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(71) Demandeur/Applicant:
SALMINEN, REIJO K., US

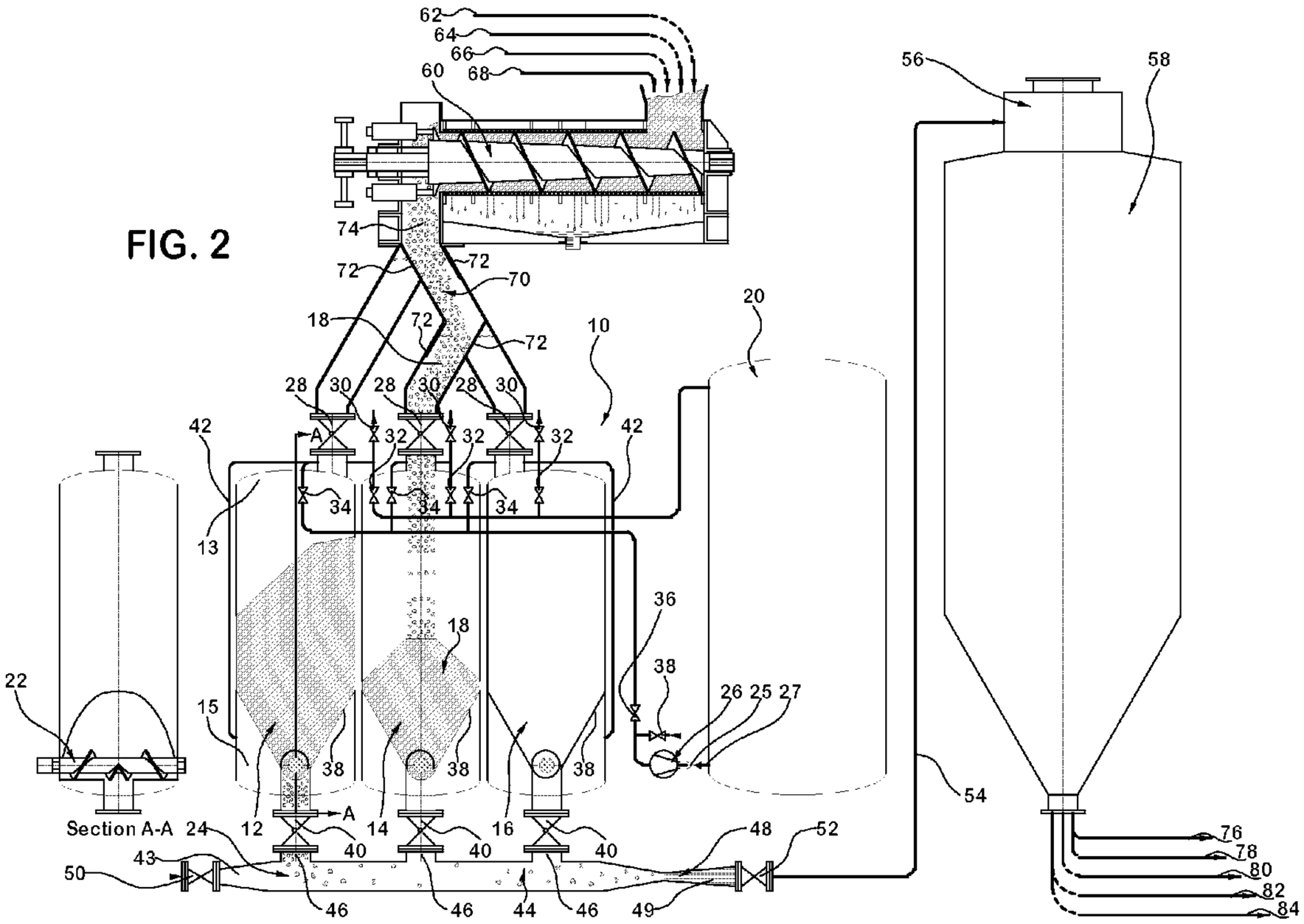
(72) Inventeur/Inventor:
SALMINEN, REIJO K., US

