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(71) Applicant: **DARAMIC, LLC** [US/US]; 11430 N. Community House Road, Suite 350, Charlotte, NC 28277 (US).

(72) Inventors: **MITTAL, Surendra, Kumar**; Flat No. 1105, Andes Block, The Heritage Estate, Puttenahalli, Doddaballapur Road,yelahanka, Bangalore 560064 (IN). **SHANMUGAM, Naveen, Prabhu**; Flat No. El303, Princetown Apartment, No. 1 Settih, Near Air Force Technical College, Jalahalli West, Bangalore 560015 (IN).

(74) Agents: **MEUNIER, Andrew, T.** et al.; Meunier Carlin & Curfman, LLC, 999 Peachtree St. NE, Suite 1300, Atlanta, Georgia 30309 (US).

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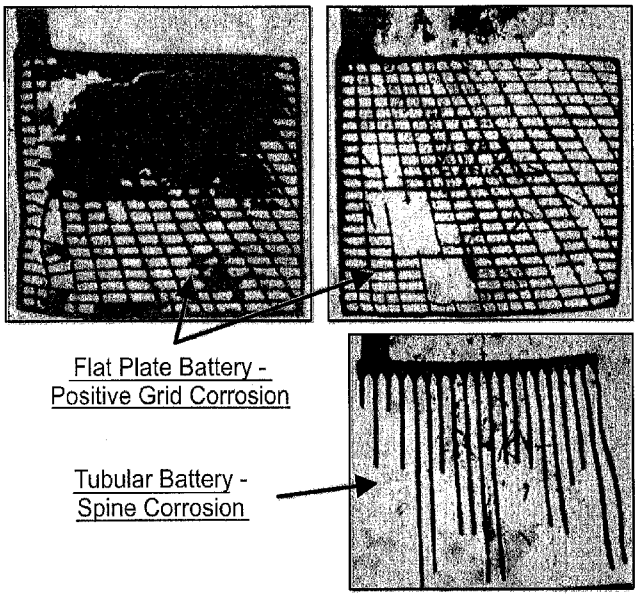

FIG. 1

(57) Abstract: Disclosed herein are novel or improved separators, battery separators, lead battery separators, batteries, cells, and/or methods of manufacture and/or use of such separators, battery separators, lead battery separators, cells, and/or batteries. In accordance with at least certain embodiments, the present disclosure or invention is directed to novel or improved battery separators for lead acid batteries. In addition, disclosed herein are methods, systems and battery separators for enhancing battery life, reducing active material shedding, reducing grid and spine corrosion, reducing failure rate reducing acid stratification and/or improving uniformity in at least lead acid batteries, in particular batteries for electric rickshaws. In accordance with at least particular embodiments, the present disclosure or invention is directed to an improved separator for lead acid batteries wherein the separator includes improved membrane profiles, improved coatings, improved configurations, and/or the like.

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IMPROVED BATTERY SEPARATORS FOR E-RICKSHAW AND SIMILAR VEHICLE LEAD ACID BATTERIES

FIELD

In accordance with at least selected embodiments, the present disclosure or invention is directed to separators, particularly separators for lead acid batteries, more particularly battery separators for E-rickshaw or similar vehicle lead acid batteries. In accordance with at least selected embodiments, the present disclosure or invention is directed to novel or improved separators, battery separators, batteries, cells, and/or methods of manufacture and/or use of such separators, battery separators, cells, and/or batteries for electric rickshaws. In accordance with at least certain embodiments, the present disclosure or invention is directed to an improved separator for lead acid batteries and/or improved methods of using such batteries having such improved separators, especially in the context of electric rickshaws. In addition, disclosed herein are methods, systems and battery separators for enhancing battery life, reducing battery failure, reducing active material shedding, reducing positive grid and spine corrosion, reducing water loss, increasing wettability, reducing acid stratification, improving acid diffusion, and/or improving uniformity in lead acid batteries, especially for electric rickshaw batteries. In accordance with at least particular embodiments, the present disclosure or invention is directed to an improved separator for lead acid batteries wherein the separator includes improved rib profiles, improved coatings, improved envelope and sleeve configurations, and/or the like.

BACKGROUND

Electric rickshaws (E-rickshaws or e-rickshaws) and similar vehicles, are commonly employed in many Asian countries like China, India and Bangladesh to transport passengers and cargo over short distances. E-rickshaws have electric drive motors (rather than gasoline engines) and are typically powered by a series of 12V lead acid batteries, commonly four batteries or more arranged in series. The failure rate of batteries in an e-rickshaw is often higher than for batteries used in other vehicles or contexts. There are multiple factors which contribute to e-rickshaw battery failure. For instance, certain low end electric rickshaws may be designed and manufactured to a price point that sacrifices quality for cost. By way of example, low quality battery chargers can overcharge the battery which increases corrosion of the plate grid and spine. Inferior AC/DC converters and voltage loss from poor wiring may also increase the load on the battery. Travel over poorly maintained roads subjects the e-rickshaw battery to increased vibration and shock, leading to loosening of battery components and dislodging active material from the grids. E-rickshaw operators (who may not be familiar with best practices of lead acid battery operation) seeking to maximize their own productivity may expend up to 90% of the total charge (i.e., a deep discharge). Such deep discharge/recharge cycling places additional stress on the battery system. As a consequence of the foregoing factors and more, it is estimated that warranty claims for e-rickshaw batteries can exceed 10-15%.

There is a need for improved batteries for e-rickshaws that solve the aforementioned problems without substantially increasing the cost of the product. There is a need for new or improved battery separators and/or battery technologies to meet and overcome the challenges arising from e-rickshaw lead-acid battery needs, especially to reduce battery failure, active material shedding and corrosion.

SUMMARY

In accordance with at least selected embodiments, the present disclosure or invention may address the above issues or needs. In accordance with at least certain embodiments, the present disclosure or invention may provide an improved battery separator and/or battery which overcomes the aforementioned problems, for instance by enhancing battery life, reducing battery failure, reducing active material shedding, reducing grid and spine corrosion, reducing water loss, increasing wettability, reducing acid stratification, improving acid diffusion, and/or improving uniformity in the e-rickshaw lead acid batteries.

In accordance with at least certain embodiments, the present disclosure or invention is directed to an improved separator for lead acid batteries and/or improved methods of using such batteries having such improved separators. In accordance with at least selected embodiments, the present disclosure or invention may address the above issues or needs and/or may provide novel or improved lead acid batteries. In accordance with at least selected embodiments, the present disclosure or invention is directed to novel or improved separators, battery separators, lead acid battery separators, batteries, cells, and/or methods of manufacture and/or use of such separators, battery separators, lead acid battery separators, cells, and/or batteries. In accordance with at least certain embodiments, the present disclosure or invention is directed to novel or improved lead acid battery separators for e-rickshaw applications, and/or improved methods of making and/or using such improved separators, cells, batteries, systems, and/or the like. In addition, disclosed herein are methods, systems and battery separators for enhancing battery life, reducing battery failure, reducing active material shedding, reducing positive grid corrosion, reducing water loss, increasing wettability, reducing acid stratification, improving acid diffusion, and/or improving uniformity in lead acid batteries. In accordance with at least particular

embodiments, the present disclosure or invention is directed to an improved separator for lead acid batteries wherein the separator includes improved membrane profiles, improved coatings, improved configurations, and/or the like.

In accordance with at least certain selected embodiments, a microporous separator exhibiting reduced active material shedding, for instance positive active material shedding, is provided. Because the separator may be in direct contact with the electrode, it immobilizes any dislodged materials from dispersing into the electrolyte.

In accordance with at least certain selected embodiments, a microporous separator with improved coatings and/or additives leading to reduced grid corrosion is provided.

In accordance with at least certain selected embodiment, the improved separator may include an improved porous membrane. The improved porous membrane can include ribs profiles and/or fibrous layers intended to reduce shorts and failures caused by active material shedding and/or grid corrosion. Provided herein are battery separators in the form of a sleeve, tube, envelope, pocket, hybrid envelope/pocket and/or the like. The improved shapes reduce shorts and failures due to active material shedding, while facilitation the circulation of electrolyte within the cell.

The separator may contain one or more performance enhancing additives, such as a surfactant, along with other additives or agents, residual oil, and fillers. Such performance enhancing additives can further reduce separator oxidation, reduce water loss, and/or facilitate the transport of ions across the membrane.

