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**Title:** PROCESS FOR DENSITY SEPARATION USING IMMISCIBLE LIQUIDS

**Abstract:** A technique for separating particles by density is described using an emulsion formed from two or more immiscible liquids. The liquids preferably have different densities. The emulsion is formed to have a desired overall density that is between the densities of lightest and heaviest particles in a feedstock to be separated.
PROCESS FOR DENSITY SEPARATION USING IMMISCIBLE LIQUIDS

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part application (CIP) and claims priority upon US application Serial No. 11/301,003, filed February 6, 2004. This application also claims priority upon US provisional applications Serial No. 60/985,303 filed November 5, 2007; and Serial No. 61/037,848 filed March 19, 2008.

FIELD OF THE INVENTION

[0001] The present invention is directed to the field of separation processes and specifically, separation methods based upon differences in density such as float-sink separations. In particular, the present invention relates to reclaiming one or more solid components, such as plastics, metal, etc. from a multiple domain solid feedstock. The solid components can initially be either discrete particles or physically bonded to each other, but should differ in density. More specifically, the present invention relates to the use of a particular process fluid in any type of density separation equipment that requires a fluid phase.

BACKGROUND OF THE INVENTION

[0002] Float / sink separations typically employ a process fluid in which particulate solids are dispersed. The solution density is typically selected so that at least one of the components in the feedstock moves in a different direction (i.e.
either floats or sinks) relative to the other components. The ability to select, maintain, and control the density of the process fluid is critical to the facile operation of a float / sink separation process.

[0003] In an aqueous float / sink process, the solution density can be increased by adding relatively large amounts of salts that dissolve in the solution. Although satisfactory in many regards, after prolonged use of the solution, it is necessary to recycle or process the solution and remove the salt(s) dissolved therein. This is time consuming and typically an expensive undertaking. Accordingly, it would be desirable to provide a new separation strategy which did not require subsequent removal of salts in solution.

[0004] If it is desired to decrease the specific gravity of an aqueous solution, typically one or more water soluble liquids having a specific gravity less than 1.0 are added. Examples of such liquids include ammonia, certain alcohols and ethers, and other polar organics with low specific gravity. As noted, eventually, recycling or processing of the solution occurs, and so it is then necessary to separate the two liquids. Frequently, the solution must be subjected to a distillation process, which is typically very costly. In view of this, it would be desirable to provide a new separation strategy in which such intensive and costly separations were not required.

[0005] Another disadvantage in using certain liquids having a specific gravity less than 1.0 is that they are typically flammable and have low flash points. As will be appreciated it is undesirable to store, maintain, or use flammable liquids or aqueous solutions with low flash points, and particularly in the relatively large amounts necessitated in a commercial operation using a sink-float process. Therefore, it would be desirable to provide a new separation strategy that did not require the use of highly flammable components.
SUMMARY OF THE INVENTION

[0006] The difficulties and drawbacks associated with previous systems are overcome in the present method and system for separating comminuted materials differing in density by use of a process fluid comprising two or more immiscible liquids, in which the overall density of the fluid is different than, and preferably between that of the densities of the materials to be separated.

[0007] In a first aspect, the present invention provides a process for the separation of particles that differ in density utilizing a float-sink operation, wherein the process fluid comprises at least two immiscible liquids.

[0008] In another aspect, the present invention provides a process for separating two or more types of feedstock particles in which the at least two types of particles have a different density. The process comprises forming an emulsion including at least two immiscible liquids. At least two of the liquids in the emulsion have different densities. The emulsion is formulated to have an overall density that is greater than that of the lightest particles and/or less than that of the heaviest particles in the feedstock. The process also comprises dispersing the particles into the emulsion, and allowing the particles to float or sink by virtue of their individual densities relative to the density of the emulsion. Any number of mechanical devices can be used for this float / sink separation, including static tanks, continuous tanks, and hydroclones. The process can employ static separation vessels, continuous separation devices such as hydroclones or hydrogravity tanks, or other float / sink devices. The devices can be use individually, or in a series. Sequential operations can be carried out with the same density solution, or with solutions of different density.
As will be realized, the invention is capable of other and different embodiments and its several details are capable of modifications in various respects, all without departing from the invention. Accordingly, the drawings and description are to be regarded as illustrative and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic flow diagram of one embodiment of a hydrogravity reclaiming system of the present invention containing different operational stages for removal and purification of solid components having different specific gravities.

Figure 2 is a side elevational view of a hydrogravity separation tank used in the system depicted in Figure 1.

Figure 3 is an end side view of a hydrogravity separation tank used in the system depicted in Figure 1.

Figure 4 is a cross sectional view of a dispersion mixer used in the system of Figure 1, which disperses agglomerated particles.

Figure 5 is a schematic flow diagram of an alternate embodiment of a hydrogravity reclaiming system for removing oversized and fine particles.

Figure 6 is a block flow diagram of a preferred embodiment process that can be used for the treatment of ASR and ESR for the recovery of metals and plastics.

Figure 7 is a block flow diagram of a preferred embodiment process that can be used to further separate the plastic components from the process depicted in Figure 6.
[0017] Figure 8 is a block flow diagram of a preferred embodiment complex hydrogravity stage comprising four hydrogravity tanks to treat and purify light components of a mixture, and four more hydrogravity tanks to treat and purify heavy components of a mixture.

[0018] Figure 9 is a block flow diagram of a preferred embodiment separation process using process fluid having a density less than 1.0 g/cm³.

[0019] Figure 10 is a block flow diagram of a preferred embodiment separation process using a plurality of tanks, each with a process fluid having a different density in which the tanks are arranged sequentially in order of decreasing density.

[0020] Figure 11 is a block flow diagram of a preferred embodiment separation process using a plurality of tanks, each with a process fluid having a different density in which the tanks are arranged sequentially in order of increasing density.

[0021] Figure 12 is a block flow diagram of a preferred embodiment separation process using a plurality of tanks all using process fluid having the same density, the process comprises three hydrogravity tanks to treat and purify light components of a mixed feed, and three more tanks to treat and purify heavier components of the mixed feed.

[0022] Figure 13 is a block flow diagram of a preferred embodiment separation process utilizing a plurality of cyclone separators sequentially arranged in order of decreasing process fluid density.

[0023] Figure 14 is a block flow diagram of a preferred embodiment separation process utilizing a plurality of cyclone separators sequentially arranged in order of increasing process fluid density.
[0024] Figure 15 is a block flow diagram of a preferred embodiment separation process utilizing a plurality of cyclone separators using process fluid of the same specific gravity.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0025] The present invention relates to a process for separating two or more solid materials of differing density by admixing the materials with a fluid, herein periodically referred to as a "process fluid," having a density such that at least some of the particles float and/or at least some of the particles sink. More specifically, the present invention relates to the use of two or more immiscible liquids each preferably having a different density from one another, that are collectively used as a process fluid in a separation process. The two or more liquids are combined such that they form a relatively uniform liquid system having an average overall density. The system of the combined immiscible liquids is preferably in the form of a dispersion or an emulsion. The system of liquids and associated separation operation(s) are preferably used in a method for reclaiming individual components or classes of components from a solid feedstock comprising multiple components, at least two of which component have a different density or specific gravity. For example, an individual plastic component can be separated from various non-plastic components, including metals, various cellulosic materials such as woods, paper, and the like using the system and process of the invention. Alternatively a group of mixed plastics can be separated from various non-plastic components, including metals, various cellulosic materials such as woods, paper, and the like using the system and process of the invention. The multiple components or domains are often present in
the form of layers, regions, areas, and the like. The term "domain" as used herein, refers to a portion of material, generally in particulate form, in a feedstock or feed stream which has the same or nearly the same, density or specific gravity. As a result of this characteristic, when that portion of material is slurried into a fluid or the process fluid, and then allowed to respond to gravity and buoyancy forces, it tends to form a common layer, region, or area within the slurry or liquid system. The material within a single domain is typically the same, and therefore; often, a domain is homogeneous, and each particle within a domain is homogeneous. The aspects are described in greater detail herein.

[0026] Float-sink technology in its broadest sense can be used to separate solid particles that differ in density by using a process fluid that has a density such that at least some of the particles float and/or some of the particles sink. The present invention, in a preferred embodiment, utilizes an emulsion of two or more different liquids as the process fluid for this float-sink separation.

[0027] The present invention process fluid comprises two or more components which are at least partially immiscible at some temperature. These components are preferably used to create an emulsion using mixing, sheering, blending, or any other method.

[0028] Optionally, a surfactant such as soap, detergent, ionic surfactant, non-ionic surfactant, insoluble fine solid, or any other additive may be used to improve the stability of the emulsion.

THE PROCESS GENERALLY

[0029] In a preferred process according to the present invention, articles and products which serve as feedstock and contain multiple domains such as layers or
regions of two or more different solid components are reclaimed by a float / sink separation strategy. Initially, the feedstock is granulated to reduce the size of the multiple components into small particles of substantially a single component. The particles can be subjected to optional steps including: air-washing and aspiration, screening to remove "fines" and washing to remove dirt.

[0030] The particles are then combined with the process fluid comprising two or more immiscible liquids as described herein, such fluid having an overall density which is different than the density of one or more domains of particles, and preferably intermediate to the density of the heaviest solid components and the lightest solid components of the slurry. The slurry is passed through one or more processing units such as a hydrogravity tank or hydroclone. If hydrogravity tanks are employed, each processing unit preferably contains a dispersion mixer to disperse any agglomerated particles, and a relatively quiescent hydrogravity separation tank which allows heavy components to sink and lighter components to float.

[0031] Since the separation of particles is not complete in any one processing unit, due to various types of inter-particle interference, slow floating or sinking times, etc., it is preferred to use a number of processing units employing a process fluid of substantially the same density to achieve a reasonably pure product stream that is marketable.

[0032] Examples of articles or products utilized as feedstocks in various embodiments of the invention include insulated wire or cable including plastics such as polyvinyl chloride, polyethylene, nylon, and fluoropolymers, and metals such as aluminum, copper, or steel; plastic laminates or layered items; plastics items containing inorganics or other non-plastics; extrusion "bleeders"; recycled materials containing thermoplastics such as recycled carpeting or recycled consumer goods;
vinyl-clad materials such as various window frames; doorframes, and the like; automotive components including laminated or layered thermoplastic and/or thermoset parts; shredder residue from auto shredding, white goods shredding, and electronic shredding (either before or after any beneficiation and metals removal); industrial material; mixed waste plastic streams (including post-consumer and post-industrial), and the like.

[0033] Examples of specific thermoplastic polymers which can be separated include, but are not limited to, polyolefins such as polyethylene and polypropylene; styrenic polymers; acrylic polymers; polyvinyl esters such as polyvinyl acetate; polyvinyl alcohol; chlorine-containing polymers such as polyvinyl chloride and polyvinylidene chloride; various fluorocarbon polymers such as polytetrafluoroethylene (PTFE), polyvinyl fluoride, and the like; polyamides, including various nylons; polyesters, including Mylar, and polyethylene terephthalate; polyurethanes; polycarbonates; silicon-containing polymers, copolymers of the above, and the like. Also included in this class are all compounds made with these polymers. Compounded plastics are comprised of the base plastic resin along with various additives to modify physical or chemical properties. These additives include inorganic fillers, plasticizers, colorants, impact modifiers, stiffeners, and the like.

[0034] Examples of specific thermoset polymers include various phenolic resins, various amino resins, various polyester resins, epoxy resins, various urethanes including urethane foams, various silicone resins, and the like including copolymers of various thermoset resins. They also include cross-linked versions of the thermoplastic species listed above, such as cross-linked polyethylene.

[0035] Other solid items which can be separated from other domains by hydrogravity separation include metals such as iron, nickel, platinum, platinum,
silver, copper, gold, zinc, aluminum, tin, antimony, titanium, chrome, and the like.

Still other solid items include various types of wood including plywood, particle board, etc., various types of paper including cardboard, corrugated paper, and the like.

[0036] Still other solid items which can be reclaimed include inorganic fillers such as silica oxides, metal carbonates, clay, limestone, alumina silicates, and the like.

[0037] Depending upon the application, the feedstock can comprise two or more components selected from the group consisting of (i) polyvinyl chloride, (ii) polyolefins, (iii) nyons, (iv) fluorinated polymers, (v) cellulose materials, (vi) metals, (vii) styrenic polymers, (viii) acrylic polymers, and (ix) foamed or porous materials.

[0038] The overall reclaiming system and process preferably includes, but is not limited to, the following operation stages: Granulation, air separation, slurrying, washing, drying, multi-stage hydrogravity separation, rinsing, and drying.

[0039] Granulation involves sizing the feed stock by cutting, shredding or grinding the same into suitably-sized particles of substantially single domains.

[0040] An optional step involves the use of air separation and/or dry screening of the particles at this point to remove film, paper and some fines which may hinder or inhibit subsequent operations.

[0041] Another optional step involves washing the particles using water and an optional suitable surfactant to remove dirt, dust, grime, and the like, yielding a more pure product downstream.

[0042] In addition to, or instead of, the previously noted operations involving air separation, screening, washing or the like, the present invention may optionally include the use of one or more operations to remove unwanted matter from the particles. Such unwanted matter may result from being carried along with the
particles, or constitute matter that is adhered or otherwise associated with the particles. Non-limiting examples of such matter may include paint flakes, other coatings, dirt, material residue, contaminants, non-contaminants, and the like.

[0043] It is anticipated that certain recycled or waste materials that comprise feedstock to this invention may have undergone other pre-processing to remove trash or valuable components. These process include hand sorting and machine sorting, including the use of X-ray devices, near infra-red sortation, eddy current sortation, and sortation involving the use of various types of electronic sensors and/or compressed air jets.

[0044] The cleaned and sized particles are then added to a liquid system of two or more immiscible liquids differing in density as described herein. Preferably, the system is in the form of an emulsion. The emulsion preferably has a density intermediate between that of the most dense particles and that of the least dense particles so that some particles will tend to float and other will tend to sink.

[0045] The solid / liquid mixture is optionally fed to a dispersion mixer to sever, divide, and especially to break up agglomerated particles of the feedstock before they are admitted into a float / sink separation device. It is important that each particle be free to float or sink as its density (and the density of the process fluid) dictates. If a heavy particle and a light particle were to remain agglomerated together, and were to report to a product stream, the agglomerate would introduce some measure of impurity into that product stream by virtue of the other particle in the agglomerate.

[0046] Dispersion mixers are preferably utilized before each stage of float / sink separation.
[0047] A hydrogravity separation occurs in a largely quiescent tank preferably having steep angled walls generally greater than the angle of repose to prevent particle build-up thereon. A heavy product is recovered from the bottom of the tank, and a light product is recovered from the upper portion of the tank. Alternatively, one can use a hydrocyclone or other float / sink separation device to achieve a sortation based on particle specific gravity. If the quantity of heavy or light material is small, it may be preferable to allow the minor product to simply accumulate in the separation tank, and to recover this material by periodically.