(74) Agent: FINLAYSON & SINGLEHURST

(54) Titre : PROCEDE ET APPAREIL POUR LA SEPARATION DE FIBRES CELLULOSIQUES, PROCEDE POUR LE TRAITEMENT DE PATES FIBREUSES POUR UN PROCEDE DE FABRICATION DE PAPIER, PROCEDES POUR LE SECHAGE DE PAPIER ET DE PRODUITS PAPETIERS AVEC DES FIBRES SEPAREE

(54) Title: METHOD AND APPARATUS FOR THE SPLITTING OF CELLULOSIC FIBERS, METHODS FOR THE TREATMENT OF FIBROUS PULPS FOR A PAPERMAKING PROCESS, METHODS FOR PAPER DRYING AND PAPER PRODUCTS WITH SPLIT FIBER

FIG. 2



(57) Abrégé/Abstract:
The invention relates to a method for longitudinal splitting of hollow cellulosic fibers. The method comprises the steps of wetting the fibers, feeding the wet fibers to an above atmospheric gaseous flow, and conducting the gaseous flow carrying the fibers through a

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(57) Abrégé(suite)/Abstract(continued):
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(72) Inventor; and
(71) Applicant : **SALMINEN, Reijo K.** [FI/US]; 373 Cove Rd., Bellingham, Washington 98229 (US).

(74) Agent: **BERGGREN OY AB**; P.O. Box 16, (Antinkatu 3 C), FI-00101 Helsinki (FI).

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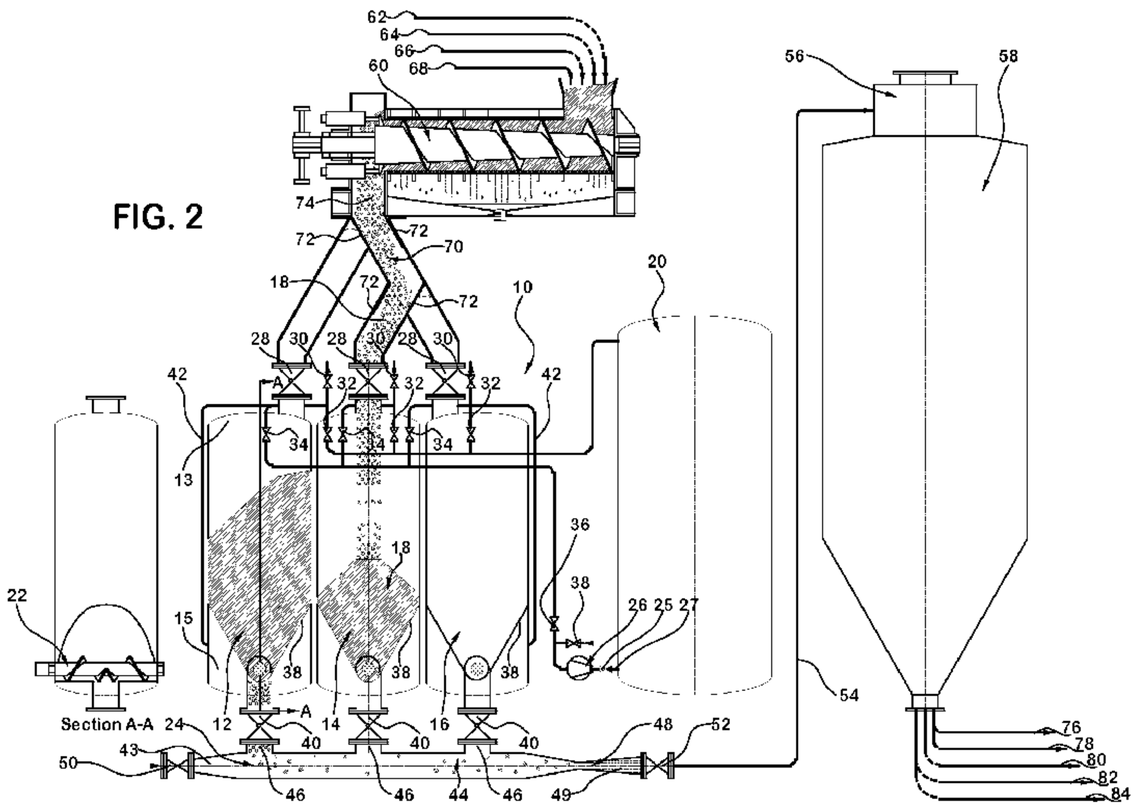
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FIG. 2