In certain selected embodiments, a separator having an improved porous membrane is provided with improved rib, negative rib and backweb profile. The porous membrane may

further include one or more performance enhancing coatings and/or fibrous layers. The separator may be in the form of a sleeve, envelope, pocket or hybrid envelope/pocket and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 includes a depiction of corroded grids from lead acid batteries.

Figure 2 includes a depiction of the effect of AC ripple current on battery life.

Figure 3 include a depiction of battery strain during various phases of e-rickshaw operation.

Figure 4 includes a depiction of voltage variation as a consequence of electric wiring.

Figure 5 includes a comparison of water loss in batteries equipped with a standard separator, and batteries equipped with additive coated separator.

Figure 6 includes a comparison of float current in batteries equipped with a standard separator (top trace), and batteries equipped with additive coated separator (bottom trace).

DETAILED DESCRIPTION

The inventive separator includes a porous membrane (such as a microporous membrane having pores less than about 5 microns, preferably having pores less than about 1 micron, mesoporous membrane, or a macroporous membrane having pores greater than about 5 microns) made of natural or synthetic materials, such as polyolefin, polyethylene, polypropylene, phenolic resin, PVC, rubber, synthetic wood pulp (SWP), glass fibers, cellulosic fibers, or combinations thereof, more preferably a microporous membrane made from thermoplastic polymers. The preferred microporous membranes may have average pore size within the range of 0.05 to 0.5 μm, preferably 0.1 to 0.2 μm, and/or pore diameters of about 0.1 micron (100 nanometers),

and/or porosities of about 20 to 80%, preferably about 60%. The thermoplastic polymers may, in principle, include all acid-resistant thermoplastic materials suitable for use in lead acid batteries. The preferred thermoplastic polymers include polyvinyls and polyolefins. The polyvinyls include, for example, polyvinyl chloride (PVC). The polyolefins include, for example, polyethylene, such as ultrahigh molecular weight polyethylene (UHMWPE), and polypropylene. One preferred embodiment may include a mixture of filler (for example, silica) and UHMWPE.

The porous membrane layer can include a polyolefin, such as polypropylene, ethylene-butene copolymer, and preferably polyethylene, more preferably high molecular weight polyethylene, i.e. polyethylene having a molecular weight of at least 600,000, even more preferably ultra high molecular weight polyethylene, i.e. polyethylene having a molecular weight of at least 1,000,000, in particular more than 4,000,000, and most preferably 5,000,000 to 8,000,000 (measured by viscosimetry and calculated by Margolie's equation), a standard load melt index of substantially 0 (measured as specified in ASTM D 1238 (Condition E) using a standard load of 2,160 g) and a viscosity number of not less than 600 ml/g, preferably not less than 1,000 ml/g, more preferably not less than 2,000 ml/g, and most preferably not less than 3,000 ml/g (determined in a solution of 0.02 g of polyolefin in 100 g of decalin at 130° C.).

In accordance with at least one embodiment, the porous membrane can include an ultrahigh molecular weight polyethylene (UHMWPE) mixed with a processing oil and precipitated silica. In accordance with at least one embodiment, the microporous membrane can include an ultrahigh molecular weight polyethylene (UHMWPE) mixed with a processing oil, additive and precipitated silica. The mixture may also include minor amounts of other additives or agents as is common in the separator arts (such as wetting agents, colorants, antistatic additives, and/or the like). The microporous polymer layer can be a homogeneous mixture of 8

to 100 vol. % of polyolefin, 0 to 40 vol. % of a plasticizer and 0 to 92 vol. % of inert filler material. The filler can be dry, finely divided silica. The preferred plasticizer is petroleum oil. Since the plasticizer is the component which is easiest to remove from the polymer-filler-plasticizer composition, it is useful in imparting porosity to the battery separator. In some embodiments, the porous membrane may be made by mixing, in an extruder, about 30% by weight silica with about 10% by weight UHMWPE, and about 60% processing oil.

The microporous membrane can be made by passing the ingredients through a heated extruder, passing the extrudate generated by the extruder through a die and into the nip formed by two heated calender rolls to form a continuous web, extracting a substantial amount of the processing oil from the web by use of a solvent, drying the extracted web, slitting the web into lanes of predetermined width, and winding the lanes into rolls. The heated calender rolls may be engraved with various groove patterns to impart ribs to the membrane. Alternatively, or additionally, ribs may be imparted to the porous membrane by passing the extruded membrane through additional appropriately grooved embossing rolls, calender rolls or presses.

The microporous polymer layer can have an average pore size of less than 1 μm in diameter. Preferably more than 50% of the pores are 0.5 μm or less in diameter. It is especially preferred that at least 90% of the pores have a diameter of less than 0.5 μm. The microporous polymer layer preferably has an average pore size within the range of 0.05 to 0.5 μm, preferably 0.1 to 0.2 μm.

In some embodiments, the additive includes a surfactant. Suitable surfactants include surfactants such as salts of alkyl sulfates; alkylarylsulfonate salts; alkylphenol-alkylene oxide addition products; soaps; alkyl-naphthalene-sulfonate salts; dialkyl esters of sulfo-succinate salts; quaternary amines; block copolymers of ethylene oxide and propylene oxide; and salts of mono

and dialkyl phosphate esters. The additive can be a non-ionic surfactant such as polyol fatty acid esters, polyethoxylated esters, polyethoxylated alcohols, alkyl polysaccharides such as alkyl polyglycosides and blends thereof, amine ethoxylates, sorbitan fatty acid ester ethoxylates, organosilicone based surfactants, ethylene vinyl acetate terpolymers, ethoxylated alkyl aryl phosphate esters and sucrose esters of fatty acids.

In certain embodiments, the additive can be represented by a compound of Formula (I)

$$R(OR^1)_n(COOM^{x+}{}_{1/x})_m \quad (I)$$

in which

- R is a non-aromatic hydrocarbon radical with 10 to 4200 carbon atoms, preferably 13 to 4200, which can be interrupted by oxygen atoms,
- R^1 is H, $—(CH_2)_kCOOM^{x+}{}_{1/x}$ or $—(CH_2)_k—SO_3M^{X+}{}_{1/X}$, preferably H, where k is 1 or 2,
- M is an alkali metal or alkaline-earth metal ion, H^+ or NH_4^+, where not all the variables M simultaneously have the meaning H^+,
- n is 0 or 1,
- m is 0 or an integer from 10 to 1400 and
- x is 1 or 2,

the ratio of oxygen atoms to carbon atoms in the compound according to Formula (I) being in the range from 1:1.5 to 1:30 and m and n not being able to simultaneously be 0. However, preferably only one of the variables n and m is different from 0.

By non-aromatic hydrocarbon radicals is meant radicals which contain no aromatic groups or which themselves represent one. The hydrocarbon radicals can be interrupted by oxygen atoms, i.e. contain one or more ether groups.

R is preferably a straight-chain or branched aliphatic hydrocarbon radical which can be interrupted by oxygen atoms. Saturated, uncross-linked hydrocarbon radicals are quite particularly preferred.

Surprisingly it was found that through the use of the compounds of Formula (I) for the production of battery separators, they can be effectively protected against oxidative destruction. Battery separators are preferred which contain a compound according to Formula (I) in which

- R is a hydrocarbon radical with 10 to 180, preferably 12 to 75 and quite particularly preferably 14 to 40 carbon atoms, which can be interrupted by 1 to 60, preferably 1 to 20 and quite particularly preferably 1 to 8 oxygen atoms, particularly preferably a hydrocarbon radical of formula R^2—$[(OC_2H_4)_p(OC_3H_6)_q]$—, in which
  - R^2 is an alkyl radical with 10 to 30 carbon atoms, preferably 12 to 25, particularly preferably 14 to 20 carbon atoms,
  - P is an integer from 0 to 30, preferably 0 to 10, particularly preferably 0 to 4 and
  - q is an integer from 0 to 30, preferably 0 to 10, particularly preferably 0 to 4,
  - compounds being particularly preferred in which the sum of p and q is 0 to 10, in particular 0 to 4,
- n is 1 and
- m is 0.

Formula R^2—$[(OC_2H_4)_p(OC_3H_6)_q]$— is to be understood as also including those compounds in which the sequence of the groups in square brackets differs from that shown. For example according to the invention compounds are suitable in which the radical in brackets is formed by alternating (OC_2H_4) and (OC_3H_6) groups.

Additives in which R^2 is a straight-chain or branched alkyl radical with 10 to 20, preferably 14 to 18 carbon atoms have proved to be particularly advantageous. OC_2H_4 preferably stands for OCH_2CH_2, OC_3H_6 for $OCH(CH_3)CH_2$ and/or $OCH_2CH(CH_3)$.