[0048] After one stage of separation, usually neither the float nor the sink stream is pure. There are always some entrained particles that would have moved in the opposite direction but for the mass action of other particles surrounding it. Therefore, multiple separations at the same density are preferably performed to achieve a reasonably pure product. This is analogous to the multiple separation stages that occur in a distillation column to produce a pure liquid stream.

[0049] Another factor that can cause problems in any float / sink process is air bubbles. These bubbles can preferentially attach to certain types of particles, reducing their apparent density and causing them to float unexpectedly. The configuration of the preferred embodiment float / sink system, and the choice of optional surfactant chemicals, is designed to minimize bubble generation, bubble attachment, and froth flotation.

[0050] To achieve the required purity, either the light product stream, the heavy product stream, or both can be individually sent to another dispersion mixer and hydrogravity tank for a second stage of hydrogravity separation using a fluid system of substantially the same density, or another hydroclone or other float / sink separation device again operating using a fluid of substantially the same density.
This process can be repeated multiple times until the desired purity is achieved.

[0051] It is possible to operate a set of dispersion mixers and hydrogravity tanks, a set of hydroclones, or a set of other float / sink devices in a configuration known in the mineral industry as "rougher - cleaner" wherein one stream is sequentially processed to improve product purity, and the other stream is recycled to an earlier stage to improve recovery.

[0052] The overall density of the process fluid is typically controlled to a point intermediate between that of the heaviest and that of the lightest particles in the slurry. This enables the heavy particles to sink and/or the lighter particles to float. Specifically, the process fluid will have a density intermediate or between that of the heaviest component in the system and that of the lightest component in the system. Preferably, by adjusting the proportions of the components of the process fluid, one can adjust the overall density of the process fluid and optimize the float-sink separation. It will be understood that the present invention includes processes in which the separated materials do not necessarily float and/or sink. Instead, density separation operations can be tailored such that some of the materials undergoing separation are suspended in the process fluid. Thus, instead of a sink-float outcome, the separated material domains may be more accurately described as float-suspend, or sink-suspend. That is, one or more material domains may form regions within the system that are intermediate between states of floating material and/or sinking material.

[0053] As a process fluid is used, it often becomes admixed with other soluble species that are carried into the separation stage by the solid particles, and which can potentially alter the specific gravity of the process fluid. These would include fluids of a different specific gravity carried in from a previous separation stage on the
surface or in the pores of the solid particles being separated. It is important to have
the ability to adjust the process fluid composition to maintain the appropriate fluid
density for the desire separation, and to be able to compensate for the introduction
of these other components.

[0054] The viscosity of the process fluid should also be sufficiently low to allow
particles to sink or float in a hydrogravity tank within the design residence time for
the particular hydrogravity tank.

[0055] The selected separated particles from the last hydrogravity tank,
hydroclone, or other float / sink separation device of a given set are collected. They
can be washed, dried, and utilized for any desirable purpose such as reuse or
resale, or they can be subjected to further float / sink separation in another device
operating at a different density.

[0056] Although the vessel in which the density separation is preferably
performed is often described herein as a hydrogravity tank or hydroclone, it is to be
understood that the present invention includes numerous other tanks, vessels, and
process equipment. Representative examples of such process equipment includes,
but is not limited to, reactor tanks, continuously stirred reactor tanks, liquid
separation and/or settling tanks, liquid holding and storage tanks, and the like.
Generally, any vessel capable of retaining an effective amount of process fluid
having particles to be separated or otherwise recovered therefrom, may be used.
The more dense product can be removed through a port near the bottom, or can be
extricated by means of an archimedian-type screw type device or a drag-chain type
device. Examples of other such vessels may for example include, fabricated metal
tanks and containers both open and enclosed, liquid holding or processing regions
formed by concrete walls or other retention walls, man-made enclosures and also
naturally occurring liquid basins and the like. In such devices, the fluid may be essentially static, moving in a specific direction, or induced to move in a manner that causes centrifugal forces to act upon the fluid and suspended particles. It is also possible to allow the light product, the heavy product or both products to simply accumulate in the vessel, followed by periodic recovery rather than continuous extraction of such product.

[0057] As noted, it is preferred that the process fluid comprising two or more immiscible liquids differing in density, is in the form of an emulsion. However, it is to be understood that the present invention includes two or more component process fluids that are not in the form of an emulsion. In addition, while the preferred embodiment of the present invention utilizes an aqueous emulsion system as the process fluid, it is within the scope of the present invention to utilize non-aqueous emulsions. Description will now be provided as to the preferred embodiment process fluids and specifically preferred embodiment emulsions.

PREFERRED PROCESS FLUIDS

[0058] As noted, the present invention process fluid comprises two or more immiscible liquids. Liquids are immiscible as that term is used herein, if at the temperature of their intended use in the process described herein, and if in their intended proportions in the process fluid, the liquids are not completely soluble or miscible with each other and do not form a homogeneous phase on their own, i.e. without the addition of energy or stabilizing agents at the process conditions. The temperature at which the various processes are typically performed is generally in the range of from about 1°C (32°F) to about 99 °C (210°F), and typically from about 5°C to about 30°C (86°F). It will however be appreciated, that depending upon the
particular application and selection of process fluids, the temperature(s) at which the
preferred embodiment processes can be performed, may be less than and/or greater
than these noted temperatures. So, the determination of whether liquids are
immiscible relative to one another for purposes herein, is made at the temperature at
which the float / sink process is conducted. For example, at the noted typical
temperatures of from 5°C to 30°C, water and ethanol are miscible in all proportions,
and so are not immiscible as that term is used herein. In contrast, if two liquids
intended to be used at 15°C and in proportions of 50% each were not completely
soluble with each other, then those liquids are immiscible as that term is used herein,
and thus they could potentially be used as the process fluid. Restated, for example,
in a system of water and xylene, although very small amounts of xylene can be
dissolved in water at 15°C (in furtherance of the previous example); at proportions of
50% each, these liquids are immiscible with respect to one another, and so under
the present definition, could potentially be used as the process fluid.

A preference for the two or more immiscible liquids used in the process
fluid, is that they differ in density. Density, as is well understood, is mass per unit
volume of a material. Common units of density are grams per cubic centimeter.
Although density depends upon temperature, this phenomenon is negligible for
liquids, and particularly in a temperature range of about 5°C to about 60°C. The
extent or degree of difference in the densities of the two or more immiscible liquids
can be relatively small. However, the greater the difference in densities, the wider
the potential range of the overall density of the resulting process fluid. That is, if for
example, two immiscible liquids having densities of 0.8 g/cm³ and 1.2 g/cm³ are
used, the overall density of the process fluid is potentially, within a wide range such
as slightly greater than 0.8 g/cm³ to slightly less than 1.2 g/cm³, depending upon the
proportions of the two immiscible liquids in the process fluid. Thus, the reference that the two or more immiscible liquids have "different densities" refers to a density difference of at least 0.5%. Although it is preferred that the densities of the selected immiscible liquids be different from one another, the present invention includes the use of two or more immiscible liquids having the same or substantially the same density.

[0060] The term "overall density" as that term is used herein, refers to the density of the resulting system of selected immiscible liquids after they are combined and dispersed within one another. It is preferred that the overall density be measured. However, in most applications, the overall density can be approximated through mathematical calculation. Calculating an overall density assumes that the resulting system of selected immiscible liquids is an ideal system such that the respective volumes of the immiscible liquids are additive, so that the total volume of the selected liquids does not change regardless of whether the liquids are combined or separate from one another. It is also assumed, in calculating an overall density that the selected liquids are nonreacting with one another. So, for an ideal and nonreacting system, the overall density can be calculated by summing the densities of each selected liquid multiplied by their corresponding volume fraction:

\[ \text{d}_{\text{overall}} = \sum d_j X_j \]  

(1)

where \( d_{\text{overall}} \) is the overall density of the process fluid, \( d_j \) is the density of the selected liquid and \( X_j \) is the volume fraction of the selected liquid. Alternately, the overall density \( d_{\text{overall}} \) can be calculated by summing the masses of the components, and dividing that sum by the total volume of the components. It is to be understood that the present invention is not limited to the use of process fluids that can be
considered ideal systems. The present invention includes the use of process fluids that are non-ideal systems. In these applications, the overall density of the process fluid should be measured, as deviations will result if attempts are made to calculate it as described herein. Of course, sophisticated equations for non-ideal liquid systems could be employed to estimate an overall density.

[0061] The overall density of the process fluid can range from about 0.3 g/cm³ or less to about 3.0 g/cm³ or more, more typically from about 0.5 g/cm³ to about 2.5 g/cm³, preferably from about 0.75 g/cm³ to about 2.0 g/cm³, and more preferably from about 0.8 g/cm³ to about 1.8 g/cm³. It will be appreciated that the present invention includes processes utilizing process fluids exclusively with densities less than 1.0 g/cm³, or with densities greater than 1.0 g/cm³.

[0062] The process fluid can include a dissolved solid component such as an inorganic salt, ammonia, an acid or a base. The process fluid can include a soluble organic species such as an alcohol, organic acid, amine, or other polar organic species.

[0063] The process fluid can include species that are normally gaseous under ambient temperatures and pressures, and this invention can be practiced at superatmospheric pressures. For example, a fluid consisting of a mixture of propane and water could be formed at ambient temperature and superatmospheric conditions.

[0064] As previously noted, a preferred form of the process fluid is an emulsion. An emulsion is defined herein as a dispersion of two or more immiscible liquids, one in the other. The liquids are preferably water and one or more organic components such as hydrocarbons, collectively referred to herein as "oil." The emulsion or dispersion may either be that of oil in water (oil-in-water) or vice versa (water-in-oil).
It will be appreciated that the present invention process fluid comprises two or more immiscible liquids, and that these liquids are preferably in the form of an emulsion. The present invention includes the use of a dispersion for the process fluid. The term dispersion as used herein refers to the process fluid comprising two or more immiscible liquids wherein the two liquids do not form a true emulsion, but are simply finely divided one within the other. Dispersions also include fluids comprising two or more immiscible liquids and also comprising fine particles dispersed or distributed in the process fluid. The particles may originate from the process fluid as it is used or be added to a process fluid, or may originate from feed to be separated and so for example could be in the form of fine particles of dirt, organic matter, plastic, or other like matter.

[0065] Although some emulsions form spontaneously, many emulsions are typically stabilized by the addition of surfactants or emulsifiers which lower the interfacial tension between the two phases, thereby reducing the amount of energy input needed to form the emulsion. Emulsions can also be "solid stabilized" by small insoluble particles that gather at the oil-water interface and stabilized the micells. There is also a distinction between the types of emulsions based on rheological (physical) properties. An emulsion which is transparent, thermodynamically stable, and has a small particle size (5-100 nm) is referred to herein as a microemulsion; whereas an opaque, kinetically stable emulsion with a larger particle size (200-10,000 nm) is considered herein as a macroemulsion, or simply an emulsion. Microemulsions have a much longer shelf-life than emulsions because of their stability as discussed in greater detail herein.

[0066] Microemulsions have been defined as dispersions of either water in oil (w/o) or oil in water (o/w) that are stabilized by pure or mixed amphiphiles.
Microemulsions may also be considered as pseudo-homogeneous mixtures of water-insoluble organic compounds, water and a surfactant/co-surfactant mixture. The amphiphiles (surfactant/co-surfactant mixture) are involved in lowering the oil-water interfacial tension by means of their interfacial adsorption thereby minimizing the positive free energy change of dispersion associated with surface formation. The microemulsions formed are isotropic, have a low viscosity and are thermodynamically stable. They have a prolonged shelf life and an average particle size of 5-100 nm. Other characteristics include optical transparency (the droplets are too small to latter visible light) and polydispersity, which decreases with decreasing particle size. There are different types of microemulsions including polar oil, polymer oil, biological etc.

[0067] Microemulsions can evolve from the addition of an oil to a micellar solution (aqueous solution of surfactant) and the resulting swollen micelles gradually change into microemulsion droplets with further addition of the oil.

[0068] Water-in-oil microemulsions are topological similar to reverse micelles in that the polar heads of the amphiphile are orientated inward and the non-polar tails are orientated toward the oil continuum. Compositions having mobile or free water in the core after satisfying the hydration requirements of the amphiphile head groups and counter ions are then called microemulsions. Mixtures of water, oil and non-ionic amphiphile separate within a well-defined temperature interval into three liquid phases: an aqueous phase, oil-rich and amphiphile-rich phases. In the amphiphile-rich phase, the maximum mutual solubility between water and oil can be found combined with a minimum interfacial tension. The temperature range in which microemulsions are formed is shifted systematically depending on the length of the
alkyl or ethylene oxide chain of the amphiphile and the polarity of the organic medium.

A surfactant mixed with a co-surfactant in certain proportions is most often used as the amphiphile. Lower alcohols such as butanol, pentanol or hexanol and amines such as butylamine or hexylamine are used for this purpose. Their presence in the interface between water and oil causes flexibility as well as lowering the interfacial tension allowing easier surface bending to an energetically favored dispersion. The co-surfactant penetrates the surfactant film and thereby creates a disordered film caused by the void space among surfactant molecules. The solubility of the ionic amphiphile in water increases with rising temperature in contrast to the non-ionic amphiphile where with increasing temperature the amphiphile becomes more oil soluble. Non-ionic amphiphiles have significantly lower electrolyte sensitivity than ionic amphiphiles. The electrolytes reduce the solubility of the hydrophilic head groups of the amphiphiles in water. For non-ionic amphiphiles, they compete for the hydrating water of the head groups. For the ionic amphiphiles, the electrostatic interactions between the charged head groups are strongly influenced by the addition of electrolytes, so that the phase behavior is significantly altered. The effects of electrolytes are opposite for w/o and o/w microemulsions, where the electrolytes decrease inter-droplet attraction rather than increasing it for the former.

There are essentially four different characteristic phase formations which mixtures of water-amphiphile-oil or water-surfactant-co-surfactant-oil fall into as described by categories I-IV:

I - dispersion of oil-in-water (o/w) in contact with essentially oil;

II - dispersion of water-in-oil (w/o) in contact with essentially water;
III - both o/w and w/o dispersions are simultaneously present in the same
domain in mixed state in separate contacts with both oil and water; and

IV - homogeneous single phase of either o/w or w/o dispersion not in contact
with any other phase.

[0071] Inter-conversion between the different phase types can be achieved by
adjusting the proportion of constituents. The phase forming behaviors of the
microemulsion formation depend upon the following factors: types of polar medium
(water, glycol, glycerol etc.), oil, amphiphile, presence of additives (electrolytes),
temperature, pressure etc. Both spherical and non-spherical forms of the dispersed
state may aggregate forming chains, lamellae, mesophases, liquid crystalline etc.
Gels of varying consistency may also be formed.