(57) Abstract: The invention relates to a method for longitudinal splitting of hollow cellulosic fibers. The method comprises the steps of wetting the fibers, feeding the wet fibers to an above atmospheric gaseous flow, and conducting the gaseous flow carrying the fibers through a venturi tube. The pressure drop in the venturi tube throat brings a pressure difference between the inside and the outside of the fibers and causes the fibers to split in their longitudinal direction. Further objects of the invention are an apparatus for splitting the fibers, a method of washing fibrous pulp, methods for the bleaching of fibrous pulp, methods for the chemical treatment of fibrous pulp, a method for the deinking of recycled paper, methods for the pretreatment of fibrous pulp or recycled paper for papermaking, methods for the preparation of dried paper, and finished paper products comprising longitudinally split fibers. Splitting of the fibers provides access to the bound liquid inside the lumen of the fibers, benefiting the various fiber treatments and drying operations, and reduces the freeness of the finished paper while preserving its strength.

Method and apparatus for the splitting of cellulosic fibers, methods for the treatment of fibrous pulps for a papermaking process, methods for paper drying and paper products with split fibers

FIELD OF THE INVENTION

The present invention relates to a method and an apparatus for the longitudinal splitting of hollow cellulosic fibers. Further objects of the invention are a method of washing fibrous pulp, methods for the bleaching of fibrous pulp, methods for the chemical treatment of fibrous pulp, a method for the deinking of recycled paper, methods for the pretreatment of fibrous pulp or recycled paper for papermaking, methods for the preparation of dried paper, and finished paper products comprising longitudinally split fibers.

BACKGROUND OF THE INVENTION

Fiber morphology

In the pulp and paper industry all processing apparatuses and methods are influenced by the pulp characteristics, which derive particularly from fiber morphology, population, length, coarseness, coarseness to length ratio, wall thickness and diameter, and fiber types to list the most important ones.

Fiber morphology is the key element that influences the pulp characteristics. Up to now the paper industry has not given fiber morphology full consideration as regards pulp processing and papermaking.

Among the most important aspects that affect the morphology of the fibers are the species of the trees or non-wood plants that are processed into pulp. The huge difference between hardwood or softwood pulps is best illustrated by the consistent difference in their fiber populations. Thus fines-free softwood market pulps range from 2.3 to 5.2 million fibers/g, while fines-free hardwood pulps range from 9.8 to 27.6 million fibers/g. In terms of fiber length, the average length-weighted fiber length of softwood chemical pulps range from 1.8 to 2.7 mm, while the shorter hardwoods range from 0.58 to 1.1 mm. These data show that softwood fibers are, on average, approximately 2.5 times longer than hardwood fibers. There is a sharp difference in the paper structure that

these two groups of pulp produce, and in fact most papers are made from a mixture of hardwood and softwood pulps.

Another major aspect of fibrous pulp is coarseness, a measure of how much fiber wall material there is in a fiber per unit-length of that fiber. Since the fiber wall densities of market chemical pulps do not differ greatly, coarseness can be visualized as the solid cross-sectional area of the fiber wall. Once more a significant difference between softwood and hardwood fibers is evident. Coarseness values for the softwoods range from 13.7 to 27.5 mg/100 m, while hardwoods range from 6.9 to 12.6 mg/100 m.