As preferred additives there may be mentioned in particular alcohols (p=q=0; m=0) primary alcohols being particularly preferred, fatty alcohol ethoxylates (p=1 to 4, q=0), fatty alcohol propoxylates (p=0; q=1 to 4) and fatty alcohol alkoxylates (p=1 to 2; q=1 to 4) ethoxylates of primary alcohols being preferred. The fatty alcohol alkoxylates are for example accessible through reaction of the corresponding alcohols with ethylene oxide or propylene oxide.

Additives of the type m=0 which are not, or only difficulty, soluble in water and sulphuric acid have proved to be particularly advantageous.

Also preferred are additives which contain a compound according to Formula (I), in which

- R is an alkane radical with 20 to 4200, preferably 50 to 750 and quite particularly preferably 80 to 225 carbon atoms,
- M is an alkali metal or alkaline-earth metal ion, H^+ or NH_4^+, in particular an alkali metal ion such as Li^+, Na^+ and K^+ or H^+, where not all the variables M simultaneously have the meaning H^+,
- n is 0,
- m is an integer from 10 to 1400 and
- x is 1 or 2.

As suitable additives there may be mentioned here in particular polyacrylic acids, polymethacrylic acids and acrylic acid-methacrylic acid copolymers, whose acid groups are at least partly, i.e. preferably 40%, particularly preferably 80%, neutralized. The percentage refers

to the number of acid groups. Quite particularly preferred are poly(meth)acrylic acids which are present entirely in the salt form. By poly(meth)acrylic acids are meant polyacrylic acids, polymethacrylic acids and acrylic acid-methacrylic acid copolymers. Poly(meth)acrylic acids are preferred and in particular polyacrylic acids with an average molar mass M_w of 1,000 to 100,000 g/mol, particularly preferably 1,000 to 15,000 g/mol and quite particularly preferably 1,000 to 4,000 g/mol. The molecular weight of the poly(meth)acrylic acid polymers and copolymers is ascertained by measuring the viscosity of a 1% aqueous solution, neutralized with sodium hydroxide solution, of the polymer (Fikentscher's constant).

Also suitable are copolymers of (meth)acrylic acid, in particular copolymers which, besides (meth)acrylic acid contain ethylene, maleic acid, methyl acrylate, ethyl acrylate, butyl acrylate and/or ethylhexyl acrylate as comonomer. Copolymers are preferred which contain at least 40 wt.-%, preferably at least 80 wt.-% (meth)acrylic acid monomer, the percentages being based on the acid form of the monomers or polymers.

To neutralize the polyacrylic acid polymers and copolymers, alkali metal and alkaline-earth metal hydroxides such as potassium hydroxide and in particular sodium hydroxide are particularly suitable.

The porous membrane can be provided in various ways with the additives, agents, and/or fillers, and/or can be coated with the additives. For example, the additive be applied to the porous membrane when it is finished (i.e. after the extraction) and/or added to the mixture used to produce the membrane. According to a preferred embodiment, the additive or a solution of the additive is applied to the surface of the porous membrane. This variant is suitable in particular for the application of non-thermostable additives and additives which are soluble in the solvent used for the subsequent extraction. Particularly suitable as solvents for the additives according to

the invention are low-molecular-weight alcohols, such as methanol and ethanol, as well as mixtures of these alcohols with water. The application can take place on the side facing the negative electrode, the side facing the positive electrode or on both sides of the microporous membrane.

The application may also take place by dipping the microporous membrane in the additive or a solution of the additive and subsequently optionally removing the solvent, e.g. by drying. In this way the application of the additive can be combined for example with the oil extraction often applied during separator production.

Another preferred option is to mix the additive or additives into the mixture of thermoplastic polymer and optionally fillers and other additives which is used to produce the porous membrane. The additive-containing homogeneous mixture is then formed into a web-shaped material.

The additive can be present at a density of at least about 0.5 g/m^2, 1.0 g/m^2, 1.5 g/m^2, 2.0 g/m^2, 2.5 g/m^2, 3.0 g/m^2, 3.5 g/m^2, 4.0 g/m^2, 4.5 g/m^2, 5.0 g/m^2, 5.5 g/m^2, 6.0 g/m^2, 6.5 g/m^2, 7.0 g/m^2, 7.5 g/m^2, 8.0 g/m^2, 8.5 g/m^2, 9.0 g/m^2, 9.5 g/m^2 or 10.0 g/m^2. The additive can be present on the separator at a density between about 0.5-10 g/m^2, 1.0-10.0 g/m^2, 1.5-10.0 g/m^2, 2.0-10.0 g/m^2, 2.5-10.0 g/m^2, 3.0-10.0 g/m^2, 3.5-10.0 g/m^2, 4.0-10.0 g/m^2, 4.5-10.0 g/m^2, 5.0-10.0 g/m^2, 5.5-10.0 g/m^2, 6.0-10.0 g/m^2, 6.5-10.0 g/m^2, 7.0-10.0 g/m^2, 7.5-10.0 g/m^2, 5.0-10.5 g/m^2, 5.0-11.0 g/m^2, 5.0-12.0 g/m^2, or 5.0-15.0 g/m^2. The additive can be present on the microporous membrane at a density of about 6.0-10.0 g/m^2, 6.5-9.5 g/m^2, 6.5-9.0 g/m^2, 6.5-8.5 g/m^2, 6.5-8.0 g/m^2, or 7.0-8.0 g/m^2. In some embodiments, the additive is present at a density of about 7.5 g/m^2.

In certain selected embodiments, the porous membrane may further contain one or more PIMS material. A PIMS mineral derived from fish bone (such as commercial, lab ground fish meal) has been shown to have greatest affinity for metal ions. The fish bone powder can be extruded via pilot operation into a typical battery separator format at several loading concentrations. In accordance with at least certain embodiments, it is preferred that the fish bone powder be added to substitute for a portion of the silica at substitution levels of about 1% to 20% of the silica, more preferably about 2% to 10%, and most preferably at about 2% to 5%. In accordance with at least other certain embodiments, it is preferred that the ground fish bone powder (ground fish meal) be added to substitute for a portion of the silica at substitution levels of about 1% to 50% or more of the silica, more preferably about 5% to 30%, and most preferably at about 10% to 20%.

In accordance with at least another object of the present invention, there is provided a microporous membrane with ribs. The microporous membrane can have transverse cross-ribs on the opposite face of the membrane as the longitudinal ribs. The cross-rib can be parallel to the longitudinal ribs, or can be disposed at an angle thereto. For instance, the cross ribs can be oriented about 90°, 80°, 75°, 60°, 50°, 45°, 35°, 25°, 15° or 5° relative to the longitudinal ribs. The cross-ribs can be oriented about 90-60°, 60-30°, 60-45°, 45-30°, or 30-0° relative to the longitudinal ribs. Typically the cross ribs are on the face of the membrane facing the negative electrode. In some embodiments of the present invention, the ribbed membrane can have a transverse cross-rib height of at least about 0.005 mm, 0.01 mm, 0.025 mm, 0.05 mm, 0.075 mm, 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm, or 1.0 mm. In some embodiments of the present invention, the ribbed membrane can have a transverse cross-rib height of no greater than about 1.0 mm, 0.5 mm, 0.25 mm, 0.20 mm, 0.15 mm, 0.10 mm or 0.05

mm. The ribbed membrane can have a transverse cross-rib height between about 0.005-1.0 mm, 0.01-0.5 mm, 0.025-0.25 mm, 0.05-0.25 mm, 0.075-0.25 mm, 0.075-0.20 mm, 0.075-0.15 mm, 0.10-0.25 mm, 0.1-0.20, 0.10-0.15 mm, or 0.10-0.125 mm.

In some embodiments of the present invention, the ribbed membrane can have a transverse cross-rib width of at least about 0.005 mm, 0.01 mm, 0.025 mm, 0.05 mm, 0.075 mm, 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm, or 1.0 mm. In some embodiments of the present invention, the ribbed membrane can have a transverse cross-rib width of no greater than about 1.0 mm, 0.5 mm, 0.25 mm, 0.20 mm, 0.15 mm, 0.10 mm or 0.05 mm. The ribbed membrane can have a transverse cross-rib width between about 0.005-1.0 mm, 0.01-0.5 mm, 0.025-0.25 mm, 0.05-0.25 mm, 0.075-0.25 mm, 0.075-0.20 mm, 0.075-0.15 mm, 0.10-0.25 mm, 0.1-0.20, 0.10-0.15 mm, or 0.10-0.125 mm. The spacing between the transverse cross-ribs (pitch-to-pitch width) can be from about 0.10-1.0 mm, 0.2-1.0 mm, 0.3-1.0 mm, 0.4-0.9 mm, 0.4-0.8 mm, 0.5-0.8 mm, 0.5-0.7 mm, or 0.6-0.7 mm.

