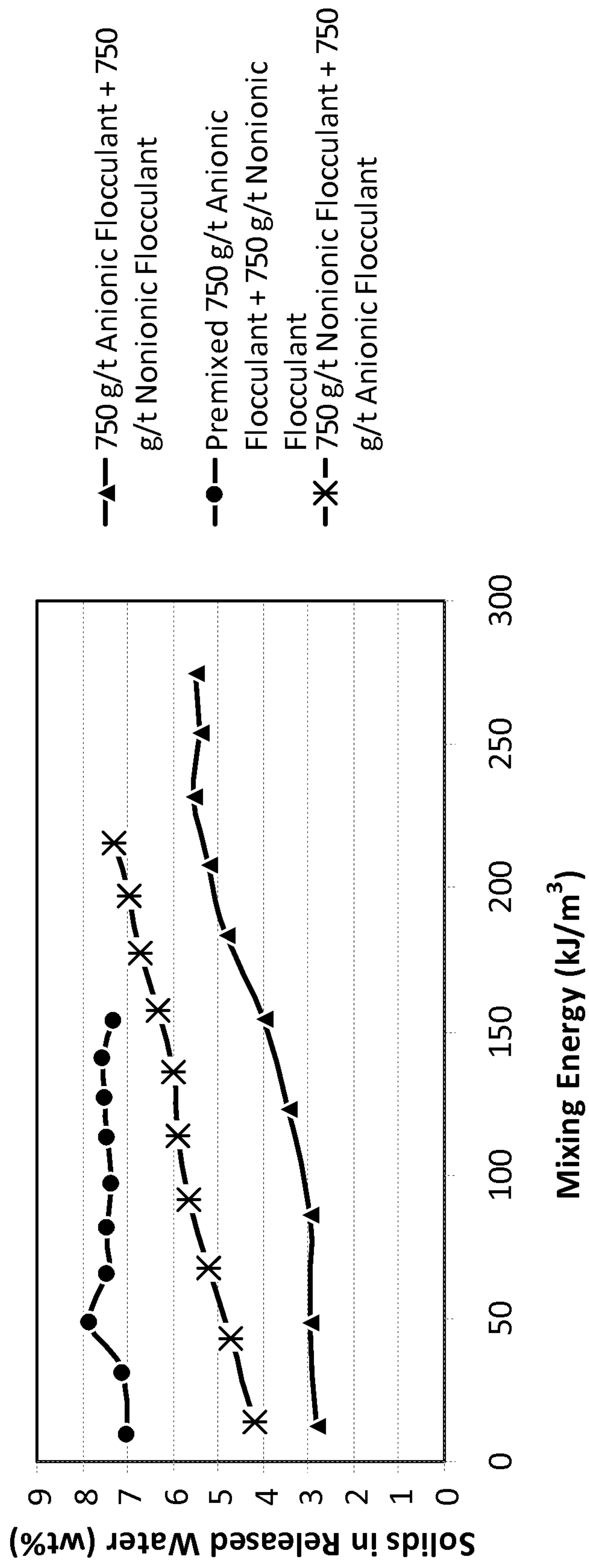


Figure 8

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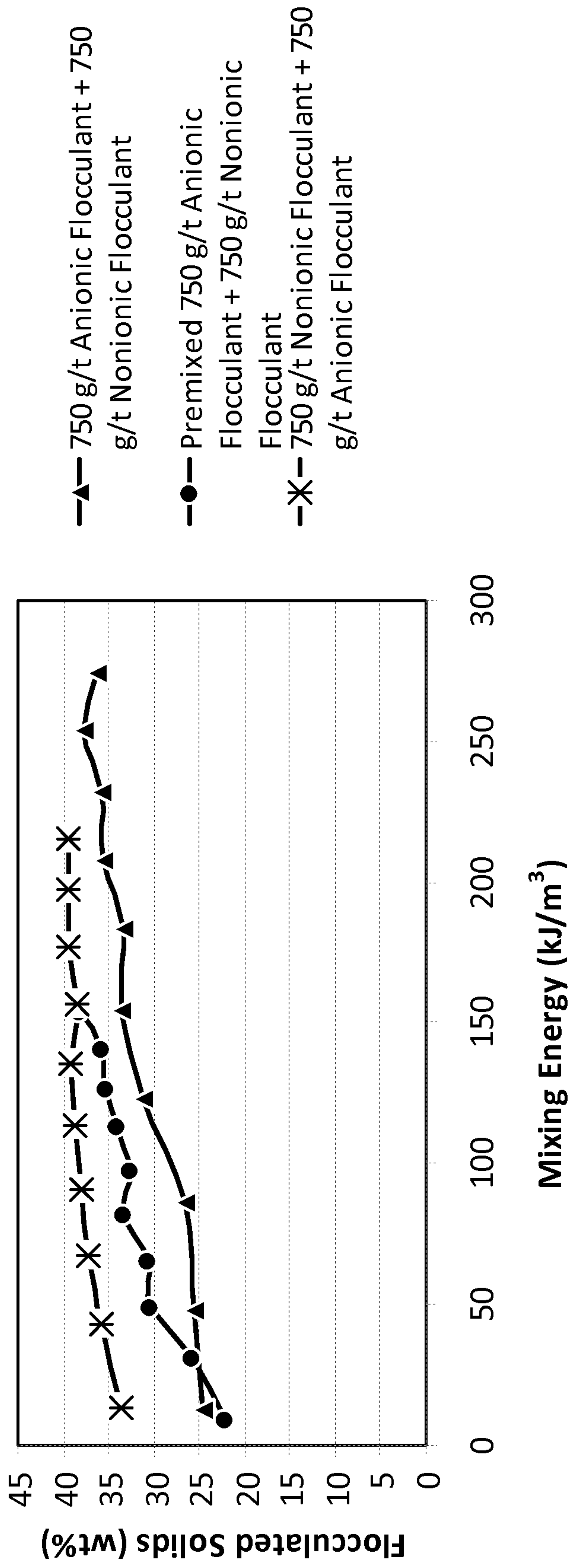