The relationship of fiber diameter and wall thickness affects the tendency of the fiber to collapse. Fibers with the same coarseness, but different diameters, will have different collapsing tendencies. A good example of this difference can be seen by comparing a 100% aspen NBHK, and a SBMHK, “Southern Bleached Mixed Hardwood Kraft” pulp. They have nearly the same coarseness values (10.1 versus 10.6 mg/100 m), but the aspen pulp fibers have a larger diameter and a thinner wall than the southern mixed hardwood fibers. As a result, the aspen pulp collapses readily and therefore requires only a third as much refining to form a sheet with the same density as the southern hardwood pulp.

Pulp fines are generally considered to be detrimental to pulp properties because they don’t contribute significantly to sheet strength and they displace longer fibers, they lower freeness and impede the drainage on the paper machine, they aren’t easily retained on the paper machine wire, they tend to produce paper surfaces prone to picking and dusting, and they have a high specific surface area that attracts a disproportionate amount of additives.

There is another category of fines, called secondary fines that are fragments of fibers and fiber walls. Secondary fines result from fiber damage in wood chip production and transport, pulping, mixing and refining. Secondary fines, within some reasonable limits, are generally considered beneficial for sheet strength, opacity and surface properties.

As regards non-wood pulps, cotton linters pulps are nearly pure cellulose fibers produced from second-cut cotton linters. The distribution of fiber lengths, average fiber length (1.45 mm), coarseness (19.1 mg/100 m) and fiber population (5.5 million/g) position this pulp’s gross morphology as being similar to

short softwood. From a strength potential perspective, the nearly pure cellulose severely limits hydration and bonding potential. As a consequence refining has little influence on strength development and, while these pulps are quite durable and stable, they are not used to make strong papers without being combined with other fibers and/or bonding additives.

Three other non-wood pulps belong to the category of pulps with very uneven fiber length distribution and quite different fiber types. Bamboo, kenaf and bagasse pulps have very similar fiber length (~ 1.1 mm), but their coarseness values, which are 9.3, 12.5 and 17.9 mg/100 m respectively, cover a fairly broad range. All three pulps have at least two very distinct fiber types, namely a long, relatively thick-walled fiber much like softwood latewood fiber, and a large diameter thin-walled short fiber.

Wood cell structure

Another difference between softwoods and hardwoods is that softwoods are dominated by one fiber type, the tracheid, while hardwoods have fiber tracheids and vessel elements. The vessel elements specialize in vertical transportation of water in the tree trunk. Each vessel consists of vessel elements that are cylindrical cells with open ends. They are connected longitudinally to form pipe structures. All hardwoods have vessels in the range of 10% to 50% of their volume, depending on species. Vessel elements of some hardwood species are extremely large in diameter compared to their fibers. In addition to having more fiber types, the volume that the fiber types occupy, and their size and shape, is more varied in hardwoods.

In softwoods the tracheids are 90+% of the wood volume and 94+% of the pulp mass. In contrast, the hardwood fiber tracheid volume ranges from 40 to 70%, while the vessel elements occupy 10 to 40% of the wood.

There is a third group of small cells, namely the ray tracheids in softwoods and the ray and axial parenchyma in hardwoods. Ray cells constitute less than 10% of the volume of softwoods, but the parenchyma cells in hardwoods can be up to 40% of the wood volume and more than 20% of the mass of a market pulp. These very small cells are commonly referred to as primary fines.

To illustrate the ultrastructure of typical softwood cells reference is made to **FIG. 1** The main cell (fiber) type is the axially aligned tracheid (TR) **302**. Other

cell types in softwoods are the fusiform wood ray (FWR) and wood ray (WR) cells **304**, and the longitudinal and epithelial parenchyma cells, which are the cells surrounding the horizontal (HRD) **306** and vertical (VRD) **308** resin ducts.