In some embodiments of the present invention, the ribbed membrane can have longitudinal rib height of at least about 0.005 mm, 0.01 mm, 0.025 mm, 0.05 mm, 0.075 mm, 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm, 1.0 mm, 1.1 mm, 1.2 mm, 1.3 mm, 1.4 mm, or 1.5 mm. The ribbed membrane can have a longitudinal rib height between about 0.005-1.5 mm, 0.01-1.0 mm, 0.025-1.0 mm, 0.05-1.0 mm, 0.075-1.0 mm, 0.1-1.0 mm, 0.2-1.0 mm, 0.3-1.0 mm, 0.4-1.0 mm, 0.5-1.0 mm, 0.4-0.8 mm or 0.4-0.6 mm. The ribbed membrane can have a longitudinal rib height from about 0.01-0.2 mm, 0.05-0.2 mm, 0.05-0.15 mm, 0.075-0.15 mm, 0.1-0.15 mm, or 0.1 to 0.125 mm.

In some embodiments of the present invention, the ribbed membrane can have longitudinal rib width of at least about 0.005 mm, 0.01 mm, 0.025 mm, 0.05 mm, 0.075 mm, 0.1

mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm, 1.0 mm, 1.1 mm, 1.2 mm, 1.3 mm, 1.4 mm, or 1.5 mm. The ribbed membrane can have a longitudinal rib width between about 0.005-1.5 mm, 0.01-1.0 mm, 0.025-1.0 mm, 0.05-1.0 mm, 0.075-1.0 mm, 0.1-1.0 mm, 0.2-1.0 mm, 0.3-1.0 mm, 0.4-1.0 mm, 0.5-1.0 mm, 0.4-0.8 mm or 0.4-0.6 mm. The ribbed membrane can have a longitudinal rib width from about 0.01-0.2 mm, 0.05-0.2 mm, 0.05-0.15 mm, 0.075-0.15 mm, 0.1-0.15 mm, or 0.1 to 0.125 mm. The spacing between the longitudinal ribs (pitch-to-pitch width) can be from about 0.10-1.0 mm, 0.2-1.0 mm, 0.3-1.0 mm, 0.4-0.1 mm, 0.5-1.0 mm, 0.5-0.9 mm, 0.6-0.9 mm, 0.6-0.8 mm, or 0.7-0.8 mm.

The longitudinal ribs can be present in a "U" shape, semicircular or rectangular. In some embodiments, the rib height of the longitudinal ribs can be greater than the height of the cross ribs.

In certain selected embodiments the porous membrane can have a transverse cross-rib (negative cross ribs, transverse mini-ribs) height of about 0.10-0.15 mm, and a longitudinal rib height of about 0.1-0.15 mm or greater. In some embodiments, the porous membrane can have a transverse cross-rib height of about 0.10-0.125 mm, a longitudinal rib height of about 0.1-0.125 mm, a transverse cross rib width of about 0.5-0.7 mm and a longitudinal rib width of about 0.6-0.9 mm.

The microporous membrane can have a backweb thickness that is at least 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm or 1.0 mm. The ribbed separator can have a backweb thickness that is no more than about 1.0 mm, 0.9 mm, 0.8 mm, 0.7 mm, 0.6 mm, 0.5 mm, 0.4 mm, 0.3 mm, 0.2 mm or 0.1 mm. In some embodiments, the microporous membrane can have a backweb thickness between about 0.1-1.0 mm, 0.1-0.8 mm,

0.1-0.5 mm, 0.2-0.5 mm, 0.2-0.4 mm, 0.25-0.35 mm. In some embodiments, the microporous membrane can have a backweb thickness of about 0.3 mm.

In certain selected embodiments the porous membrane can have a transverse cross-rib height of about 0.10-0.15 mm, a longitudinal rib height of about 0.1-0.15 mm, and a backweb thickness of about 0.25-0.35 mm. In some embodiments, the porous membrane can have a transverse cross-rib height of about 0.10-0.125 mm, a longitudinal rib height of about 0.1-0.125 mm, and a backweb thickness of about 0.3 mm.

In some embodiments, the porous membrane can have a total thickness (i.e., rib tip to rib tip) from about 0.2-0.8 mm, 0.3-0.7 mm, or 0.4-0.6 mm. In some embodiments, the total thickness can be about 0.5-0.55 mm.

In some selected embodiments, the separator also contains one of more fibrous layers. In certain embodiments, the side of the microporous membrane facing the positive electrode has a fibrous layer, while in other embodiments, the side of the microporous membrane facing the negative electrode has a fibrous layer. In some preferred embodiments, a fibrous layer is present on both sides of the microporous membrane.

The fibrous layers can be made of glass fibers, polymeric fibers or a mixture of glass fibers and polymeric fibers. Suitable mats made of polymer fibers which may be used as fibrous layers in the present invention are disclosed in U.S. Pat. No. 5,962,161, the disclosure of which is incorporated herein by reference.

The preferred fibrous material is glass. Generally all glass fiber materials known in the art for producing glass mats or absorptive glass mat (AGM) separators may be used for forming the fibrous layers of the present invention. A preferred fibrous material are absorptive microfiber glass fleeces without organic components like binder or polymeric fibers. It is preferred that the

fibers have a diameter ranging from 0.1 to 10 μm, more preferably from 0.1 to 5 μm. The fibers are preferably blends of acid resistant glass fibers of various diameter, usually extremely thin fibers with an average fiber diameter below 1 μm, referred to as microfibers, and "coarse" fibers with an average diameter of approx. 3 μm. The microfibers increase the internal surface, improve the tensile strength and decrease the pore diameter but significantly increase the product cost. The larger fibers facilitate the battery filling by creating larger pores with faster acid pick-up, often referred to as wicking rate.

In some embodiments, the fibrous glass layers can comprise 20 to 40% by weight of glass microfibers having an average diameter of less than 1 μm and 60 to 80% by weight of coarse glass fibers having an average diameter of about 3 μm, for instance 30% by weight microfibers and 70% by weight coarse fibers. In certain embodiments, the fibers can have higher diameters, for instance about 5-25 μm, 5-15 μm, 10-15 μm, 10-25 μm, 10-20 μm or 15-20 μm. Blends of such fibers can also be employed, for instance blends of 10-15 μm fibers and 15-20 μm fibers. In some embodiments, fibers having a length of about 0.5-2.0 mm, 0.5-1.5 mm, or 1.0-1.5 mm can be employed. Suitable glass fiber mats and the preparation thereof are well known to a person skilled in the art (see for instance Böhnstedt W., in Handbook of Battery Materials, Editor Besenhard J. O., Wiley-VCH, Weinheim 1999, pages 245 to 292 and literature cited therein).

Preferred fibrous layers made of polymer fibers comprises a nonwoven web, mat or fleece of fibers of a diameter of 0.1 to 10 μm, preferably 0.1 to 5 μm. It is preferred that more than 10% by weight of the fibers, more preferably more than 15% by weight of the fibers and most preferably 20 to 40% by weight of the fibers have a diameter smaller than 1 μm, preferably about 0.1 μm, and it is further preferred that at least 60% by weight of the fibers have diameters of less than 5 μm. The fibers are made of a thermoplastic polymer, which is preferably selected