[0072] The internal structure of microemulsions has been physiochemically
conceived such that on the lower side of water addition the amphiphile requirement
is low (III) and a spherical dispersion of amphiphile-coated water nanodroplets exist
in the oil continuum. For compositions with low oil percentage and high water
percentage (I) there is increased dispersant concentration, decreased droplet
dimension and distortion of spherical shape. At comparable proportions of both oil
and water irregular dispersions of both oil and water may simultaneously exist in a
bi-continuous state.

[0073] It is also contemplated that multiple emulsions comprising a primary water-
in-oil (w/o) or oil-in-water (o/w) as the internal phase and an external aqueous phase
could be used as the process fluid. Similarly, it is also contemplated that a primary
aqueous phase as the internal phase and a water-in-oil (w/o) or oil-in-water (o/w) as
the external phase could be used as the process fluid.
The general physiochemical properties of microemulsions have been studied using a variety of techniques such as: static and dynamic light scattering, small angle neutron scattering (SANS), small angle x-ray scattering (SAXS), ultracentrifugation, transmission electron microscopy (TEM), pulse radiolysis, electron spin resonance (ESR), self diffusion, fluorescence spectroscopy, NMR, viscosity, conductance, interfacial tensions etc. Self-diffusion and conductivity studies have elucidated the existence of a characteristic zone with an isotropic microemulsion domain in a continuum. The Fourier transform pulsed gradient spin echo NMR method has been used to investigate the changes in the microstructure of microemulsions (both aqueous and nonaqueous) as a function of temperature, salinity, co-surfactant, additives and mixture of oils. Light scattering studies of ionic and non-ionic microemulsions have found that droplets fit into the hard sphere model amenable to interparticle interactions. Electrochemical techniques (cyclic voltammetry and rotating disc voltammetry) have been used to characterize o/w microemulsions. SANS and dynamic light scattering techniques have been employed in the understanding of the structure and dynamics of w/o microemulsions. The intermolecular interaction and rearrangement in the structure of non-ionic and anionic microemulsions has been investigated using high-resolution 1H, 2H and 13C NMR.

Macroemulsions (normally termed emulsions), on the other hand have a larger particle size (200-10,000 nm in diameter), no transparency and shorter stability time. They are usually formed by imposing high sheer on one phase to create small droplets that are dispersed into the other phase. They are described as kinetically stable in comparison to the thermodynamically stable microemulsion, which can be formed spontaneously using just the thermal energy of the system.
In emulsions, the dispersed phase and the dispersion medium are both fluids. The most common fluids are oil and aqueous media. They may be of two types: oil-water-emulsions (fine oil droplets dispersed in the aqueous phase) or water-in-oil emulsions (aqueous droplets dispersed in oil). A bi-continuous emulsion is formed when one phase forms a continuous network in the other.

In order to distinguish between the types of emulsions, the effect of dilution with one of the phases can be studied where adding water to an oil-in-water emulsion dilutes it. Adding oil however, causes the oil phase to form a separate layer. Oil-in-water emulsions have electrical conductivities similar to those of the water phase, whereas water-in-oil emulsions are not significantly electrically conductive. Water-in-oil emulsions can be colored by oil soluble dyes but oil-in-water emulsions are faintly dyed. The converse is true when using water soluble dyes. If the two phases have different refractive indices, microscopic examination of the droplets will reveal their type. A droplet, on focusing upwards in a refractometer, will appear brighter if its refractive index is greater than the continuous phase. This is used to identify the component if the refractive indices are known. In filter paper tests, a drop of an oil-in-water emulsion produces an immediate, wide and moist area while a water-in-oil emulsion does not.

Yet another type of emulsion is a nanoemulsion. A nanoemulsion is a type of emulsion in which the sizes of the particles in the dispersed phase are defined as less than 1000 nm.

The present invention process fluid can be in the form of a microemulsion, an emulsion, or a nanoemulsion, for instance. The process fluid is preferably in the form of an emulsion, i.e. a macroemulsion, primarily due to the ability to selectively...
maintain or break the emulsion as desired. This feature is described in greater detail herein.

For emulsions comprising an aqueous phase and an oil phase, the aqueous phase can range from about 0.5% to about 99.5% (all percentages expressed herein are by weight unless noted otherwise), preferably from about 5% to about 95%, and most preferably from about 10% to about 90% of the system. The organic phase can range from about 1% to about 99%, preferably from about 5% to about 95%, and most preferably from about 10% to about 90% of the system.

As previously noted, the formation of emulsions is caused by the dispersion of droplets of one of the liquids into the other. This causes a large increase in the interfacial area and the accompanying free energy. This then makes the system thermodynamically unstable and the presence of an emulsifying agent helps to stabilize the interfacial regions. It does this by reducing the interfacial tension between the two liquids so that the increase in energy associated with the increase in area is reduced. It also reduces the rate of coalescence of the dispersed liquid droplets by forming mechanical, steric and/or electrical barriers around them. The steric and electrical barriers prevent droplets from getting too close enough to coalesce. The mechanical barrier increases the resistance to coalescence upon shock or shear.

The stability of emulsions is affected by numerous factors such as the physical nature of the interfacial film where a condensed film with very strong lateral forces and good elasticity will be an excellent barrier to collision coalescence. Preparing a system where the interfacial components push the surfactant film into the liquid crystal phase creates a highly viscous phase. This phase resists
coalescence and sterically prevents molecules from getting close enough for van der Waals forces to cause attraction.

[0083] The stability of emulsions is also affected by electrical or steric barriers. The presence of a charge on the dispersed droplets will cause electrostatic repulsion.

[0084] The stability of emulsions is additionally affected by viscosity. If the continuous phase has a high viscosity, the motion of the dispersed phase and their diffusion will be slowed and the rate of coalescence minimized.

[0085] The stability of emulsions is also affected by the size distribution of the droplets which also affects stability where a more uniform distribution causes a more stable emulsion. Ostwald ripening causes the larger droplets in a broad range of droplets to grow at the expense of the small droplets.

[0086] The stability of emulsions is also affected by the volume of the dispersed phase. As the volume of the dispersed phase increases, the continuous phase must spread out further to cover all the droplets. This increases the probability of collisions and decreases the emulsion stability.

[0087] And, the stability of emulsions is affected by temperature. Emulsions are very sensitive to temperature changes and are more stable when the temperature is near the point of minimum solubility of the emulsifying agents.

[0088] In all of the typical emulsions, there are tiny droplets (discrete phase) suspended in a liquid (continuous phase). In an oil-in-water emulsion, oil is the discrete phase, while water is the continuous phase. Generally, the phase in which an emulsifier is more soluble constitutes the continuous phase. This is known as the Bancroft rule. What the Bancroft rule states is that contrary to common sense, what makes an emulsion oil-in-water or water-in-oil is not the relative percentages of oil or
water, but which phase the emulsifier is more soluble in. So even though there may be a formula that is 60% oil and 40% water, if the emulsifier chosen is more soluble in water, it will create an oil-in-water system. There are some exceptions to Bancroft's rule, but it is a very useful rule of thumb for most systems.

[0089] The Hydrophilic-lipophilic balance (or HLB) of a surfactant can be used in order to determine whether it is a good choice for the desired emulsion or not. In Oil in Water emulsions - use emulsifying agents that are more soluble in water than in oil (High HLB surfactants). In Water in Oil emulsions - use emulsifying agents that are more soluble in oil than in water (Low HLB surfactants).

[0090] Bancroft's rule suggests that the type of emulsion is dictated by the emulsifier and that the emulsifier should be soluble in the continuous phase. This empirical observation can be rationalized by considering the interfacial tension at the oil-surfactant and water-surfactant interfaces.

[0091] Inversion between emulsion types can be carried out by changing one or more of the following: the order of mixing of components, the nature of the emulsifier, the volume ratio of water to oil, the phase in which the emulsifier was originally dissolved, the temperature of the system, the amount of electrolyte, and combinations of these factors.

[0092] Amphiphilic surfactants are characterized by the HLB, which is a relative ratio of polar and non-polar groups in the surfactant. A surfactant that is lipophilic in character is assigned a low HLB value (below 9) and one that is hydrophilic is assigned a high HLB value (above 11). Those in the range of 9-11 are intermediate. The HLB of a surfactant or blend of surfactants is an excellent indication of what the surfactant system will do, i.e. whether it will make an oil-in-water emulsion or a water-in-oil emulsion, or even act as a solubilizer for some oil (Table 1). The HLB of
a surfactant class or blend is also an indication of the efficiency of chemically related
surfactants, or of a blended pair of surfactants, for performing any given
emulsification task. The HLB is not an indication of the relative efficiency of one class
to another. The "class" efficiency is more related to chemical structure and the
relationship to the chemical structure of the material to be emulsified.

Table 1. Classifications of surfactants by their HLB values

<table>
<thead>
<tr>
<th>HLB Range</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-6</td>
<td>w/o emulsifier</td>
</tr>
<tr>
<td>7-9</td>
<td>wetting agent</td>
</tr>
<tr>
<td>8-18</td>
<td>o/w emulsifier</td>
</tr>
<tr>
<td>13-15</td>
<td>Detergent</td>
</tr>
<tr>
<td>10-18</td>
<td>Solubilizer</td>
</tr>
</tbody>
</table>

[0093] Knowing the HLB value, the chemical type of surfactant can be matched to
the oil. As previously noted, the HLB allows for the blending of two surfactants in
order to achieve the exact HLB needed instead of using only one surfactant. The
blend can be adjusted to suit the oil or other active ingredients instead of the
adjusting the active ingredients to suit the surfactant. The most stable emulsion
systems usually consist of blends of two or more surfactants where one has lipophilic
tendencies and the other hydrophilic. The preferred chemical type is related to the
chemical family of the surfactant whether it be stearates, laurates, palmitates or
oleates, each blended to have the correct HLB. For example, a polyethoxylene
sorbitan oleate ester type of blend (Tween 80) with its unsaturated lipophilic oleate
“tail” in the oil is compatible with oils having unsaturated bonds. Tween 60, which is a stearate; Tween 20, a laurate and Tween 40, a palmitate, are all more compatible with oils having saturated bonds. Thus, although both oils might require the same HLB, which these types of surfactants have, the emulsifier which attracts the oil will be more effective.

[0094] This classification system completely disregards the interaction of the surfactant with the oil and only considers water solubility. Surfactants with low HLB are more oil soluble and are thus suitable for preparing water-in-oil emulsions whereas those surfactants with high HLB values have good water solubility thereby rendering them suitable for oil-in-water emulsions. For non-ionic surfactants containing ethylene oxide chains, the larger the portion of ethylene oxide molecules (hydrophilic portion of the surfactant molecule), the more water-soluble the surfactant. The hydrophobic part of the surfactant embeds itself in the oil droplet and the hydrophilic ethylene oxide chain interacts with water to surround the oil droplet and form an emulsion. Surfactants must remain in solution to perform their function and in contrast to salts, which dissolve more readily in hot water, non-ionic surfactant solubility has a temperature limit called a cloud point. At this temperature the surfactant drops out of solution and causes the solution to become turbid. Surfactant activity and performance are usually at an optimum below the cloud point.

[0095] It is also contemplated that finely divided solids can be added to the emulsion to stabilize the emulsion. These finely divided solids can be used exclusively or in combination with one or more emulsifying agents.

[0096] Numerous devices and strategies are described in the patent literature for forming dispersions and emulsions, such as for example, US Patents 6,149,293; 6,722,780; 5,01 1,293; 4,755,325; 4,068,830; 5,366,287; and 2,125,245. Additional
details as to emulsions and their formation are provided in US Patents 3,272,758; 2,546,169; 3,006,880; and 2,508,342; 2,550,211.

[0097] Emulsions can be formed by large-scale industrial mixing equipment and small-scale laboratory and pilot-plant models of planetary mixers, motor-driven propellers, turbines, colloid mills and homogenizers. Electric egg-beaters, high-speed blenders, milk homogenizers, and shaking machines can also be used.

[0098] The purpose of emulsification equipment is to break up or disperse the internal phase in the external phase so that the resulting particle size is sufficiently small enough to retard coalescence and resulting breakdown of the emulsion for the required time of stability. The type of agitation largely affects the preparation of emulsions.

[0099] Manual stirring is the simplest form of agitation. Depending upon the emulsifier selection and the components to be emulsified, either semi-stable or stable, large- or small-sized particles can be prepared. A mechanically rotated paddle or anchor type agitator is suitable for viscous emulsions containing high solids, soap gels etc.

[0100] Propeller agitation is suitable for low and medium viscosity emulsions and when used with suitable emulsifiers result in finer particle size than homogenization or milling with smaller quantities of emulsifiers.

[0101] A colloid mill typically produces a uniform particle size due to the extremely high shearing action. Milling may be done on fluids and pastes.

[0102] In homogenization, emulsification is effected by forcing the two phases past one or two spring-seated valves at pressures of 0.35-34.5 MPa. Emulsification occurs not only while the components pass under the valve seat but also when the
emulsion impinges against the retaining wall that surrounds the valve. Homogenizers are used on liquids or pastes.

[00103] A high-frequency ultrasonic emulsifier is suitable for low viscosity liquids where the ultrasonic energy is developed mechanically or electrically.

[00104] In addition to providing a useful medium for float sink separation, the emulsion fluid may offer other useful properties such as cleaning of the particles, removal of adsorbed or absorbed contaminants, coating the particles, dispersion of additives, addition of plasticizers or modifiers, addition of anti-corrosion agents, etc. For example, in a process fluid in accordance with the present invention, one or more of the immiscible liquids may serve an additional function besides contributing in a density separation operation. They can chemically or physically interact with the particles undergoing float / sink separation in a wide variety of ways. For example, it is contemplated that one or more liquids could be added to the process fluid that also serve as solvents or extraction agents to remove desired materials from the feed or comminuted particles to be separated. One or more finely divided solids can also be added to the emulsion. The emulsion disperses the finely divided solids which are then free to interact with the particles undergoing float / sink separation. It is also envisioned that a wide array of other liquids may be used in the process fluid, which may not necessarily differ in density from one or more of the at least two other immiscible liquids differing in density. For example, surfactants and co-surfactants, emulsion stabilizing agents, defoaming agents, co-solvents and the like can be utilized in the process fluid.

[00105] When appropriate, the emulsion can also be deconstructed into its components or "broken" as periodically referred to herein by applying conventional emulsion breaking technology, such as salt addition, pH change, addition of
chemical de-emulsification agent(s), mechanical processing, temperature change, or any other process known to those skilled in the art. The type of emulsion breaking technology employed will depend on the composition of the emulsion. Representative agents and/or techniques for breaking emulsions are described in the patent literature, such as in US Patents 4,141,854; 4,261,812; 4,374,734; 3,350,301; 5,156,767; 4,194,972; 2,485,298; and 2,318,034.

[00106] Generally, the process fluids are in the form of emulsions. It is also preferred that the emulsion not be too stable, hence it may be difficult to separate the process fluid into its constituents such as when the fluid is recycled, reprocessed or renewed. Typically, it is preferred that the process fluids are emulsions having a stability such that the emulsion is readily breakable by a conventional technique, or that the emulsion will naturally separate into its constituents in less than about one month, at ambient conditions and at rest (e.g. without input of kinetic energy into the system). However, the present invention includes process fluids being emulsions that are much more stable.