A simplified structure of a cylindrical woody cell, i.e. a wood fiber, comprises the middle lamella (ML) **312**, the primary wall (P) **314**, the outer (S1) **316**, middle (S2) **318**, and inner (S3) **320** layers of the secondary wall, and the warty layer (W) **322**.

The warty layer **322** is a thin, typically 0.1 micron thick, amorphous membrane located in the inner surface of the cell wall. In the inner layer **320** the direction of the micro-fibrils is nearly perpendicular to that in the middle layer **318**. The void space inside the inner layer **320** is called lumen **321** and its diameter is typically in the 20 micron range.

The middle layer **318**, typically 3 micron thick, forms the main portion of the cell wall. The micro-fibrils are oriented in bands (lamellae) nearly parallel to the cell axis.

In the outer layer **316**, typically 0.2 micron thick, the micro-fibril groups are in helixes alternately crossed. The fibrils have great tensile strength, which renders the outer layer **316** capable of extreme resistance to swelling of the interior layers of the fiber wall.

In the outer portion of the primary wall **314** the micro-fibrils form an irregular network. In the interior they are oriented nearly perpendicular to the cell axis. In the presence of reagents (e.g. white liquor), which induce strong swelling, the primary wall **314**, typically 0.1 micron thick, is peeled off and the belts around the fibers expand (balloon).

The middle lamella **312** is located between the cells and serves the function of binding the cells together. It consists typically of 90% lignin, 10% of hemicelluloses, and little, if any, of cellulose.

In softwoods, liquid is transferred from rays **304** to tracheids **302** and between tracheids **302** through tiny voids called bordered pits (BP) **310** in the cell walls. Typically the bordered pits **310** are only in one single row aligned with the longitudinal axis of the cell.

To give some perspective of the weight each cell type and their layers represent in a virgin softwood cell structure, typically the percentages are in descending order as follows: middle layer **318** 67%, middle lamella **312** 15%, wood rays **304** and resin ducts **306** and **308** (including resins) 8%, outer layer **316** 5%, primary wall **314** 3%, and inner layer **320** 2%.

Pulping

The major types of fibrous pulps produced today are chemical pulps made by digesting, thermomechanical pulps (TMP) made by heat and mechanical defibrillation and chemi-mechanical and chemi-thermomechanical pulps (CMP and CTMP) made by mechanical refining with use of heat and/or chemicals. Chemical pulping has a low yield and the pulps are rather expensive. Mechanical pulps are rather weak and yield lower-quality although cheaper paper products compared with chemical pulps. Ultra-high-yield chemi-mechanical (CMP) pulps and chemi-thermo-mechanical (CTMP) pulps represent alternatives, which combine high yield, low cost, and fewer pollution problems while achieving good mechanical properties. The only major drawback of CMP/CTMP pulps is their relatively high defibrillation energy.

The production of CMP or CTMP generally comprises the steps of chip sulfonation with a sodium sulfite mixture ($NaHSO_3$ / Na_2SO_3 / NaOH) and high-consistency refining at atmospheric or higher pressure.

Explosion pulping is an ultra-high-yield pulping process based on short time vapor-phase cooking at temperatures in the range of 180 to 210 °C, followed by explosive decompression.

It is generally accepted that the chemical treatment is mainly responsible for permanent fiber softening and increases in long fiber content, fiber specific surface, and conformability. Treatment of chips with steam at high temperature, followed by explosive decompression, also contributes to the softening of the fibers. Moreover, the explosive decompression of treated chips leads to a reduction in energy consumption in subsequent refining stages.