from the group consisting of polyolefins, polystyrenes, polyamides, polyesters, halogenated polymers, and the respective copolymers, more preferably polyolefins and in particular polyethylenes and polypropylenes. To render the fibrous layer wettable, a suitable surface active agent is added to the polymer prior to extrusion or hydrophilic groups are covalently bonded to the surface of the fibers after formation. Suitable treatments are described in U.S. Pat. No. 5,962,161, the disclosure of which is incorporated herein by reference. Nonwoven mats of this type can be manufactured by extrusion and blowing processes. One preferred way is described in U.S. Pat. No. 6,114,017, which comprises melting a polymer by polymer heating and extrusion means, extruding said polymer at flow rates of less than 1 g/min/hole through polymer orifices arranged in one or more spaced apart cross directional rows on one or more modular dies heated by a heating unit, wherein the diameters of said orifices may be equal to each other or may differ from row to row to obtain a web comprising fibers of essentially uniform or varying diameter, blowing said polymer extrudate using heated air of at least 95° C. from two or more constant or variable cross-section air jets per polymer orifice, preferably variable cross-section air jets being converging-diverging nozzles capable of producing supersonic drawing velocities, or tempered air between 10° C. and 375° C. of two or more continuous converging-diverging nozzle slots placed adjacent and essentially parallel to said polymer orifice exits to attenuate said filaments and to produce essentially continuous polymer filaments, and depositing said liberized polymer on a collecting means to form a self-bonded web consisting of as many layers of disbursed continuous polymer filaments as the number of rows of said polymer orifices in said die. U.S. Pat. No. 5,679,379 discloses modular die units suitable for the production of the above nonwoven mats. The disclosure of both U.S. Pat. Nos. 6,114,017 and 5,679,379 is incorporated herein by reference. The self-bonded webs produced in the above process may also be thermally

bonded to provide even greater strength by using conventional hot calendering techniques where the calender rolls may pattern engraved or flat. The nonwoven webs, mats or fleeces have low average diameters, improved uniformity, a narrow range of fiber diameters, and significantly higher unbonded strength than a typical meltblown web. When the material is thermally bonded it is similar in strength to spunbonded nonwovens of the same polymer and basis weight.

When a mixture of glass fibers and polymeric fibers is used, the different fibers are preferably used in such proportions that the sheet has an absorbency with respect to the electrolyte of from 75 to 95% in the absence of a surfactant. Preferably the glass and polymeric fibers defined above are used. Fibrous sheets of this type may be prepared by the methods disclosed in U.S. Pat. No. 4,908,282, the disclosure of which is incorporated herein by reference.

The fibrous layers can be present on the microporous membrane at a thickness of at least about 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm, 1.0 mm, 1.1 mm, 1.2 mm, 1.3 mm, 1.4 mm or 1.5 mm. In some embodiments, the fibrous layers can be present on the microporous membrane at a thickness from about 0.1 – 1.5 mm, 0.5 – 1.5 mm, 0.75 – 1.5 mm, 0.75 – 1.25 mm or 1.0 – 1.25 mm.

In certain selected embodiments the porous membrane can have a transverse cross-rib height of about 0.10-0.15 mm, a longitudinal rib height of about 0.1-0.15 mm, a backweb thickness of about 0.25-0.35 mm, and fibrous layers present on both faces of the membrane having a thickness of about 0.75-1.25 mm. In certain embodiments, it is preferred that the fibrous layer is only on the side of the porous membrane that faces the positive electrode. In some embodiments, the porous membrane can have a transverse cross-rib height of about 0.10-0.125 mm, a longitudinal rib height of about 0.1-0.125 mm, a backweb thickness of about 0.3

mm, and fibrous layers present on both faces of the membrane having a thickness of about 0.75-1.25 mm.

The separators of the present invention can be provided either in sheet form or in the form of an envelope. In some embodiments, a microporous membrane, covered on at least one side with at least one fibrous layer, is provided as a pocket or envelope. In such embodiments, it is preferred that the microporous membrane has a larger surface area than the fibrous layers. Thus, when combining the microporous membrane and the fibrous layers, the fibrous layers do not completely cover the microporous layer. It is preferred that at least two opposing edge regions of the membrane layer remain uncovered to provide edges for heat sealing which facilitates the formation of pockets or envelope. The separators can be processed to form hybrid envelopes. The hybrid envelope can be formed by forming one or more slits or openings before, during or after, folding the separator sheet in half and bonding edges of the separator sheet together so as to form an envelope. The slits are preferably in or near the bottom fold of the pocket or envelope. The sides are bonded together using welds or mechanical seals to form seams that bring one side of the separator sheet into contact with another side of the separator sheet. Welds can be accomplished, for instance, using heat or ultrasonic processes. This process results in an envelope shape having a bottom folded edge and two lateral edges. The fibrous layer can be present on the inner face or the envelope, the outer face or the envelope, or both faces of the envelope.

Separators disclosed herein in the form of an envelope may have one or more slits or openings along the folded or sealed creases of the envelope. The length of the openings can at least $1/50^{th}$, $1/25^{th}$, $1/20^{th}$, $1/15^{th}$., $1/10^{th}$, $1/8^{th}$, $1/5^{th}$, $1/4^{th}$, or $1/3^{rd}$ the length of the entire edge. The length of the openings can be $1/50^{th}$ to $1/3^{rd}$, $1/25^{th}$ to $1/3^{rd}$, $1/20^{th}$ to $1/3^{rd}$, $1/20^{th}$ to $1/4^{th}$,

$1/15^{th}$ to $1/4^{th}$, $1/15^{th}$ to $1/5^{th}$ or $1/10^{th}$ to $1/5^{th}$ the length of the entire edge. The hybrid envelope can have 1-5, 1-4, 2-4, 2-3 or 2 openings, which may or may not be equally disposed along the length of the bottom edge. It is preferred that no opening is in the corner of the envelope. The slits may be cut after the separator has been folded and sealed to give an envelope, or the slits may be formed prior to shaping the porous membrane into the envelop.

Besides lowering water loss and leading to extended battery life, preferred separators are also designed to bring other benefits. With regard to assembly, the separators have the negative cross rib design to maximize bending stiffness and ensure highest manufacturing productivity. To prevent shorts during high speed assembly and later in life, the separators have superior puncture and oxidation resistance when compared to standard PE separators.

Disclosed herein are novel or improved separators, battery separators, lead battery separators, batteries, cells, and/or methods of manufacture and/or use of such separators, battery separators, lead battery separators, cells, and/or batteries. In accordance with at least certain embodiments, the present disclosure or invention is directed to novel or improved battery separators for lead acid batteries. In addition, disclosed herein are methods, systems and battery separators for enhancing battery life, reducing active material shedding, reducing grid and spine corrosion, reducing failure rate reducing acid stratification and/or improving uniformity in at least lead acid batteries, in particular batteries for electric rickshaws. In accordance with at least particular embodiments, the present disclosure or invention is directed to an improved separator for lead acid batteries wherein the separator includes improved membrane profiles, improved coatings, improved configurations, and/or the like.

The present invention may be embodied in other forms without departing from the spirit and the essential attributes thereof, and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification, as indicating the scope of the invention.

Additionally, the invention illustratively disclosed herein suitably may be practiced in the absence of any element which is not specifically disclosed herein.

Claims

1. An improved separator for use in a battery for an electric rickshaw comprising:

a porous membrane comprising

an additive at a density from about 5.0-10.0 g/m^2;

cross ribs having a height from about 0.075-0.15 mm;

longitudinal ribs having a height from about 0.075-0.15 mm; and optionally

a fibrous layer on at least one face of the porous membrane and/or one or more slits in the separator.

2. The separator according to claim 1, wherein the porous membrane is a microporous membrane.

3. The separator according to either of claim 1 or claim 2, wherein the membrane comprises polyethylene.

4. The separator according to any of claims 1-3, wherein the membrane comprises ultrahigh molecular weight polyethylene.

5. The separator according to any of claims 1-4, wherein the additive is a surfactant.

6. The separator according to any of claims 1-5, wherein the additive is a non-ionic surfactant.

7. The separator according to any of claims 1-6, wherein the additive is present at a density of about 7.5 g/m^2.

8. The separator according to any of claims 1-7, wherein the cross ribs have a rib height of about 0.075-0.125 mm.

9. The separator according to any of claims 1-8, wherein the longitudinal ribs have a rib height of about 0.075-0.125 mm.

10. The separator according to any of claims 1-9, wherein the fibrous layer comprises glass fibers.

11. The separator according to any of claims 1-10, wherein the fibrous layer is present on both sides of the porous membrane.

12. The separator according to any of claims 1-11, wherein the fibrous layer is from about 0.75-1.25 mm thick.

13. The separator according to any of claims 1-12, wherein the porous membrane is in the shape of an envelope or pocket.

14. The separator according to claim 13, wherein the envelope comprises at least one slit.

15. A lead acid battery characterized by at least one of the following:

reduced active material shedding;

reduced grid and spine corrosion;

reduced failure rate;

wherein the battery comprises the separator of any of claims 1-14.

16. A method of reducing failure in a lead acid battery for an electric rickshaw, wherein the method comprises providing a separator according to any of claims 1-14.