Figure 9

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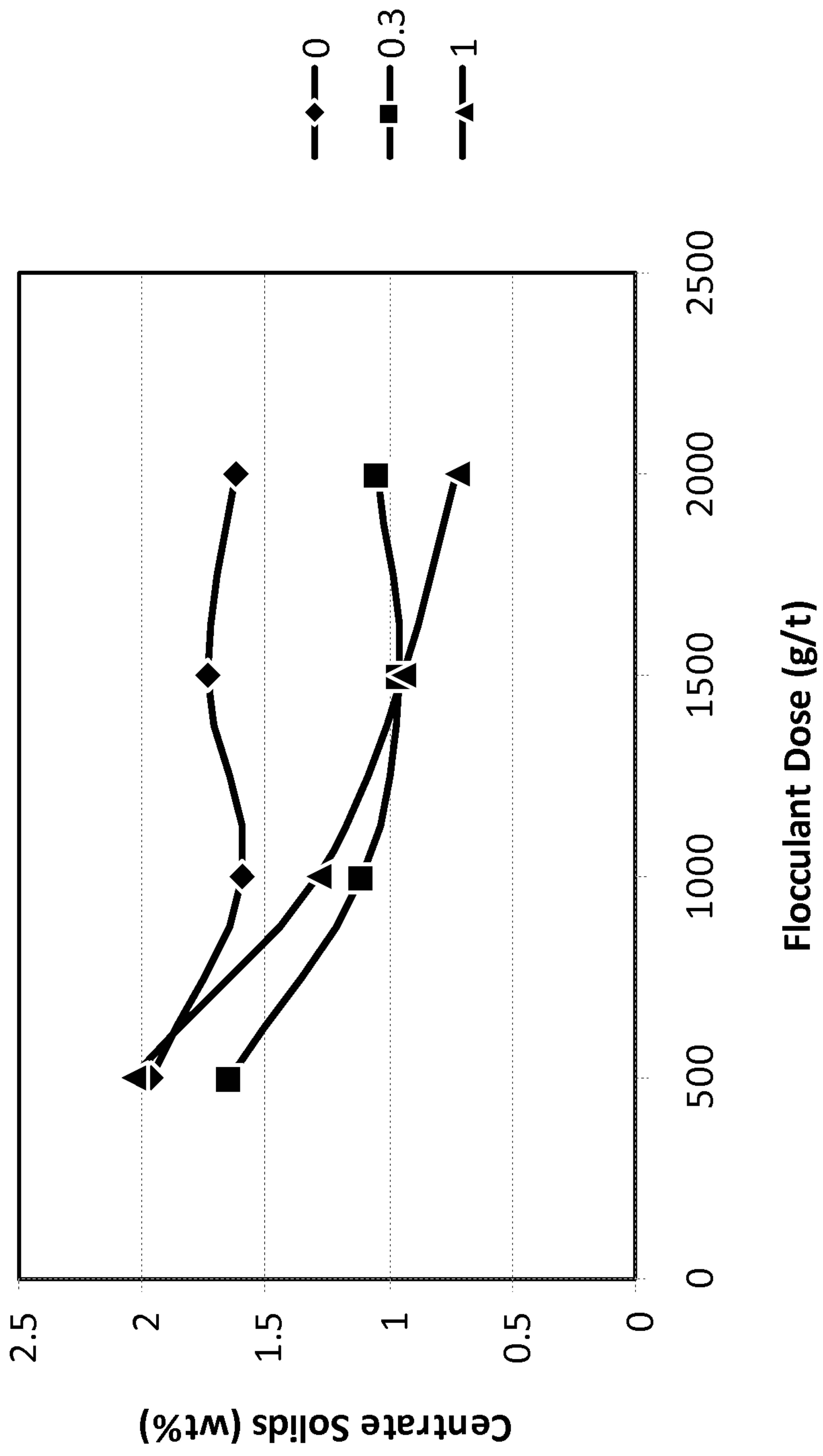