PREFERRED EMBODIMENT PROCESSES

[00107] The present invention and use of two or more immiscible liquids utilized as a process fluid in one or more float-sink separation operations, can be used in a wide array of applications. For example, the present invention can be used to separate materials having densities less than 1.0 g/cm³, or more than 1.0 g/cm³, or multiple materials having densities less than, greater than, and/or including these densities. As described herein, the present invention can be used in the recovery or separation of one or more material(s) from another material or collection of multiple materials, which typically can be in the form of ground, shredded, or otherwise size-
reduced materials, and preferably waste materials. Several examples of preferred embodiment processes are described herein to further illustrate the implementation and utility of the present invention. In a first set of representative examples of processes in accordance with the present invention, various materials are recovered from ground wire and cable feedstock. In another set of representative examples of processes in accordance with the present invention, various materials are recovered from shredder residue such as automotive shredder residue (ASR) and electronic shredder residue (ESR).

Recovery of Materials from Ground Wire and Cable

[00108] The present invention will now be described with respect to reclaiming one or more solid components from a multi-component article such as an insulated copper cable. It will be understood that, as noted above, generally any article or product having multiple domains of different plastics or other components such as various plastics, metal, wood, etc., can serve as feedstock which is reclaimed with a high degree of purity.

[00109] Referring to FIG. 1, a preferred embodiment hydrogravity system and process for reclaiming and purifying a solid feedstock using a process fluid is generally indicated by reference number 10. In one embodiment, the reclaimed article is a wire cable which contains a plurality of separated copper wires each surrounded with a thermoplastic such as polyethylene or other domain thermoplastic with the same being contained or encapsulated within an insulating thermoplastic such as polyvinyl chloride or other domain thermoplastic. The insulated cable has an outer jacket which is generally a thermoplastic nylon or other domain thermoplastic.
In other embodiments, any number of domains can be present, including paper, rubber, string, and Mylar.

[00110] The solid article, such as a copper cable, is initially cut into pieces less than 12 to 25 mm in length for primary copper recovery and fed from feedstock container 110 to granulator 120. Generally any type of cutting device or machine can be utilized with a reel type high shear cutting blade being desired. Primary copper recovery is generally accomplished using some form of air classification, using technology well known in the art. The light product from this stage, comprising the plastic insulation layers, the outer jacket, paper, dirt, and other contaminants is a desirable feedstock for the hydrogravity process.

[00111] The first process step is an optional feed pretreatment to remove any over-sized pieces and to protect downstream equipment. This can be accomplished in a screener with screen openings of approximately 12 mm. Materials suitable for further processing pass through the screen, while large pieces of "trash" are rejected. This screening device may also be "double decked", allowing the removal of some fine particles and dirt. In such an application, the material suitable for further processing is the middle fraction.

[00112] The next optional processing step involves one or more air separations at velocities typically lower than those used in the primary copper separation. The purpose of this air separation is primarily to remove paper, which tends to disintegrate in the hydrogravity process, forming a wet sludge in the tanks. This air separation can also be used to partially remove certain plastics that have the proper "shape factor". Species such as nylon and Mylar tend to have the appearance of flat "flakes" while PVC, PE and the like tend to be more granular. The shape of the nylon
and Mylar particles causes them to be preferentially lifted in an air separation device, and concentrated in the lighter product fraction.

[00113] A granulator is then used to further reduce the feedstock particle size to about 6 mm or less. Generally any type of cutting device or machine can be utilized with a reel type cutting blade being desired. The purpose of the granulator is to size, that is to break, chop, shred, etc. the precut lengths into particles of 25 mm or less and more desirably from about 0.5 mm to about 10 mm. The granulator reduces the feedstock containing layers of different domains, regions, etc., into small particles containing substantially only one domain or component, e.g. a single thermoplastic or metal. Since the various layers, regions, etc., of the feedstock are only physically bonded, granulation of the same readily separates the various domains or components to produce particles of substantially only a single domain or component. Thus, the amount of any particles having two or more thermoplastic domains or components after granulation is very small, generally less than about 5% by weight, desirably less than about 3% by weight, and preferably less than about 1% by weight, or zero percent by weight based upon the total weight of the feedstock.

[00114] Granulators for producing metal and/or thermoplastic particles are well known in the art and generally any suitable granulator 120 can be utilized such as a Cumberland granulator or a CMG granulator, made in Italy. It has been found that granulators that use a sheering action to reduce particle size (as opposed to direct impact such as that found in a hammer-mill type device) tend to provide better separation of the domains in a feedstock.

[00115] The granulated particles often contain paper particles, dust and fines. Such fine particles can cause problems downstream, and are optionally preferentially
removed at this point. Aspiration and screening are useful. For reasons set forth below, fines are desirably removed and filtered or screened in unit 130 and collected in unit 140. Fine sized particles can vary but often have a maximum size of about 0.1 to about 1.0 mm in size.

[0016] The removal of fines from the particular article feedstock, while optional, is generally preferred. A high concentration of fines can tend to clog the reclaiming system because the fines generally do not rapidly settle or float in the hydrogravity tanks but remain in suspension. This phenomenon is largely described by Stokes Law. Generally any conventional method of removing the fines can be utilized such as air classification, air separation, or screening. For example, a screen containing openings of generally less than about 1.0 mm and desirably less than about 0.5 mm can be utilized to permit the fines to fall through. A vibrating or rotating screen is preferred. The holes in the screen can be round, square, or rectangular. Rectangular screen openings, for example 0.5 mm x 25 mm are useful in removing and concentrating fine copper wires for subsequent dry recovery. The fines can be collected in container 160. Preferably, at least about 90% by weight of the fines are removed from the feedstock prior to directing the feedstock, i.e. the particles, to one or more hydrogravity separation stages. More preferably, at least about 95%, and even more preferably, at least about 98% of the fines are removed from the feedstock.

[0017] The next optional step involves washing and drying the feedstock to remove dirt and grime.

[0018] To further remove dirt and grime, the particles are preferentially washed with water or a water-based solution containing a suitable surfactant.

Referring to FIGURE 1, the dry granulated particles often contain dirt, grime, and
fines and are thus fed to wash unit 150 wherein they are mixed under high agitation to create a suspension of the particles in water. Any type of industrial washing device or a high agitation mixing tank can be utilized, with high shear agitation and/or turbulent flow being preferred. The washing step may be continuous or batch. One or more washing stages can be employed. The amount of the granulated feed is desirably such that the solids loading of the slurry in the wash unit is desirably from about 5% to about 40% by weight. Generally any conventional soap, surfactant, detergent, wetting agent, or mixture comprising these components known in the art which is non-foaming or low foaming can be utilized so long as it aids in wetting the granulated thermoplastic and copper particles. Suitable anti-foaming agents can also be added at this step to minimize undesirable foam generation.

[00119] It is usually desirable to then partially dewater or dry the particles to avoid diluting or contaminating the subsequent process fluids used for hydrogravity separation. This can be accomplished through centrifugation, air blowing, or the use of any type of industrial drier. Gala or Carter-Day type spin dryers are particularly useful in this application. The use of the proper surfactant to lower surface tension in the prior washing step can assist in the physical removal of water in a spin drier.

[00120] Referring to FIGURE 1, the washed thermoplastic and copper particles are substantially dewatered so when they are fed to a hydrogravity separator tank, contamination or interference with the process fluid, which is preferably an emulsion, is prevented. Generally any type of drying process or apparatus 170 can be utilized with a mechanical or vibratory screen, basket centrifuge or a conventional spin dryer being preferred to remove the excess solution leaving a product having about 0% or about 0.1 % to about 15% and desirably from about .1 % to about 7% by weight of solution.
Washing and drying can also be accomplished by wet screening, optionally using spray bars to help force fines and dirt through the screen openings. An air jet on the lower part of the screen can be used to partially dry the plastic after washing.

While specific embodiments have been described with regard to the removal of undesired components from the feedstock such as dirt, angel hair, oversized particles, and fines, it is to be understood that numerous different types of operations and other embodiments can be utilized and that the same are within the concepts of the present invention.

The pretreated feedstock can now be subjected to hydrogravity separation to recover individual components of different density. Each hydrogravity stage preferably includes a high shear dispersion mixer and a quiescent settling tank. In the mixer, the particles in the slurry are subjected to very high shear forces, causing any agglomerates to break up into their individual components. This allows each particle to act somewhat independently in the hydrogravity tank, allowing particles with a density heavier than that of the process fluid to sink, and particles with a density lighter than that of the process fluid to float. In this manner, two product streams are generated - a light product stream rich in low density components, and a heavy product stream rich in higher density components. These product streams can be removed continuously or intermittently.

The hydrogravity stages can comprise a single separation stage, or can be arranged in groups of two or more. Generally 3 to 5 stages are optimum, although higher numbers can be employed to further increase purity.

A plurality of stages at essentially the same density is preferred, and is a significant aspect of the present invention, because no single float-sink stage is
100% effective. Rather, a float-sink stage tends to produce an upper product richer in the lighter components, and a lower product richer in the heavier components. The separation is not completely effective because there is always some inter-particle interaction and entrapment.

[00127] By way of example, assume a two-component feedstock and a hydrogravity separation efficiency of 90%. After one stage of separation, the desired product stream will contain about 90% of the desired product, and about 10% of the other material as a "contaminant". After a second stage of hydrogravity separation, the level of contamination is reduced to 1%. After a third stage of hydrogravity separation, the level of contamination is reduced to 0.1 %, and after a fourth stage of hydrogravity separation, the level of contamination is reduced to 0.01 %.

[00128] Each group of hydrogravity stages preferably operates using a process fluid with substantially the same density. Sequential groups of hydrogravity stages usually operate using fluids of different densities.

[00129] In one embodiment, it is desirable to arrange a series of hydrogravity tank groups so that the density of the fluid increases as the particles move from one group of tanks to the next, or so that the density of the fluids continually decreases as the particles move from one group to the next.

[00130] With respect to a feedstock of copper cable particles containing a mixture of copper, nylon, polyvinyl chloride compound (PVC) and polyethylene compound (PE), the following sequence of hydrogravity tank groups has been found to be useful:
### Table 2. Preferred Sequence of Tanks

<table>
<thead>
<tr>
<th>Group</th>
<th>Fluid Density (g/cm³)</th>
<th>Heavy Product</th>
<th>Light Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.45</td>
<td>Copper</td>
<td>Mixed plastics</td>
</tr>
<tr>
<td>2</td>
<td>1.20</td>
<td>PCV</td>
<td>Nylon and PE</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>Nylon</td>
<td>PE</td>
</tr>
</tbody>
</table>

[00131] In another embodiment, it may be more desirable to perform the first separation using a group of hydrogravity stages at an intermediate density, with the light product going on to further separation with a lower density process fluid, and the heavy product going on to further separation with a higher density process fluid.

[00132] Each group comprises one or more hydrogravity separation units, and each hydrogravity separation unit preferably comprises a dispersion mixer and a hydrogravity tank.

[00133] The hydrogravity process fluid has two key properties - density and viscosity. The density must be such that the fluid density is intermediate between the density of the lightest and heaviest particles to achieve a hydrogravity separation. The viscosity must be sufficiently low to allow the particles to achieve sufficient vertical velocity in either the upward or downward direction to reach the upper or lower exit port in the nominal residence time of the slurry in the quiescent hydrogravity tank.

[00134] Tests with copper cable-derived granules indicate that the fluid viscosity should be desirably about 100 centipoise or less and more desirably about 25 centipoise or less and most desirably about 10 centipoise or less.

[00135] In the event that the process fluid includes water, it may be preferred to include one or more surfactants to promote particle wetting. Generally any
conventional soap, surfactant, etc., can be utilized such as household soaps, laundry detergents, industrial detergents, and the like. Other useful surfactants include DF12 available from Dow Chemical and LF60 available from DeForest. Foaming tendencies can also be compensated for through the addition of various anti-foaming or de-foaming agents such as poly dimethyl siloxane (PDMS).

Surfactants can generally be anionic, cationic, nonionic, amphoteric, and the like and the same are known in the art. Examples of other surfactants are set forth in 2003 McCutheon's Volume 1: Emulsifiers & Detergents (The Manufacturing Confectioner - Publishing Company; Glen Rock, NJ) which is hereby fully incorporated by reference. Whether a surfactant is suitable or not can be readily determined by adding various amounts to the process fluid containing particles of the various components and determining whether the particles are wetted out. Anionic surfactants ordinarily comprise alkyl hydrophobic hydrocarbon chains having terminal anionic hydrophilic polar groups such as carboxylate, sulfonate, sulfate, phosphonate and phosphate polar groups.

Another class of agents which has been found to promote particle dispersion in an aqueous system is various defoamers which are known in the art. Examples of suitable defoamers include compounds containing amorphous silica, various siloxanes such as polydimethyl siloxane, and the like such as Dow Corning 200, 1430, 1520, etc.

The amount of such surfactants, detergents, wetting agents, defoamers, etc., generally varies with the strength of the surfactant, the amount of "dirt" in the feedstock, and the chemical nature of the aqueous solution. It is also contemplated that depending upon the application these agents or analogous agents can be used in a process fluid not utilizing water.
The preferred embodiment hydrogravity separation tank is designed to promote good separation of multiple domain feedstocks after granulation. In accordance with the present invention, generally one or more of the heaviest components are removed from the bottom of the hydrogravity separation tank as a heavy product, and one or more of the lightest particles float to the top of the tank and are removed or skimmed off as a light product. The density of the solution in the tank is thus generally intermediate between the density of the heaviest or most dense particles and the density of the lightest or least dense particles.

Accordingly, the overall density of the process fluid is desirably at least about 0.01 g/cm³ lighter or heavier and preferably from about 0.05 g/cm³ to about 0.10 g/cm³ lighter or heavier than the density of any selected component particles.

In one embodiment, in any given stage of the reclaiming operation, substantially only a single heaviest particle component is removed from the bottom or only a single lightest particle component is removed from the top of the separation tank.

In another embodiment, in any given stage of the reclaiming operation, two or more types of heavy particles are removed from the bottom of the tank, or two or more types of light particles are removed from the top of the tank.

As noted above, it is an important aspect of the present invention that in order to obtain a high yield and purity of any specific particles of one or more components, such selected particles are fed to a plurality or multiple of subsequent hydrogravity separation stages wherein the removal operation is repeated with the selective component being reclaimed being transferred to all the tanks in one operational group of hydrogravity stages.
The number of such hydrogravity stages in any operational group can vary from 1 to about 10, desirably from about 3 to about 8, and preferably from about 3 to about 5 until the selected component(s) is highly purified. The density of the process fluid(s) in any plurality of hydrogravity separation stages of any single operational group is preferably substantially the same.