17. Novel or improved separators, battery separators, lead battery separators, batteries, cells, and/or methods of manufacture and/or use of such separators, battery separators, lead battery separators, cells, and/or batteries; novel or improved battery separators for lead acid batteries; novel or improved lead acid batteries; novel or improved e-rickshaws; methods, systems and battery separators for enhancing battery life, reducing active material shedding, reducing grid and spine corrosion, reducing failure rate reducing acid stratification and/or improving uniformity in at least lead acid batteries, in particular batteries for electric rickshaws; improved separator for lead acid batteries wherein the separator includes improved membrane profiles, improved coatings, improved configurations, and/or the like; and/or combinations thereof as shown or described herein.

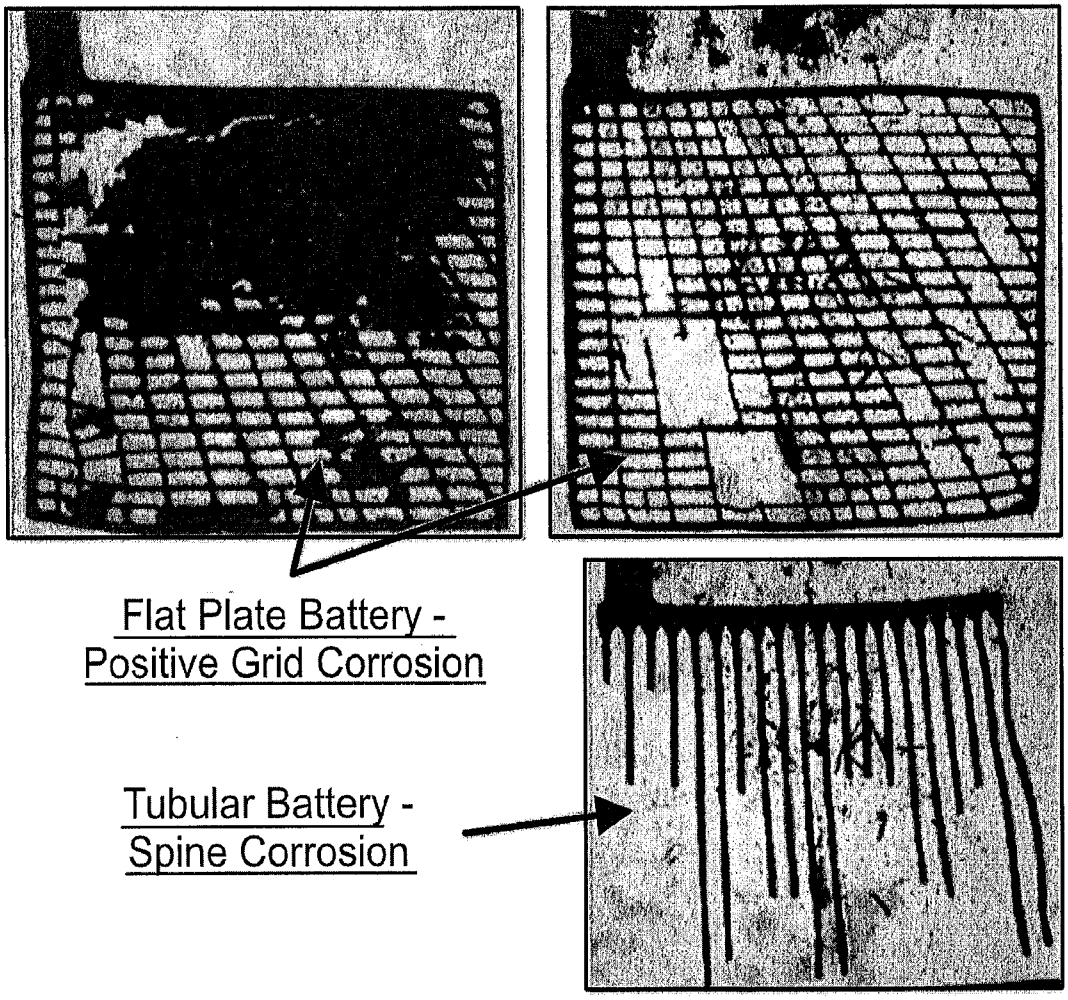
Flat Plate Battery -
Positive Grid Corrosion
Tubular Battery -
Spine Corrosion

FIG. 1

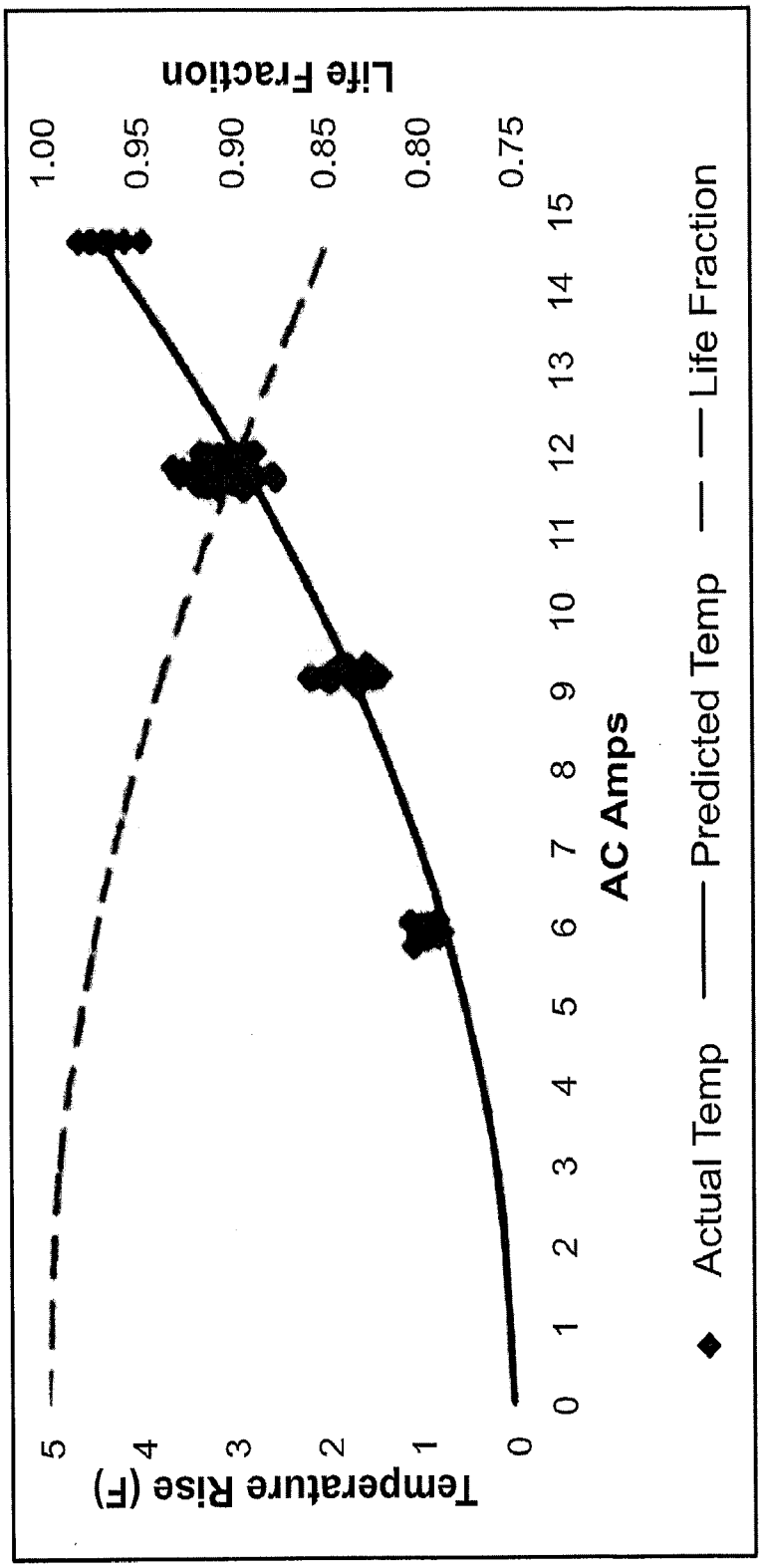
Temperature Rise (F)
0
1
2
3
4
5
Life Fraction
1.00
0.95
0.90
0.85
0.80
0.75
AC Amps
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Actual Temp
Predicted Temp
Life Fraction