Explosion pulping was invented by Mason (1928) in the early 1930s. In this process, the chips are fed from a chip bin through a screw loading valve in a masonite gun. The chips are then steam heated at a very high temperature, about 285 °C, and at a pressure of 3.5 MPa for about 2 min. The pressure is

increased rapidly to about 7 MPa for about 5 s, and the chips are then discharged through restricted orifices (slotted port) and explode at atmospheric pressure into a pulp. Two stages of low-consistency atmospheric refining result in a dark pulp of about 75% yield suitable for the manufacture of high-density fiberboard. This process is very effective as a means of fiber separation with low energy consumption. However, the masonite pulp is very coarse in texture and dark in color. The fibers are mostly un-collapsed, rigid, and degraded and display a highly lignin-rich surface structure, which is unsuitable for papermaking.

Scanning electron micrographs and microscopic studies of fibers produced by explosion pulping have demonstrated a clear separation in the middle lamella. It is known that the surface of explosion pulp contains numerous large pores with evidence of considerable ultra-structural rearrangements. Fragments of cell wall form more or less spherical particles, primarily from lignin. During the action of organic solvents or other de-lignifying agents, the lignin particles swell, then their structure is destroyed, and finally they move from the liquid phase and disappear from the fiber structure.

Steam explosion pulping (SEP) was suggested as an alternative to CMP/CTMP processes in the early 1990s because of the reduced refining energy required for the SEP pulp. A much higher temperature is used (180-210°C) as compared with that used in conventional CMP/CTMP processes (120-150°C) and a shorter time. Moreover, the cook is terminated by a sudden pressure release.

Paper recycling is the process of recovering waste paper, pulping the paper and turning it into new paper products. There are three categories of paper that can be used as feed stocks for making recycled paper, namely mill broke, pre-consumer waste, and post-consumer waste. Mill broke is paper trimmings and other paper scrap from the manufacture of paper, and is recycled internally in a paper mill. Pre-consumer waste is material which left the paper mill but was discarded before it was ready for consumer use. Post-consumer waste is material discarded after consumer use, such as corrugated containers, magazines, newspapers, office paper, telephone directories etc.

Pulp processing

The most usual processes fibrous wood or non-wood pulps are subjected to washing, bleaching, chemical treatments of the pulp, refining, drying, and papermaking. Recycled fibrous wood or non-wood pulps are subjected to deinking, bleaching, refining and papermaking.

Pulp washing aims at the removal of residual digesting or bleaching liquor from the pulp. Washing apparatuses include diffusion washers, rotary drum washers, horizontal belt filters, wash presses and dilution/extraction washing stages. The method used in diffusion washers is to displace in a tank the spent liquor between the fibers with cleaner wash liquor, typically at 5–10% pulp consistency range. The method used in drum and belt-washers is to first dewater the pulp slurry as much as possible, typically to 10–15% pulp consistency range, and then use wash liquor for displacement of the remaining spent liquor. In the method with wash presses the spent liquor is squeezed out from between the fibers, typically to 25–35% pulp consistency range, while some wash liquor is introduced during the pressing.

All these displacement washing methods displace spent liquor only from the space outside and between the pulp fibers, but leave practically all spent liquor inside the fiber lumen. Some leaching of the inside bound liquor happens during the dilution/extraction stages between multiple washing steps in series. However, a substantial amount of spent liquor, typically 1.5–2 times the weight of the fibers, is still carried over inside the hollow fiber lumen to the next processing stage.

Bleaching of pulp fibers is done with chemicals in gaseous or liquid form. One or more bleaching stages are required to achieve desired result. Each bleaching stage is accomplished at a preferred pulp consistency, temperature, pressure, time duration, and chemical concentration.

Each bleaching stage is followed by a washing stage to remove the dissolved organic matter and the bleaching chemicals to minimize the carry-over to the next bleaching stage. In bleaching typically only one washing step is used per stage. Again, the displacement wash leaves a substantial amount of already dissolved organic matter and bleaching chemicals inside the fiber lumen. This carry-over consumes and thereby wastes some of the newly added chemicals in the next bleaching stage.