An essential aspect of the hydrogravity stages is that they have a high shear mixer upstream of the hydrogravity tank to insure that the individual particles are not agglomerated, and are free to respond to the appropriate buoyancy forces in the subsequent hydrogravity separation tank. Preferably, the high shear mixer operates to disperse or break up or otherwise separate agglomerates or collections of particles. The extent of such dispersion or agglomerate separation is preferably at least about 90%, more preferably at least about 95%, and most preferably at least about 98%. These percentages refer to the percentage of feedstock particles, which are independent and free from being part of a collection or group of particles that are bound or otherwise attached to one another such that the bound collection acts as a large particle.

An essential aspect of the hydrogravity tanks is that they utilize a non-turbulent or slow flow rate such that the tank effectively separates the heaviest component(s) or separates the lightest component(s) from the remainder of the process fluid. Such a quiescent tank has sides and bottom surfaces which are greater than the angle of repose of the particles contained therein, thus eliminating and preventing build-up thereof. The angle of-repose of the various sides will vary with the physical and chemical properties of the process fluid, the types of components such as plastic or metal, the shape of the particles, and the like. Generally, as shown in FIGURE 2, any side surface or wall of the tank has an angle
A or B to at least 45 degrees from horizontal. The angle of the various sides is generally at least 1 degree greater, desirably at least 5 degrees greater, and preferably at least about 10 degrees greater than the angle of repose of the particles of interest.

[00147] The present invention provides numerous tank designs and configurations. One such configuration of a preferred embodiment tank of the present invention is set forth in FIGURES 2 and 3 wherein tank 200 has a top 205, a vertical upper first end wall 210, an inclined upper second end wall 215, and as shown in FIG. 3, generally vertical upper first and second side walls 220 and 225 respectively. The upper first end wall 210 of the upper portion of the tank extends into inclined lower first end wall 230. As shown in FIG. 3, the upper first side wall 220 also merges into an inclined lower first side wall 235 and the same is true of upper second side wall 225 which merges into inclined lower second side wall 240, all of which are oriented greater than the angle of repose.

[00148] Utilization of the above described hydrogravity separation tank of FIG. 2 thus permits the washed and dewatered particles from dryer 170 depicted in FIGURE 1 to be fed through tank inlet 245 to tank 200 and subsequently separated into components, such as at least one component which is discharged as a slurry from the tank bottom egress 250.

[00149] Flow into the hydrogravity tank is controlled by the feed pump's rate and/or by control valves suitable for slurry service. The flow into the tank is split between the upper and lower egress points. Depending on the type of material being processed, and the amount of heavy or light material in the slurry, either egress can be operated in a continuous or an intermittent fashion. For example, one may choose to continually draw off a heavy product slurry from the bottom egress 250, or
one may choose to normally close off this egress, allow the heavy product to
accumulate in the bottom of the tank, and purge the tank periodically by briefly
opening the egress.

[00150] Alternatively, the heavy product can be removed from the bottom of the
tank by a screw-type device, or by other mechanical or hydraulic means or can accumulate there prior to subsequent batch removal by any means.

[00151] As shown in FIG. 2, hydrogravity separation tank 200 in one
embodiment optionally can contain skimmer 260 which comprises a conveyor type
belt 265 having paddles 270 dependent therefrom. Rotation of conveyor 265 will
cause the paddle to be immersed into the top of the aqueous solution and skim the
floating particles to one edge of the tank where they are collected and transferred to
a dispersion mixer 300 shown in FIGURE 4 and described in greater detail herein.
One or more simple rotational paddles can also be utilized to nudge the floating
particles towards the upper tank egress. Otherwise, the floating particles can simply
flow through an outlet opening, over a weir or through other types of removal devices
known in the art to the next stage of the system or process. A suitable fluid spray or
air stream could also be utilized to motivate floating particles towards the
hydrogravity tank's upper egress.

[00152] As with the lower egress, the upper egress can be operated on a
continuous or intermittent basis. For example, one may choose to continually draw
off a light product slurry from the top of the hydrogravity tank, or one may choose to
normally close off this egress, allow the light product to accumulate on the surface of
the fluid in the tank, and purge the tank periodically by briefly opening the egress,
and optionally turning on the skimmer, etc.
[00153] In accordance with the present invention, separation and purification of granulated solids of different components, e.g. plastic, metal, is conducted as opposed to purification of a solution. Separation of the various components is readily achieved when each feedstock component has a density at least about 0.01 g/cm³ particularly about 0.05 g/cm³, and desirably at least about 0.10 g/cm³ or at least about 0.15 g/cm³, different from another component.

[00154] Inasmuch as the various granulated particles upon immersion into the process fluid will tend to agglomerate due to surface tension, electrostatic, or other forces of attraction, it is desirable to utilize a dispersion mixer before each separation tank to disperse, sever, etc., such agglomerated particles.

[00155] A dispersion mixer 300 shown in FIG. 4 is preferably located upstream of the first hydrogravity tank of the first removal stage and desirably also before every hydrogravity tank. The same practice applies with respect to the other removal stages of other component particles. Although dispersion mixer 300 can be a batch mixer, it is highly preferred that a continuous flow mixer be utilized. The dispersion mixer can be of any shape but desirably is elongated and can have one or more mixing zones, with a plurality of zones, such as from about 2 to about 10, and from about 3 to about 5 zones being preferred. Desirably dispersion mixer 300 is in the shape of an elongated tube or cylinder 310 and has a zone separation element such as an annulus 315 located between and defining each zone. Annulus apertures 316A, 316B and 316C can vary from zone to zone so long as each aperture is less than the tube diameter with a desired aperture area of from about 10% to about 50% and preferably from about 15% to about 30% or about 35% of the total tube diameter area. The linear location of each zone separation annulus 315 can vary so that each zone can be of any desirable length and each zone length need not be the same.
The zone length to diameter ratio can be of from about 0.5 or about 0.8 to about 5 or about 10.

[00156] One or more shafts can be utilized to rotate a mixing impeller, with one axial shaft 320 being preferred, which extends through mixer 300 and can be rotated by any conventional apparatus such as motor 325. Generally two types of mixing impellers are utilized. The first is an axial mixing impeller 330, located in axial flow zone 335, which draws in and propels the granulated component particles into the mixer. While a plurality of mixing impellers can be contained in any zone, desirably only one mixing impeller is utilized in each zone. Any conventional impeller can be utilized in the first or ingress zone such as a marine propeller having two or more blades, or any other substantially axial flow generating impeller. The orientation of the elongated tube can be vertical, horizontal, or at any angle in between.

[00157] The process fluid containing the granulated particles therein is then forced through first annulus 315A into first radial flow zone 345 which contains a second type of mixing impeller, a radial flow dispersion impeller 340 designed to at least substantially break up any particles which have agglomerated. It is preferred that the radial flow dispersion impeller creates high shear and/or high turbulence to separate the agglomerated particles. Such impeller dispersion blades are more functional than a simple impeller since as the dispersion blades create a hydraulic action which tears agglomerated particles apart and disperses them uniformly throughout the process fluid. This is believed to be achieved by two different mechanisms. In the first, agglomerated particles contacting the blade are broken apart (sheared) and then in the intense turbulence surrounding the blade, particles contact one another at high speeds and are further broken up. This intense turbulence around the blade generally occurs at a zone extending a few inches
outward therefrom and is called the zone of attrition. Beyond the turbulent zone the various particles are thoroughly mixed and dispersed. The diameter of the high shear and/or turbulent impeller 340 can vary in length but is generally from about 20% to about 75% and desirably from about 25% to about 30% to about 35% or about 55% of the dispersion mixer diameter. Various types of radial dispersion impeller blades are known in the art and can be utilized such as a Cowles®, impeller, a Hockmeyer impeller, or a so-called "high vane blade".

[00158] Referring again to FIGURE 4, in a preferred embodiment of the present invention, the process fluid is fed from first radial flow zone 345 through second zone separation annulus 315B to a second radial flow zone 355 having a dispersion impeller 350 which further breaks up the agglomerated particles, etc., and further disperses the same into individual particles. The mechanisms are the same as with regard to first radial flow zone 345 and so a description of such will not be repeated.

[00159] In a preferred embodiment, the process fluid having a desired overall density flows through third zone separation annulus 315C into a fourth zone, which is a second axial flow zone 365 containing axial flow impeller 360. The axial flow impeller is desirably the same as axial flow impeller 330 and the same descriptions, along with the various other aspects of axial flow zone 365, will not be repeated. Of course, axial flow zone 365 serves to draw the process fluid from radial zone 355 into axial zone 365 and then expel it as through an egress in the mixer to a pipe or conduit leading to a subsequent hydrogravity separation tank and preferably to a mid-portion side inlet thereof.

[00160] The rpm of rotating shaft 320 can vary considerably depending upon desired throughput or flow rate but generally is from about 500 to about 5,000 and preferably from about 2,500 to about 3,500 rpm. The flow rate through mixer 300 will
generally vary with the tube diameter as well as the diameter of apertures 316A, 316B, and 316C and can be from about 1 to about 150, desirably from about 10 to about 130, and preferably from about 20 to about 100 gallons per minute with respect to a dispersion mixer having a 10 inch diameter.

[00161] With respect to using a feedstock of copper cable particles, although generally any type of feedstock can be utilized, in the various reclaiming stages a selected component is separated out such as a metal or copper in a first stage. The washed and granulated dewatered feedstock comprising different domain thermoplastic particles as well as copper particles is continuously fed preferably to a plurality of sequential hydrogravity separator tanks wherein the copper, or other non-thermoplastic materials is separated from the thermoplastic components. Desirably before each tank they are fed to a dispersion mixer for de-agglomeration and subsequently fed to the mid-portion of a sequential hydrogravity tank. By "mid-portion" it is meant from about 10% to about 90%, desirably from about 20% to about 80%, and preferably from about 30% to about 70% of the total process fluid height in the tank.

[00162] While a specific dispersion mixer has been described in detail, it is to be understood that many variations thereof as well as other mixers can be utilized so long as they generally contain at least one and preferably a plurality of dispersion zones which serve to further break up the particles as through high shear and turbulence.

[00163] For example, a dispersion mixer can contain an inlet pump and/or an outlet pump in lieu of an impeller. Moreover, in the radial flow zones, high turbulence pumps can be utilized or a radial-type pump can be run backwards to produce high turbulence and/or shear.
[00164] The hydrogravity separation of a specific wire cable feedstock will now be discussed in view of the above principles, concepts, structures, and descriptions. As noted above, the wire cable comprises a plurality of copper wires each surrounded with a polyethylene thermoplastic with the same being encapsulated in polyvinyl chloride thermoplastic insulation. The outer jacket of the insulated cable is nylon thermoplastic.

[00165] Referring again to FIGURE 1, the hydrogravity separation process described below comprises three groups 400, 500, and 600 of hydrogravity separation stages operating at process fluid densities of about 1.4 g/cm$^3$, 1.2 g/cm$^3$, and 1.0 g/cm$^3$. Each group comprises four hydrogravity separation stages. Each separation stage includes a high shear dispersion mixer and a relatively quiescent hydrogravity separation tank.

[00166] The granulated, washed, and dewatered feedstock is slurried into a process fluid containing two or more immiscible liquids as described herein and which may for example be in the form of an emulsion, with a density of about 1.4 g/cm$^3$ to form a slurry with a solids content of 1 to about 40% by weight. The slurry is fed to a first high shear dispersion mixer 415 which, is described herein above, the description, concepts, principles, etc. which are hereby incorporated by reference, contains a plurality of zones having a first axial flow zone, a first dispersion zone wherein a dispersion impeller breaks up agglomerated particles as by high shear and/or turbulence, a second radial dispersion zone followed by an axial output zone. The dispersed particles are then fed to one end of a first hydrogravity separation tank 410, the description, concepts, principles, etc., of which as set forth herein above such as with regard to tank 200 are hereby fully incorporated by reference. The density of the process fluid in tank 410, and all subsequent tanks 420, 430 and
440, is about 1.40 g/cm³ which is greater than substantially all of the thermoplastic domains or components but less than that of the copper component.

[00167] The preferred viscosity of the process fluid is low, for example less than about 20 centipoise. The sides of tank 410 have an angle sufficient to prevent build-up of any copper solids and the flow rate throughout the tank is slow and generally free of any turbulence so that quiescent separation is achieved. That is, generally the particles have a low velocity component in the horizontal direction with a greater velocity flow component in either vertical direction.

[00168] After a desired residence time to permit good separation, the copper particles, along with a small amount of plastic particles are emitted from the bottom of tank 410 in the form of a slurry which is transferred to conventional purification unit 470. Any conventional purification unit can be utilized such as a concentrating table, e.g. a Deister or a Wilfley table, generally of a rectangular shape and tilted towards one corner so the copper particles are directed thereto and collected. The copper component particles are placed in storage unit 480.

[00169] The remaining thermoplastic domain particles of nylon, PVC and polyethylene either flow out of the top of the tank over a weir or are mechanically skimmed off and fed to second high shear dispersion mixer 425. The second dispersion mixer is desirably the same as the first mixer and thus has two radial flow zones for breaking up and separating various agglomerated particles which are primarily a thermoplastic. The various thermoplastic component particles are then fed to a second hydrogravity separation tank 420.

[00170] Tank 420 preferably contains essentially the same density process fluid as first separation tank 410 and in all aspects is desirably the same as first tank 410. In other words, the structure, flow, etc., can be a duplicate of the first hydrogravity
separation tank. Thus, additional settled copper particles from the bottom of tank 420 are fed to purification unit 470 and the remaining floating particles are either skimmed or flow to third dispersion mixer 435 which is desirably the same as first dispersion mixer 415 and has multiple axial mixing zones, and multiple dispersion zones which further break up agglomerates.

[00171] In a similar manner, the system and process can be repeated any number of desirable times until essentially all of the copper component has been removed from the feedstock and has reported to the bottom of the hydrograviity separation tanks which all contain essentially the same structure and conditions as well as the same process fluid as first tank 410, with the remaining thermoplastic particles being removed from the top of the tank and passed through a mixer having the same structure and conditions as first dispersion mixer 415 and then transferred to a succeeding tank. In the embodiment shown in FIG. 1, a total of four tanks are utilized including third hydrogravity separation tank 430, fourth dispersion mixer 445, and fourth hydrogravity separation tank 440.

[00172] In accordance with the concepts of the present invention, since predominantly copper was removed from the first operation stage, the remaining thermoplastic components are subsequently separated and purified via a plurality of dispersion mixers and hydrogravity separation tanks and contain very little, if any, remaining copper particles.

[00173] In the event that the process fluid comprises water or an aqueous phase, after the last hydrogravity tank in the first group, the process fluid slurry is fed to de-watering device 460 to remove any adhering high density water or aqueous solution from the plastic particles and the solution returned to tank 410 (not shown) to minimize the amount of high density process fluid that is sent to the second group
of hydrogravity stages which would alter the density of the subsequent tanks and potentially have a detrimental effect thereon. Generally any conventional dryer or de-watering device 460 can be utilized such as a fluid bed, a vibration screen, or a centrifuge dryer, with a spin dryer such as a Gala 3016 dryer manufactured by Gala Corporation being suitable.