FIG. 2

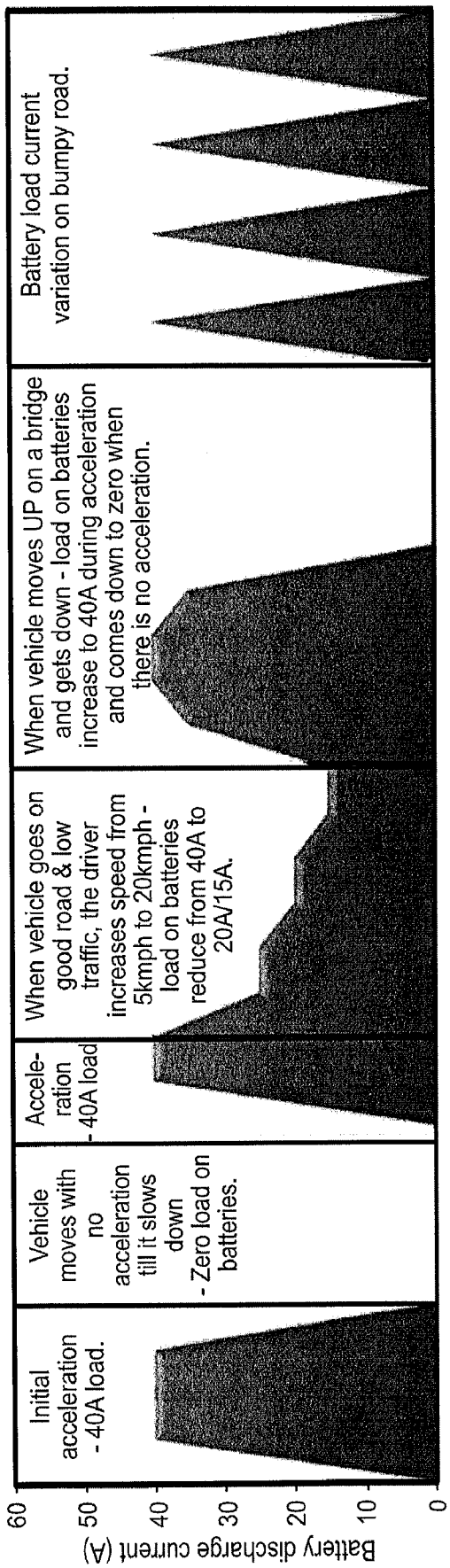
C
Battery discharge current (A)
60
50
40
30
20
10
0
Initial acceleration - 40A load.
Vehicle moves with no acceleration till it slows down - Zero load on batteries.
Accele-ration - 40A load
When vehicle goes on good road & low traffic, the driver increases speed from 5kmph to 20kmph - load on batteries reduce from 40A to 20A/15A.
When vehicle moves UP on a bridge and gets down - load on batteries increase to 40A during acceleration and comes down to zero when there is no acceleration.
Battery load current variation on bumpy road.

FIG. 3

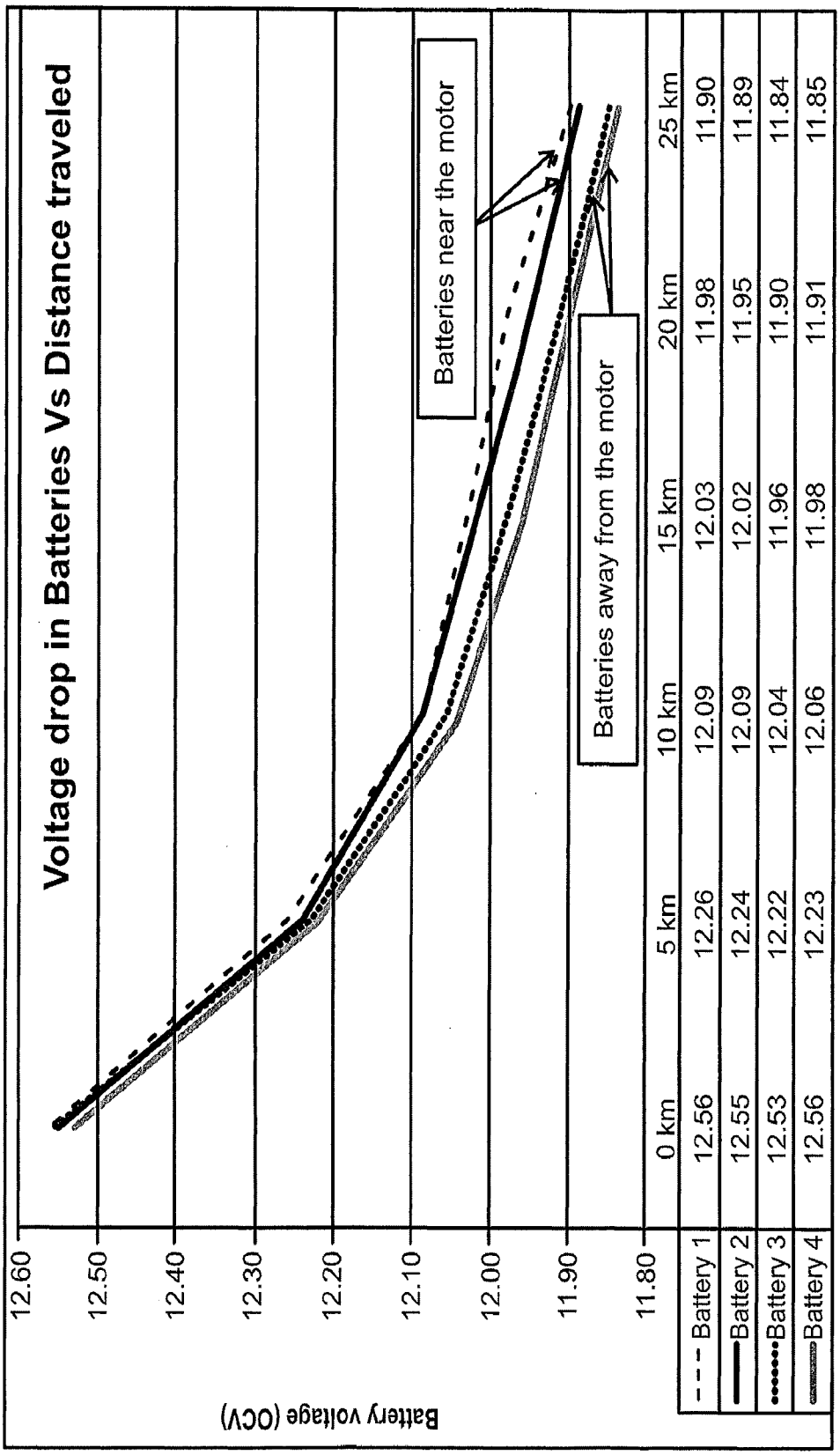
Voltage drop in Batteries Vs Distance traveled
Batteries near the motor
Batteries away from the motor
Battery voltage (OCV)
12.60
12.50
12.40
12.30
12.20
12.10
12.00
11.90
11.80
0 km 5 km 10 km 15 km 20 km 25 km
Battery 1 12.56 12.26 12.09 12.03 11.98 11.90
Battery 2 12.55 12.24 12.09 12.02 11.95 11.89
Battery 3 12.53 12.22 12.04 11.96 11.90 11.84
Battery 4 12.56 12.23 12.06 11.98 11.91 11.85

FIG. 4

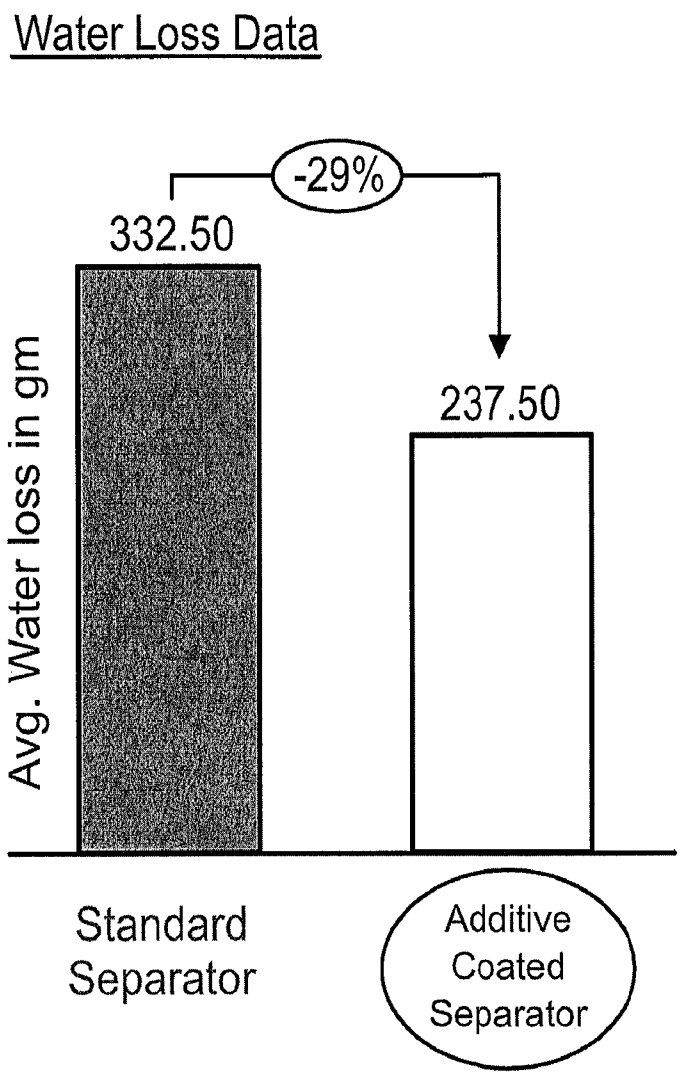
Water Loss Data
-29%
332.50
237.50
Avg. Water loss in gm
Standard Separator
Additive Coated Separator