Figure 10

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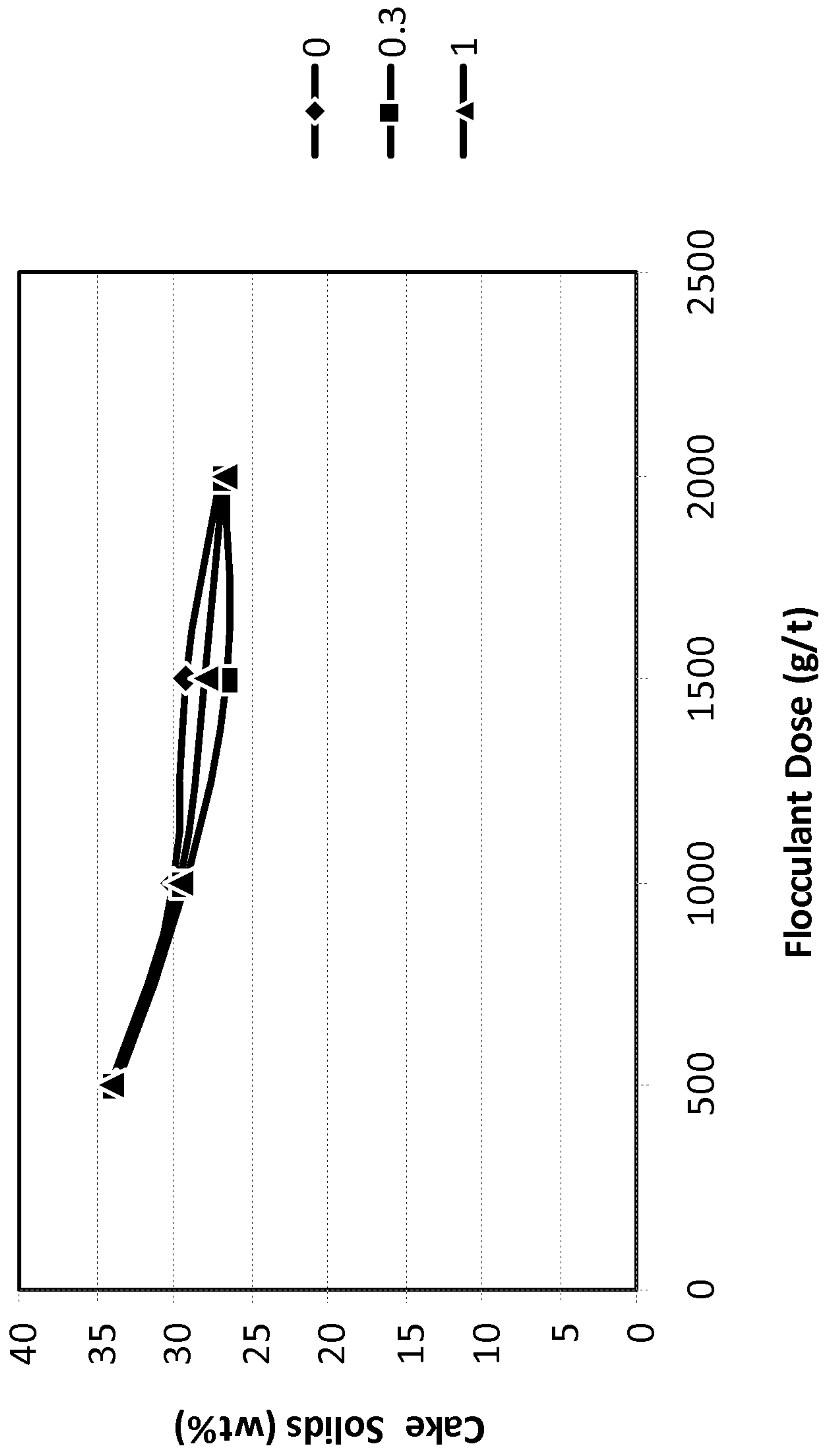
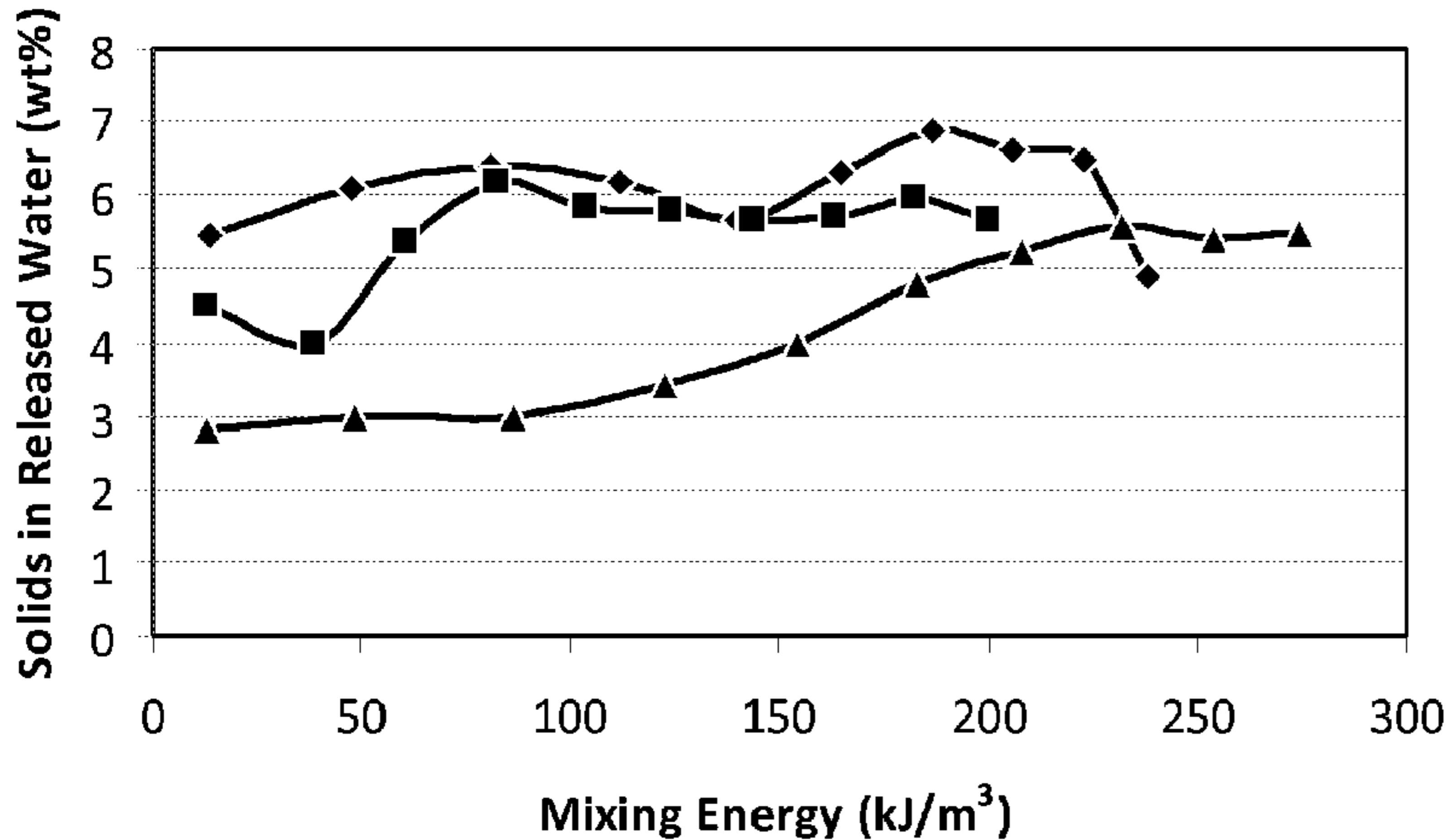


Figure 11



- ◆ 375 g/t Anionic Flocculant + 1125 g/t Nonionic Flocculant
- 1125 g/t Anionic Flocculant + 375 g/t Nonionic Flocculant
- ▲ 750 g/t Anionic Flocculant + 750 g/t Nonionic Flocculant