[00174] The utilization of the above system and process with regard to a copper cable can result in a yield of generally at least 90%, desirably at least about 95% and preferably at least about 98% or about 99% percent by weight from copper purification unit 470 based upon the total weight of copper added to first separation tank 410. The purity of copper from purification unit 470, which separates thermoplastic particles from the copper, is generally at least about 80%, desirably at least about 90%, and preferably at least: about 95% by weight based upon the total weight of material collected.

[00175] Considering the second group 500 of hydrogravity tanks of the present invention, the purified thermoplastic particles obtained from the last hydrogravity tank in the first group of hydrogravity separation states are fed to a series of a dispersion mixer and subsequent hydrogravity separation tank units desirably in accordance with the concepts, principles, structure and the description set forth hereinabove and for the sake of brevity will not be repeated. However, the same is hereby fully incorporated by reference with regard to all aspects thereon such as to the structure, shape, flow conditions of the various hydrogravity tanks, the type of dispersion mixers which utilize a plurality of zones having at least one axial flow zone and at least radial dispersion zone.

[00176] With respect to the copper cable example, the mixed plastic particles from the first set of hydrogravity tanks are slurried into a process fluid with a density
of about 1.20 g/cm³. This slurry is then fed into another high shear dispersion mixer, and then into another hydrogravity tank. At a process fluid density of about 1.2 g/cm³, PVC will tend to sink, and lighter components such as nylon and PE will tend to float.

To further purify the PVC product, the product stream from the bottom of the first hydrogravity tank is fed into the high shear dispersion mixer of the second hydrogravity tank. The same process is repeated with the third and fourth hydrogravity stages in this group.

Any remaining domain thermoplastics such as polyethylene and nylon float to the top and are removed from the top of each tank. Optionally, the floating particles of nylon and PE can be re-processed through one or more additional high shear dispersion mixers and hydrogravity tanks to further remove any residual PVC from these streams. Such mixers and tanks would also contain a processing fluid with a density of about 1.20 g/cm³.

With respect to the copper cable example, the thermoplastic particles are first fed to high shear dispersion mixer 515 and then to quiescent hydrogravity tank 510 which have walls of non-repose and non-turbulent flow conditions with adequate residence times such that the various particles can separate from one another. Subsequently, the lighter polyethylene and nylon are collected from the top of tank 510 and are fed to a third group of high shear dispersion mixers and hydrogravity tanks.

The polyvinyl chloride particles are collected from the bottom of first tank 510, fed to second dispersion mixer 525 where they pass through different mixing zones and are subjected to a dispersion impeller whereby any agglomerates are substantially broken into individual thermoplastic particles. The particles are then
fed to a second hydrogravity tank 520 wherein the separation process is repeated. Thus, the lighter polyethylene and nylon particles float to the top and flow out of or are skimmed off the top of second tank 520 are then fed to the third group of dispersion mixers and hydrogravity tanks. The PVC particles settle out of the bottom of second tank 520 and are fed to third dispersion mixer 535, and then to third hydrogravity tank 530 for further separation. Once again, in a manner as described hereinabove, the polyethylene and nylon particles are separated and collected from the top of tank 530 and are fed to the third group of dispersion mixers and hydrogravity tanks. The PVC particles are collected from bottom of tank 530 and fed to fourth dispersion mixer 545 wherein agglomerates are severed and broken apart and fed to the fourth hydrogravity separation tank 540. In the fourth and last tank once again, remaining polyethylene and nylon particles that float to the surface are fed to the third group of dispersion mixers and hydrogravity tanks.

[00181] The PVC thermoplastic polymers which are collected from the bottom of fourth separation tank 540 are treated to remove the majority of the hydrogravity process fluid for recycle using a screen, centrifuge, or preferably a spin dryer such as a Gala-type spin dryer indicated by unit 550. The PVC particles are washed to remove residual hydrogravity process fluid, and dried using one or more units such as a centrifuge, vibrating screen, or Gala-type spin dryer. Further drying can be accomplished in a fluid bed drier or in other types of plastic particle dryers known in the industry. The PVC component particles are then bagged, etc. and placed in storage unit 560 for subsequent reuse and/or sale. The process fluid from unit 550 is then recycled desirably to first hydrogravity tank 510.

[00182] In the third group 600 of dispersion mixers and hydrogravity tanks, the thermoplastic components of nylon and polyethylene particles from the second unit
operation are slurried into a process fluid with a density of about 1.0 g/cm³. This slurry is fed to first dispersion mixer 615 and then to hydrogravity separation tank 610. As with the first set of hydrogravity tanks, the component which is desired to be cleaned or purified, PE, tends to float. These floating particles are recycled to a second dispersion mixer and hydrogravity tank, then to a third dispersion mixer and hydrogravity tank, and then to a fourth dispersion mixer and hydrogravity separation tank.

[00183] The heavy plastic component, predominantly nylon, can be removed and cleaned, or, optionally, can be send to another group of one or more dispersion mixers and hydrogravity tanks to further purify the nylon, removing any PE contamination.

[00184] The polyethylene-rich product slurry is cleaned, washed if necessary, and dried prior to packing in a manner similar to that described for PVC above.

[00185] The nylon-rich product slurry, is cleaned, washed if necessary, dried, and packaged in a similar fashion.

[00186] Once again, with respect to the overall system and process of the third group of dispersion mixers and hydrogravity tanks, the concepts, principles, structures; and description as set forth hereinabove with regard to the mixers, the hydrogravity tanks, and the like are hereby fully incorporated by reference and hence will not be repeated.

[00187] Thus, the feed stream from the end of the second set of dispersion mixers and hydrogravity tanks is slurried into a process fluid with a density of about 1 g/cm³. This slurry is fed to first dispersion mixer 615 wherein any agglomerated particles are substantially broken apart with the slurry then being fed to first hydrogravity separation tank 610 wherein the heavier nylon particles settle to the
bottom of the tank and are collected, washed, and directly fed to nylon dryer 650. The density of the process fluid of all of the tanks of the third set of hydrogravity tanks are all essentially the same and are all slightly less than the density of nylon and hence is approximately 1.0 g/cm³. Thus, as with the first and second operation stages, if any or a small amount of a thermoplastic component is contained with the heaviest component or an agglomerated particle containing more than one domain, it will float to the top whereupon it is de-agglomerated and fed to a subsequent tank, and so forth until all of the heaviest component has been removed therefrom.

[00188] Accordingly, the particles which float to the top of first tank 610 are fed to second mixer 625 where agglomerated particles are broken apart, added to second dispersion mixer and hydrogravity separation tank 620 with the nylon collected from the bottom thereof and fed directly to nylon dryer 650 and the remaining floating polyethylene particles fed to third dispersion mixer 635. The process is once again repeated purifying the polyethylene particles by collecting the heavy nylon particles from the bottom of tank 630 and further breaking any agglomerated floating particles by feeding them to mixer 645. Finally, any remaining nylon particles are collected from the bottom of tank 640, washed, and dried in nylon dryer 650 with the remaining particles which float being purified polyethylene particles which are optionally washed, and fed to polyethylene dryer 660. Both nylon dryer 650 and polyethylene dryer 660, as before, can be any conventional dryer such as a centrifuge dryer, a fluid bed, vibrating screen with a spin dryer such as a Gala dryer being preferred. The separate dried nylon particles can be collected in storage unit 670 for subsequent use and/or sale. The polyethylene particles can also be dried and placed in storage unit 680 for subsequent use and/or sale. As before, the
process fluid from dryers 650 and 660 are recycled to hydrogravity 610 to replenish the process fluid thereof.

[00189] It is essential to maintain clean process fluids to effect good particle separation. This involves removing dirt, fines, and any foreign materials. A number of methods can be used to continually or intermittently clean the fluids, such as clarification, centrifugation (solid bowl, screen bowl, or other), and filtration (gravity, pressure, or other). An excessive build-up of foreign particles in the process fluid will impair the ability of individual feed particles to quickly move in the direction indicated by density relative to the density of the process fluid. Process fluid cleaning steps can be conducted without breaking the emulsion in the present invention, or can deliberately cause the emulsion to break, thereby allowing recovery and separate cleaning of the two or more fluids that comprise the emulsified process fluid.

[00190] Diluted or "off-spec" process fluids can be reconstituted continually or intermittently by evaporation, addition of one or more component liquids, or other means known to one skilled in the art.

[00191] Fluids contaminated by excessive amounts of dissolved heavy metals can be purified by chemical treatment, electro-chemical treatment, or other means known to one skilled in the art. For example, a build-up of lead or copper ions can be removed by precipitating the metallic ions (after suitable pH adjustment) with a soluble sulfide solution such as calcium polysulfide or sodium hydrogen sulfide, or with a gas such as hydrogen sulfide. Reagents that form a largely insoluble species of the offending metallic ion without precipitating any components in the process fluid are preferred. The precipitant can then be coagulated and/or flocculated and removed by suitable means such as clarification, filtration, etc.
Another embodiment of the present invention with respect to granulating feedstock particles and removing fines therefrom is set forth in FIGURE 5. Precut feedstock 710 is fed to scalper 720 which removes and feeds to container 724 oversized particles such as those generally larger than 12 mm, fibers, as well as angel hair which is generally strips or strings of fibers derived from paper, polymer, and the like. Fines fall through a fine size screen and are collected in container 722.

The remaining feedstock is fed to an optional air separator to remove additional paper and other light contaminants from the more desirable components of the feed.

The remaining feedstock is fed to granulator 730, which can be similar to that described above, wherein the feedstock is broken, chopped, shredded, etc. into small particles of from about 0.5 mm or about 1 mm to about 2 mm or about 3 mm or about 4 mm. The granulator separates the dry feedstock containing different components into particles substantially containing only one component such as a specific type of thermoplastic or metal. Since fines are undesired because they can become suspended or entrained in the aqueous hydrogravity solution, they are removed by fine separator 740 which utilizes one or more fine screens to selectively remove fines and dirt and deliver the same to container 742.

The remaining feedstock is fed to another optional air separator to remove additional paper and other light contaminants from the more desirable components of the feed.

The dry substantially single component particles are then subjected to a wet system which further removes fines and dirt. The water removal system comprises the various feedstock component particles which are fed to wash tank 750 generally having agitation therein, and contain soap, surfactants, wetting agents,
etc., from tank 752. After the washing operation which may be batch or continuous, the wet feedstock particles are fed to wet screen operation 760 wherein water from tank 762 washes the particles to remove the soap or surfactant therefrom and is subsequently collected in container 766. If necessary, the particles can be subjected to another stage of washing in an agitated wash tank followed by another wet screening operation to enhance dirt removal. The removed fines and dirt are fed to container 764. The various washed feedstock component particles which are semi-wet are fed to any conventional dryer 770 such as a Gala dryer wherein water is removed to container 772. The dried multiple feedstock component particles can then be fed to any series of hydrogravity separation tanks to remove at least two different thermoplastics, through a plurality of mixing and hydrogravity separation steps.

[00197] The above described system and process will be better understood by reference to the following hypothetical examples which serves to illustrate but not to limit the present invention.

[00198] With respect to reclamation of 1000 pounds of residue from a particular copper cable "chopping" and primary copper recovery operation, and according to the format generally described hereinabove and shown in FIG. 1, 995 lbs. of feed stock was obtained from granulator 120 with the remaining 5 lbs. being recovered as fines. Depending upon the amount of residual cooper metal in the cable feedstock, the amount of copper recovered from first operation stage 400 can range from about 10 lbs. to about 150 lbs. with the purity of the copper being generally at least about 80%, at least about 90%, or at least about 95% by weight, and preferably at least about 98% or at least about 99% by weight. The recovery of the PVC from the second operation stage 500 can range from about 750 to about 975 lbs. with the
purity of the PVC being at least about 85% to at least about 90% or, desirably at least 95% by weight, and preferably at least about 98% or at least about 99% by weight of the total weight of the collected PVC stream.

[00199] The amount of the nylon and polyethylene being recovered from the third operation stage 600 each can independently vary from about 5 lbs. to about 100 lbs. based upon the total weight of both components with the purity of each component being at least 85% or at least about 90% by weight, desirably at least about 95% by weight, and preferably at least about 98% or at least about 99% by weight.

[00200] Generally, the system and process of the present invention readily recovers at least about 95%, desirably at least about 98%, and preferably at least about 99% by weight of the initial feedstock.

[00201] If desired, each of the above reclaimed component particles of PVC, polyethylene, and nylon can be further purified by additional hydrogravity separations, or by other methods known in the art if so desired.

[00202] In another hypothetical example, a mixture of solid particles with densities in the range of 0.9 to 1.0 g/cm³ is separated in a float sink apparatus using an emulsion with a density of 0.95 g/cm³. The emulsion was prepared by admixing water with a non-ionic surfactant and an organic liquid of density 0.75 g/cm³. The proportions of water, organic liquid and surfactant were chosen such that the resultant emulsion had an overall density of 0.95 g/cm³. Particles with a density of 0.95 g/cm³ or less tended to report to the floating phase, while particles with a density of 0.95 g/cm³ or more tended to report to the sinking phase.
Recovery of Materials from Shredder Residue

[00203] Automobiles at the end of their life cycle are typically shredded in large automobile shredders to recover primarily the ferrous metals and some of the non-ferrous metals in the scrapped vehicle. Automotive Shredder Residue, also known as ASR, generally refers to what remains after auto shredders remove at least a portion of the metal, reusable parts, ferrous and non-ferrous materials from a vehicle. Various means of magnetic separation can be used to remove most of the ferrous metal, and various other means, including eddy current sorting, are used to separate some of the non-ferrous metals. ASR materials typically contain plastics, polyurethane foam, various fluids and an assortment of other materials. ASR typically comprises 25% of every vehicle, which results in a large amount of materials ending up as solid wastes. Every year in the United States alone, auto shredders generate about 5 million tons of ASR, most of which is disposed in solid waste landfills. ASR is frequently in irregular pieces, usually no more than 5 to 8 inches in largest dimension.

[00204] Another type of shredder residue is residue from electronic waste, termed Electronic Shredder Residue (ESR). ESR also contains significant proportions of plastics mixed in with one or more metals and other materials. Examples of electronic waste include, but are not limited to, waste electric and electronic equipment such as discarded computers, televisions, telephones, other electronic devices, electrical components used in industry and residential applications, and a host of other devices, equipment and systems. These various devices and equipment are typically at the end of their life cycle, and are thus shredded to recover precious metals and to reduce the volume of the remaining
fraction. ESR is typically in irregular pieces, usually no more than 5 to 8 inches in largest dimension.

[00205] Yet another type of shredder residue is residue from "white goods" such as refrigerators, washers, driers and the like termed Whit Shredder Residue (WSR). WSR, like ESR, contains significant proportions of plastics mixed in with one or more metals and other materials. WSR is typically in irregular pieces, usually no more than 5 to 8 inches in largest dimension.