FIG. 5

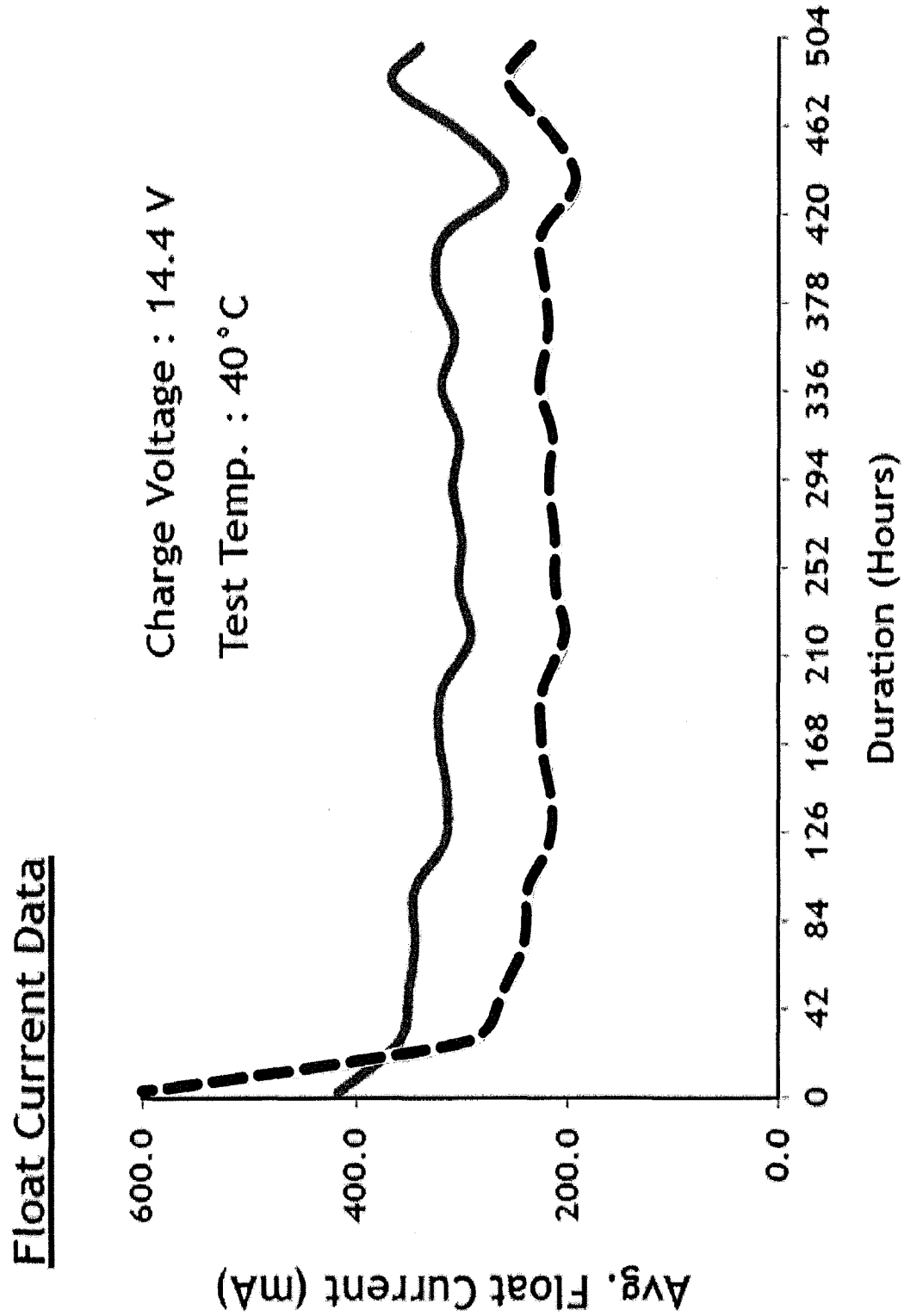
Float Current Data
Charge Voltage : 14.4 V
Test Temp. : 40°C
Avg. Float Current (mA)
600.0
400.0
200.0
0.0
0
42
84
126
168
210
252
294
336
378
420
462
504
Duration (Hours)

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/012826

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 14
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claim 14 is unclear, since it refers to one of claims which are not drafted in accordance with PCT Rule 6.4(a) (PCT Article 6).

3. ☒ Claims Nos.: 4-13,15,16
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/012826

A. CLASSIFICATION OF SUBJECT MATTER

H01M 2/16(2006.01)i, H01M 2/14(2006.01)i, H01M 10/06(2006.01)i, H01M 10/12(2006.01)i

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)
H01M 2/16; H01M 2/18; H01M 2/14; B01J 41/00; H01M 10/06; H01M 10/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: separator, electric rickshaw, porous, cross rib, longitudinal rib, lead acid battery, surfactant

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012-0070747 A1 (WHEAR, J. KEVIN et al.) 22 March 2012 See abstract; paragraphs [0002] and [0042]-[0057]; and claims 1 and 11-13.	1-3,17
X	US 2011-0091761 A1 (MILLER, ERIC H. et al.) 21 April 2011 See abstract; paragraphs [0002], [0008]-[0013], [0032] and [0060]; and claims 1-6.	1-3,17
A	US 5989750 A (KATSUMI, OHBA et al.) 23 November 1999 See abstract; columns 2 and 3; and claim 1.	1-3,17
A	US 2012-0070714 A1 (CHAMBERS, JEFFREY K. et al.) 22 March 2012 See abstract; paragraphs [0029]-[0042]; and claims 1 and 11.	1-3,17
A	US 2009-0068554 A1 (JOHNS, SANDRA) 12 March 2009 See abstract; paragraphs [0024]-[0033]; and claim 1.	1-3,17

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 October 2016 (10.10.2016)	**10 October 2016 (10.10.2016)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
MIN, In Gyou
Telephone No. +82-42-481-3326

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2016/012826

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012-0070747 A1	22/03/2012	CN 103733379 A	16/04/2014
		EP 2619824 A1	31/07/2013
		JP 2013-541162 A	07/11/2013
		JP 5807794 B2	10/11/2015
		KR 10-2013-0058753 A	04/06/2013
		WO 2012-040436 A1	29/03/2012
US 2011-0091761 A1	21/04/2011	CN 102576847 A	11/07/2012
		EP 2491605 A1	29/08/2012
		JP 2013-508917 A	07/03/2013
		JP 5781078 B2	16/09/2015
		KR 10-2012-0092115 A	20/08/2012
		KR 10-2014-0048311 A	23/04/2014
		WO 2011-049852 A1	28/04/2011
US 5989750 A	23/11/1999	CN 1178395 A	08/04/1998
		EP 0834937 A2	08/04/1998
		EP 0834937 B1	15/03/2006
		JP 10-106526 A	24/04/1998
US 2012-0070714 A1	22/03/2012	EP 2619817 A1	31/07/2013
		WO 2012-040407 A1	29/03/2012
US 2009-0068554 A1	12/03/2009	CN 101438433 A	20/05/2009
		CN 101438433 B	02/11/2011
		DE 102006014691 B3	16/08/2007
		EP 1999808 A1	10/12/2008
		EP 1999808 B1	04/11/2009
		WO 2007-110065 A1	04/10/2007