[00206] A waste processor may process automotive, electronic and white goods individually or simultaneously. The shredder residue may comprise elements from either ASR, WSR or ESR alone, or may contain a mixture of any of these elements.

[00207] With regard to ASR, plastics constitute from about 12 to about 15 percent of a vehicle's weight, and almost half the weight of ASR (after metallic components are removed). Generally, some of the more common plastics found in ASR are polyethylene (PE), polypropylene (PP), filled or high-impact polypropylene (HIPS) and acrylonitrile butadiene styrene (ABS). These materials are typically used in bumpers, dashboards and other components and soundproofing insulation. ESR and WSR typically comprises comparable levels and types of plastics. Theoretically, it is possible to recycle thermo plastics over and over again without causing any change to their properties. However, plastics lose their properties if they undergo overheating during molding, use or recycling. A completely separated plastic that has not degraded is usable in its original function. For at least this reason, using a density-based separation method for separating plastics from ASR and/or ESR, and/or WSR is particularly preferred over recycling methods using thermal
operations. And, for additional reasons explained below, it is preferred to remove any metals from a plastics fraction derived from ASR or ESR.

[00208] As noted, the particle top size of ASR is usually less than 8 inches. Often, much of the ferrous metal (iron, steel, etc.) has been removed from this residue (usually by magnetic means). In some cases, much of the non-ferrous metal (copper, zinc, aluminum, stainless steel, etc.) has also been removed, often by some type of eddy-current separation. However, it is usually impossible to remove all of the ferrous and/or non-ferrous metals by conventional processing. This residual metal thus contaminates the plastics that make up the majority of ASR and ESR, and must be removed to allow facile recycling of the plastics.

[00209] Examples of specific thermoplastic polymers which can be separated or otherwise obtained from ASR and/or ESR sources include, but are not limited to, polyolefins, polyurethanes, polyamides, polyvinyl chlorides, styrenic polymers, acrylic polymers, polycarbonates, fluorinated polymers, polyesters, and ABS. Virtually all of these polymers are present as compounds, containing additives such as inorganic fillers, plasticizers, colorants, impact modifiers, stiffeners, and the like.

[00210] The preferred embodiment processes can be used to separate classes of ASR and/or ESR materials or to isolate specific components of a mixture of these materials.

[00211] For example, a process fluid of a certain density may be used to separate a majority of the plastic components in a multiple domain feedstock such as that derived from ASR and/or ESR from the metallic components therein, thereby separating the "metallic" class from the "plastic" class.

[00212] Plastic components can also be separated from various other non-plastic components, including foams and fibers, various cellulosic materials such as
wood and paper, various rubbers and thermoplastic elastomers, tars, dirt, sand, glass, fabrics and other contaminants by air washing (aspiration) or by density separation by using the process fluids described herein.

[00213] Density separation may also be used to separate the plastic components into streams of pure single-component plastics, or into two streams of multi-component plastics such that all of the components in a stream have essentially the same density, or have specific gravities within a narrow range of each other.

[00214] Plastic particles of similar density but different chemical composition can be separated based on differences in surface chemistry by using other optional separation operations such as for example, froth flotation.

[00215] The overall preferred embodiment process preferably includes, but is not limited to, the following operational steps described in more detail below.

[00216] ASR and/or ESR and/or WSR feedstock may comprise multiple domains. These multiple domains are often present in the form of layers, regions, areas, and the like. To effect a separation of different domains by float-sink technology, it is necessary to first physically separate the domains. This can be accomplished through various mechanical means such as granulating, grinding, chopping, ball milling, hammer milling, and the like known to those skilled in the art.

[00217] Granulators such as those available from Cumberland or shredders such as those available from SSI or ring mills such as those available from American Pulverizer are particularly useful in this step. Granulation involves sizing the feed stock by cutting or chopping the feedstock into suitably-sized particles of substantially single domains. Furthermore, the largest particles must be sufficiently small enough to pass through any pumps, control valves, flow meters, etc. Particles
less than 1 inch in their largest dimension are useful, and particles less than about \( \frac{1}{2} \) inch in their largest dimension are preferred.

[00218] Depending on the "as received" quality of a given feedstock, granulation may be an optional step if the particle size distribution is sufficiently small, and if most of the particles are substantially a single domain.

[00219] The properly sized particles can be air-washed or aspirated and/ or screened to remove fines, foam and fiber. Suitable aspirators include the "waterfall" type manufactured by Kice and Forsberg. Suitable screeners include round screeners such as those manufactured by Sweco or rectangular screeners such as those manufactured by Rotex.

[00220] Removal of contaminants and "trash" at this point in the process protects the process fluids in subsequent steps from excessive contamination and reduces (but not eliminates) the need for fluid clean-up. Removal of fine particles (typically those less than about 0.5 mm) is also important, since small particles have a very low Stokes velocity, and will require excessive amounts of time to separate in the subsequent density separation steps.

[00221] For high quality feedstocks that contain minimal amounts of fluff, fines, fibers, etc. this step may be optional.

[00222] Another optional step involves washing the particles using water or an aqueous solution, (optionally containing a suitable surfactant) to remove dirt, dust, grime, oil, and the like, yielding a more pure product. A means of mixing and agitation is useful in promoting solid-liquid contacting. Particle-to-particle contact can also aid in removing and suspending dirt and oil particles in the washing fluid. Rinsing and/or spin drying can be useful after the washing step to reduce the amount of residual fluids carried forward to the next step.
Feedstocks that contain minimal amounts of dirt, oil, etc., or feedstocks that have been previously subjected to some type of washing may not require this step.

The particles are then introduced into a process fluid containing two or more immiscible liquids as described herein, having a density which is intermediate to the density of the heaviest solid components and the lightest solid components in the feed to this stage. It is also contemplated that the particles can be introduced into a process fluid having a density greater than or lesser than the density of any domain of particles in the feedstock. The slurry of particles and process fluid is passed through one or more hydrogravity processing units. Each processing unit preferably contains a dispersion mixer to disperse any agglomerated particles, and a relatively quiescent hydrogravity separation tank which allows heavy components to sink and lighter components to float.

The dispersion mixer is used to sever, divide, and especially to break up agglomerated particles of the feedstock before they are added to a hydrogravity separation tank. A number of devices can be used as a dispersion mixer, including an agitated tank, an in-line static mixer, an in-line mechanical mixer, a high shear pump such as a centrifugal pump, or any other device that serves to physically separate the mixture into individual particles.

It is important that each particle be free to float or sink as its density (and the density of the process fluid) dictates. If a heavy particle and a light particle were to remain agglomerated together, and were to report to either product stream, the agglomerate would introduce some measure of impurity into that product stream by virtue of the other particle in the agglomerate.
The actual hydrogravity separation occurs in a largely quiescent tank preferably having steep angled walls generally greater than the angle of repose of the heavy particles to prevent particle build-up thereon. A heavy product is recovered from the bottom of the tank, and a light product is recovered from the upper portion of the tank.

However, after one stage of hydrogravity separation, the floating and/or sinking product streams may not be sufficiently pure. Either of the product streams may be contaminated with some entrained particles that would have moved in the opposite direction but for the mass action of other particles surrounding it. Therefore, multiple hydrogravity separations using a fluid of approximately the same density may be required to achieve a reasonably pure product. This is analogous to the multiple separation stages that occur in a distillation column to produce a pure liquid stream.

By way of example, assume a two-component feedstock and a hydrogravity separation efficiency of 90%. After one stage of separation, the desired product stream will contain about 90% of the desired product, and about 10% of the other material as a "contaminant". After a second stage of hydrogravity separation, the level of contamination is reduced to 1%. After a third stage of hydrogravity separation, the level of contamination is reduced to 0.1%, and after a fourth stage of hydrogravity separation, the level of contamination is reduced to 0.01%.

One process configuration includes two or more groups of hydrogravity stages, with each group of hydrogravity stages using a fluid with substantially the same density. Different groups of hydrogravity stages can be operated using fluids of different densities.
It is possible to arrange a series of hydrogravity tank groups so that the density of the fluid increases as the particles move from one group of tanks to the next, or so that the density of the fluids decreases as the particles move from one group of tanks to another.

For some feedstocks, it may be preferable to introduce the feedstock in the middle of series of hydrogravity tank groups such that some of the particles move into fluids of decreasing density, while other particles move into fluids of increasing density. Such an arrangement is used to minimize exposure of lighter components to the heaviest fluids (i.e. highest density fluids), minimizing the loss of these higher viscosity and often higher cost fluids.

Particles in product streams exiting the hydrogravity process may be rinsed and/or dried to remove residual process fluid.

For certain plastics, it may be useful to use a process fluid with a density less than 1.0 to effect the necessary density separation. Such fluids are especially useful in the separation of lower density olefins or in the removal of certain polyurethanes or rubber compounds from olefins. In such cases, in lieu of adding immiscible high density fluids to increase the overall density of the process fluid, one would add immiscible fluids having relatively low densities to the process fluid. Mixtures of common light hydrocarbons immiscible with water can be used to create process fluids with densities as low as 0.60 g/cm$^3$ or lower.

The above-described preferred embodiments can be used in the separation of many different types of mixed materials containing multiple domains. The following examples are presented anticipating a feedstock derived from ASR or ESR. However, these examples are only illustrative, and are not meant to limit the scope of the invention.
In the scope of the present invention, ASR, WSR, or ESR could be treated as follows to recover individual components. Note that depending on the size and cleanliness of the feedstock, some of these steps may be optional, or the order of some steps may be changed.

FIGURE 6 shows a block flow diagram of a preferred process that could be used for the treatment of shredder residue by the present invention for the recovery of metals and plastics. FIGURE 7 shows a block flow diagram of a process that could be used to further separate the plastic components. And, FIGURE 8 shows a block flow diagram of a complex hydrogravity stage that uses four hydrogravity tanks to treat and purify the light components of a mixture, and four more hydrogravity tanks to treat and purify the heavy components of a mixture. Depending on the type of mixture and value of the components, one can choose subsets of this arrangement: For example one may choose to only purify the light components, or only purify the heavy components, or use 4 tanks for purifying the light components and only 2 tanks for purifying the heavy components, or any other combination as dictated by availability and economics.

Referring to Fig. 6, the shredder residue stream is passed through a granulator 1000 that chops the feedstock into smaller particles such that the largest dimension is less than about 0.25 to 2 inches. This serves to make the particles more flowable in downstream processes, and creates a larger percentage of single-domain particles.

To maximize blade life, a low speed, high torque twin shaft shredder like those sold by SSI Products in Oregon or a ring mill such like those sold by American Pulverizer is useful although any suitable size reduction device can be used in this step.
The sized shredder residue stream is optionally passed through an aspirator 1010 to remove fiber, paper, and foamed plastics, along with some of the dirt. The heavy fraction from the aspirator is then optionally screened in screener 1020 at about 1-2 mm to remove dust and more dirt. The fines from screening can be subjected to other subsequent separations to recover non-ferrous metal particles if there is sufficient economic incentive.

The coarse fraction from the screener is optionally mixed with water and a non-foaming or low-foaming surfactant in an agitated vessel 1030 to remove residual dirt, oil, tar, etc. from the particles. Adjustments in pH can also be made in this vessel. The particles can optionally be drained and rinsed to remove dirty fluid and surfactant. Excess fluid is then removed from the particles using a spin drier, screener, air blower, or other drying devices to avoid carrying excess water forward into the next step.

Prior to or at a first density separation unit, shown in Fig. 6 as 1040, the particles are combined with a process fluid of density 1.60 g/cm$^3$. Approximately one part by weight of particles is combined with from about 4 to about 20 parts by weight of process fluid. The process fluid, as previously described, comprises two or more immiscible liquids, and may optionally comprise one or more additional agents such as a small amount of non-foaming surfactant. A high sheer mixer is used ensure that the particles are not agglomerated in the process fluid. The dispersion of particles is introduced into a hydrogravity tank 1040 wherein the lighter particles will tend to float and the heavier particles will tend to sink.

Based on relative densities, the plastic components in the ASR or ESR will tend to float and the metallic components will tend to sink. To improve the
quality of the plastics stream, one or more additional hydrogravity stages are
employed all at approximately the same density to improve selectivity.

[00244] Metallic components, essentially free of plastics are recovered from the
heavy product stream and can be further purified by conventional means. Having a
metallic stream free of polymers, especially PVC, is very useful since most smelters
that would subsequently recycle the non ferrous metals are adverse to polymeric
inclusions which tend to create air pollution problems and add dissolved carbon into
their metals.

[00245] Mixed plastic components, essentially free of metal, are recovered from
the light product stream, and are separated into individual components in
subsequent processing steps.

[00246] Both the floating and sinking streams are optionally processed to
remove any process fluid using separate screening devices, spin driers such as a
Gala drier, or other such devices to avoid carrying excessive amounts of process
fluid into the next step.

[00247] The particles from the plastic-rich stream can be further combined with
a process fluid having a density of 1.50 g/cm³. A high sheer mixer is used ensure
that the particles are not agglomerated in the process fluid. The slurry of particles is
introduced into a hydrogravity tank wherein the lighter particles will tend to float and
the heavier particles will tend to sink.

[00248] In this stage, plastic compounds with a density between 1.50 g/cm³ and
1.60 g/cm³ will tend to sink and can be recovered. Again, multiple tanks can be used
to improve the purity of either the floating or sinking streams.

[00249] In a similar fashion, other hydrogravity separations can be carried out
using process fluids of density 1.40 g/cm³, 1.30 g/cm³, 1.20 g/cm³, 1.10 g/cm³, 1.0
and 0.9 g/cm$^3$ to recover other polymeric species of interest. Each of these steps may involve one or more hydrogravity stages depending on the yield, purity, and value of the plasties in that density range. Fig. 7 specifically illustrates three hydrogravity separations in sequence, 1060, 1080, and 1100, using process fluids having different densities, namely 1.4 g/cm$^3$, 1.2 g/cm$^3$, 1.0 g/cm$^3$, 0.95 g/cm$^3$, and 0.90 g/cm$^3$, respectively.

FIGURE 8 shows a block flow diagram of a complex hydrogravity stage 1200 that uses four hydrogravity tanks 1210, 1220, 1230, and 1240, to treat and purify the light components of a mixture, and four hydrogravity tanks 1250, 1260, 1270, and 1280, to treat and purify the heavy components of a mixture. Depending on the type of mixture and value of the components, one can choose subsets of this arrangement: For example one may choose to only purify the light components, or only purify the heavy components, or use four tanks for purifying the light components and only two tanks for purifying the heavy components, or any other combination as dictated by availability and economics.

Generally, in the products and intermediate products obtained from ASR, WSR, and ESR derived feedstocks, the middle density products (1.50 - 1.20) are rich in PVC, polycarbonates, and nylon. The low density products (1.20 - 1.0) are rich in ABS, polystyrene, and polyolefins. Of course, the density of any of these polymers can be shifted by the addition of inorganic fillers (which make them heavier), or blowing agents (which make them lighter).

Both the floating and sinking streams are preferably subjected to one or more operations to remove any process fluids such as by use of separate screening devices, spin driers such as a Gala drier, or other such devices to avoid carrying excessive amounts of process fluid into the next step.
It will be appreciated that the present invention can be used in separation strategies using process fluids having densities less than 1.0 g/cm³. For example, one could form an emulsion comprising water and a heavy naphtha having a high flash point with a specific gravity of about 0.8 grams per cubic centimeter and a small amount of surfactant. By varying the proportions of water and heavy naphtha, one can vary the density of the process fluid between about 1.0 and 0.8 grams per cubic centimeter, allowing one to control the process fluid density. Either manual or automatic density controls could be employed. Such process fluids are useful in the separation of polyolefins such as polyethylene and polypropylene. They are also useful in the separation of certain foamed plastics from non-foamed olefinic plastic, all of which have specific gravities less than 1.0. When the process fluid becomes too contaminated to be effective, the emulsion can be broken by conventional means, and a relatively clean heavy naphtha phase can be recovered for recycling into a new batch of emulsion, while the dirty aqueous phase is either discarded or cleaned and recycled into a new batch of emulsion.

Figure 9 is a block flow diagram of a preferred embodiment separation process 1300 in accordance with the present invention. In this process, a feed comprising mixed plastics or other components is directed to a hydrogravity tank 1310. The tank utilizes a process fluid having a density of less than 1.0 g/cm³, such as for example a specific gravity of 0.95. A "heavy" stream containing plastics or other components having a specific gravity greater than 0.95 is drawn off. And, a "light" stream of plastics or other components having a specific gravity less than 0.95 is also produced.

Figure 10 is a block flow diagram of a preferred embodiment separation process 1400 using process fluids having densities less than 1.0 g/cm³ in
accordance with the present invention. The preferred embodiment process 1400 comprises a plurality of hydrogravity tanks such as 1410, 1420, and 1430, each with a process fluid having a different density in which the tanks are arranged sequentially in order of decreasing density. Thus, in this configuration, as the feed travels downstream, it is exposed to process fluids of decreasing densities. Tank 1410 using a process fluid having a specific gravity of 0.95 produces a product stream of plastics or other components generally having a specific gravity greater than 0.95. Tank 1420 using a process fluid having a specific gravity of 0.90 produces a product stream of plastics or other components generally having a specific gravity of from about 0.95 to about 0.90. And, tank 1430 using a process fluid having a specific gravity of 0.85 produces a product stream of plastics or other components generally having a specific gravity of from about 0.90 to about 0.85.

[00256] Figure 11 is a block flow diagram of a preferred embodiment separation process 1500 using process fluids having densities less than 1.0 g/cm³ in accordance with the present invention. The preferred embodiment process 1500 comprises a plurality of hydrogravity tanks such as 1510, 1520, and 1530, each with a process fluid having a different density in which the tanks are arranged sequentially in order of increasing density. Thus, in this configuration, as the feed travels downstream, it is exposed to process fluids of increasing densities. Tank 1510 using a process fluid having a specific gravity of 0.85 produces a product stream of plastics or other components generally having a specific gravity less than 0.85. Tank 1520 using a process fluid having a specific gravity of 0.90 produces a product stream of plastics or other components generally having a specific gravity of from about 0.85 to about 0.90. Tank 1530 using a process fluid having a specific gravity of 0.95 produces a first product stream of plastics or other components
generally having a specific gravity of from about 0.90 to about 0.95, and a second product stream of plastics having a specific gravity greater than 0.95.

[00257] Figure 12 is a block flow diagram of a preferred embodiment separation process 1600 using process fluids having densities less than 1.0 g/cm³ in accordance with the present invention. The process 1600 comprises a plurality of tanks all using process fluid having the same specific gravity, and preferably a specific gravity less than one, such as 0.95. The process 1600 comprises three hydrogravity tanks 1610, 1620, and 1630 to treat and purify heavy components of a feed mixture such as those having a specific gravity greater than 0.95. The process 1600 also comprises three hydrogravity tanks 1640, 1650, and 1660 to treat and purify light components of a feed mixture such as those having a specific gravity of less than 0.95. It will be appreciated that process fluids having different specific gravities can be used, and different arrangements and orderings of hydrogravity tanks can be used.

[00258] Figure 13 is a block flow diagram of another preferred embodiment process 1700 using process fluids having densities less than 1.0 g/cm³ in accordance with the present invention. The process 1700 utilizes two or more hydrocyclones such as 1710 and 1720. The cyclone separators are sequentially arranged in order of decreasing process fluid density. That is, the hydrocyclone 1710 receives a feed comprising mixed plastics or other components in a process fluid having a specific gravity of 0.95 for example. A fraction of plastics or other materials having a specific gravity of greater than 0.95 is produced. A lighter fraction from hydrocyclone 1710 is directed to the hydrocyclone 1720. Hydrocyclone 1720 utilizing a process fluid with specific gravity of about 0.90 for example, produces a first stream having plastic with a specific gravity of from about 0.90 to about 0.95.
Hydrocyclone 1720 produces a second stream having plastic with a specific gravity of less than 0.90.

[00259] Figure 14 is a block flow diagram of another preferred embodiment process 1800 using process fluids having densities less than 1.0 g/cm³ in accordance with the present invention. The process 1800 utilizes two or more hydrocyclones such as 1810 and 1820. The cyclone separators are sequentially arranged in order of increasing process fluid density. That is, the hydrocyclone 1810 receives a feed comprising mixed plastics or other components in a process fluid having a specific gravity of 0.90 for example. A fraction of plastics or other materials having a specific gravity of less than 0.90 is produced. A heavier fraction from hydrocyclone 1810 is directed to the hydrocyclone 1820. Hydrocyclone 1820 utilizing a process fluid with specific gravity of about 0.95 for example, produces a first stream having plastic with a specific gravity of from about 0.90 to about 0.95. Hydrocyclone 1820 produces a second stream having plastic with a specific gravity of greater than 0.95.

[00260] Figure 15 is a block flow diagram of a preferred embodiment separation process 1900 using process fluids having densities less than 1.0 g/cm³ in accordance with the present invention. The process 1900 comprises a plurality of hydrocyclones such as hydrocyclones 1910, 1920, and 1930 using process fluid of the same specific gravity. A feed of mixed plastics or other components is directed to a hydrocyclone 1910 using a process fluid having a specific gravity of 0.90. A heavy stream from that hydrocyclone is directed to hydrocyclone 1920 using a process fluid with a specific gravity of 0.90. A heavy stream from that hydrocyclone is directed to hydrocyclone 1930 using a process fluid with a specific gravity of 0.90. A heavy stream from that hydrocyclone is withdrawn. The plastic materials in that
heavy stream have a specific gravity of greater than 0.95. Light streams are collected from each of the hydrocyclones 1910, 1920, and 1930, and contain plastics or other materials having a specific gravity less than 0.90.

[00261] In the processes 1300, 1400, 1500, 1600, 1700, 1800, and 1900, it is preferred that the process liquids having a specific gravity less than 1.0 are emulsions. However, the present invention includes liquids as dispersions or combinations of immiscible liquids.

[00262] While the present invention has been described with regard to a certain copper cable feed stock and recovery of material(s) from shredder residues like ASR, WSR, and ESR, it is understood that generally any type of solid feed stocks which contain multiple separable domains can be utilized including copper cable-derived feedstocks and ASR-derived, ESR-derived, and WSR-derived feedstocks with significantly different relative compositions from those identified in these examples. Feedstocks containing other metals such as aluminum cable, or feedstocks with multiple domains that are derived from other than the wire and cable industry, ASR, ESR, or WSR are candidates for the various processes described herein.

[00263] Many other benefits will no doubt become apparent from future application and development of this technology.

[00264] All patents, published patent applications, and articles referenced herein are incorporated by reference in their entirety.

[00265] Any and all aspects of any of the processes described herein can be combined with one or more aspects of any of the other processes described herein.

[00266] As described hereinabove, the present invention solves many problems associated with previous type methods and systems. However, it will be
appreciated that various changes in the details, materials and arrangements of parts,
which have been herein described and illustrated in order to explain the nature of the
invention, may be made by those skilled in the art without departing from the
principle and scope of the invention, as expressed in the appended claims.
WHAT IS CLAIMED IS:

1. A process for the separation of particles that differ in density utilizing a float-sink operation, wherein the process fluid comprises at least two immiscible liquids.

2. The process of claim 1 wherein the at least two immiscible liquids have different densities.

3. The process of claim 1 wherein the process fluid is in the form of an emulsion.

4. The process of claim 1 wherein the process fluid is in the form of a dispersion.

5. The process of claim 1 wherein the process fluid comprises water.

6. The process of claim 1 wherein the process fluid comprises water and an organic material.

7. The process of claim 1 wherein the process fluid is essentially non-aqueous.

7. The process of claim 3 wherein the emulsion is a macroemulsion.
8. The process of claim 3 wherein the emulsion is a microemulsion.

9. The process of claim 3 wherein the emulsion is a nanoemulsion.

10. The process of claim 1 wherein the process fluid has an overall density in the range of from about 0.3 g/cm³ to about 3.0 g/cm³.

11. The process of claim 1 wherein the process fluid has an overall density less than 1.0 g/cm³.

12. The process of claim 1 wherein the process fluid has an overall density greater than 1.0 g/cm³.

13. A process for separating two or more types of feedstock particles, the feedstock including at least two types of particles each having a different density, the process comprising:

   forming an emulsion including at least two immiscible liquids, such that at least two of the liquids have different densities, the emulsion having an overall density greater than that of the lightest particles and/or less than that of the heaviest particles in the feedstock;

   dispersing the particles into the emulsion; and allowing the particles to separate according to their specific gravity relative to that of the process fluid
such that most of the particles with a density less than that of the overall density of the emulsion float, and/or most particles with a density greater than that of the overall density of the emulsion sink.

14. The process of claim 13 wherein the emulsion comprises an aqueous component and an organic component.

15. The process of claim 14 wherein the aqueous component is water.

16. The process of claim 14 wherein the organic component includes at least one hydrocarbon or at least one non-aqueous inorganic liquid.

17. The process of claim 14 wherein the emulsion comprises from about 5% to about 95% aqueous component.

18. The process of claim 14 wherein the emulsion comprises from about 5% to about 95% organic component.

19. The process of claim 13 wherein the emulsion further includes at least one emulsifier.

20. The process of claim 13 wherein the overall density of the emulsion is from about 0.5 g/cm³ to about 2.5 g/cm³.

21. The process of claim 13 further comprising:
removing the floating particles from the hydrogravity tank to form a first product stream and removing the sinking particles from the hydrogravity tank to form a second product stream.

22. The process of claim 21 wherein the hydrogravity tank is a first hydrogravity tank, and the process further comprises:
   feeding at least one of the first and second product streams from the first hydrogravity tank to a second hydrogravity tank using a second emulsion having substantially the same overall density as the emulsion of the first hydrogravity tank, such that most particles in the at least one first and second product streams with a density less than that of the overall density of the second emulsion float, and most particles with a density greater than that of the overall density of the second emulsion sink.

23. The process of claim 22 further comprising:
   removing the floating and sinking particles from the second hydrogravity tank.

24. The process of claim 13 further comprising:
   prior to dispersing the particles into the emulsion, removing unwanted matter carried along or otherwise adhered to the particles.

25. The process of claim 13 further comprising:
   adding at least one agent to the emulsion.
26. The process of claim 13 wherein the emulsion has an overall density in
the range of from about 0.3 g/cm$^3$ to about 3.0 g/cm$^3$.

27. The process of claim 13 wherein the emulsion has an overall density
less than 1.0 g/cm$^3$.

28. The process of claim 13 wherein the emulsion has an overall density
greater than 1.0 g/cm$^3$. 

AMENDED CLAIMS received by the International Bureau on 12 February 2009 (12.02.09)

1. A process for the separation of particles that differ in density utilizing a float-sink operation, wherein the process fluid comprises at least two immiscible liquids combined such that they form a relatively uniform liquid system.

2. The process of claim 1 wherein the at least two immiscible liquids have different densities.

3. The process of claim 1 wherein the process fluid is in the form of an emulsion.

4. The process of claim 1 wherein the process fluid is in the form of a dispersion.

5. The process of claim 1 wherein the process fluid comprises water.

6. The process of claim 1 wherein the process fluid comprises water and an organic material.

7. The process of claim 1 wherein the process fluid is essentially non-aqueous

7. The process of claim 3 wherein the emulsion is a macroemulsion.
8. The process of claim 3 wherein the emulsion is a microemulsion.

9. The process of claim 3 wherein the emulsion is a nanoemulsion.

10. The process of claim 1 wherein the process fluid has an overall density in the range of from about 0.3 g/cm\(^3\) to about 3.0 g/cm\(^3\).

11. The process of claim 1 wherein the process fluid has an overall density less than 1.0 g/cm\(^3\).

12. The process of claim 1 wherein the process fluid has an overall density greater than 1.0 g/cm\(^3\).

13. A process for separating two or more types of feedstock particles, the feedstock including at least two types of particles each having a different density, the process comprising:

   forming an emulsion including at least two immiscible liquids, such that at least two of the liquids have different densities, the emulsion having an overall density greater than that of the lightest particles and/or less than that of the heaviest particles in the feedstock;

   dispersing the particles into the emulsion; and allowing the particles to separate according to their specific gravity relative to that of the process fluid.
FIG. 9

Plastic SG < 0.95

Hydrolysis @ 0.95 SG

Plastic SG > 0.95

Mixed Plastics

1300

1310
INTERNATIONAL SEARCH REPORT

A CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B03B 5/00 (2008.04)
USPC - 209/172

According to International Patent Classification (IPC) or to both national classification and IPC

B FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B03B 5/00 (2008.04)
USPC 209/172

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC 209/172 (text search - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPIL,USPT,USOC,EPAB,JPAB), Google Scholar, Google Patents, FreePatentsOnline
Search Terms - aqueous, disp $3, emulsifier$1, emulsion$1, floats 1, g/cm hydrocarbons 1, immiscible, liquid$1, macro, microemulsion$1, nanometer$1, organic$1, overall, particles, remove$3, separate$3, sink$3, stream$1, water

C DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim N o</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 2,686,592 A (MILLER) 17 August 1954 (17 08 1954), entire document, especially FIG 1, col 1, in 1-7, col 2, in 1-10</td>
<td>1-6, 10, 12-18, 20-21, 25-26 and 28</td>
</tr>
<tr>
<td>WO 2006/024095 A1 (LARM et al) 09 March 2006 (09 03 2006), pg 1, in 3-5</td>
<td>7</td>
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</table>

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Date of the actual completion of the international search
02 December 2008 (02 12 2008)

Date of mailing of the international search report
DEC 2008

Lee W Young

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