In general, recycled pulp can be bleached with the same chemicals used to bleach virgin pulp, but hydrogen peroxide and sodium hydrosulfite are the most common bleaching agents.

The industrial process of removing printing ink from paper fibers of recycled paper to make deinked pulp is called deinking. Many newsprint, toilet paper and facial tissue grades commonly contain 100% deinked pulp and in many other grades, such as lightweight coated for offset and printing and writing papers for office and home use, deinked pulp makes up a substantial proportion of the furnish.

In the fast-growing digital printing market, a noteworthy development is the introduction of commercial inkjet web presses for on-demand newspapers and various publications and business forms. However, inkjet inks are generally not de-inkable and are, therefore, incompatible with paper recovery and recycling. Ten percent is a reasonable estimate for the percentage of inkjet-printed paper that a mill can tolerate.

Very small and hydrophilic ink pigments are generally easily dislodged from the fiber surface during pulping. The mechanical action imparted to the pulp in a repulper, however, causes the small ink pigments to enter into the lumen via pit apertures where they deposit irreversibly on the surface of fiber lumen.

Some end products in chemical pulping require additional chemical treatment after the conventional bleaching stages. For instance, mercerized pulps are produced by post-treatment of steeping a bleached pulp in caustic to swell the fibers, to remove hemicelluloses and to render the pulp inert as far as strength development from refining is concerned. Market pulps are used to produce cellulose derivatives including sodium carboxyl methyl cellulose (CMC), hydroxyl ethyl cellulose (HEC), methyl ethyl cellulose (MEC) and cellulose diacetate. Dissolving pulps having uniform intrinsic viscosity, also measured as degree of polymerization, undergo a process that reduces it to syrup that can be further processed into cellophane film and fibers for rayon, acetate and other man-made fibers.

Refining or beating of chemical pulps is the mechanical treatment and modification of fibers so that they can be formed into paper or board of the desired properties. The main target of refining is to improve the bonding ability of fibers so that they form strong and smooth paper sheet with good printing properties.

Refining affects fibers by cutting and shortening of fibers, fines production, removal of parts from fiber walls, external fibrillation, delamination, internal fibrillation, swelling, curling, creating kinks etc., and dissolving or leaching out colloidal material into the external liquor. As a result of the above effects, fibers after refining are collapsed (flattened) and made more flexible, and their bonding surface area is increased.

Production of market pulp as well as various types of paper and board products requires drying of the final product. Most market pulp is air dried (90% fiber, 10% water) and compressed into bales or in some cases the pulp mat is split and rewound into rolls. Two basic systems are employed in the production of dry market pulp: the conventional system, and the flash-drying system.

The conventional system of producing dry market pulp parallels conventional papermaking: a thick pulp mat is formed with a Fourdrinier wet end, most remaining free water between the fibers is removed mechanically in the press section, and evaporative drying is employed with either a steam-heated cylinder dryer or an air-float dryer section.

Flash or spray drying refers to the process whereby the fibrous material is introduced as a spray or an analogous form into a stream of hot gases. The high-temperature heat content of the gas stream causes flashing of moisture to vapor.

However, the entrapped water in the lumen immediately turns to steam (one cc of water becoming 1700 cc of steam), creating an internal explosion. The water in the fiber's wall and interior lumen evaporates, causing the fiber to shrink and contract. Each fiber reacts to this explosion in varying ways, depending on the structural weaknesses along the length of the fiber. These inherent weaknesses create knuckles in the fibers' shape. Along with the knuckles the fibers develop a characteristic curly shape and become convoluted. These misshapen fibers have made flash-dried pulps recognized as being ideally suited to the needs of those mills producing filter papers and latex-saturated paper and board.

In drying a sheet of paper two basic physical processes are involved, heat transfer and mass transfer. Heat is transferred from some source such as steam to the wet sheet in order to provide the energy required to drive the moisture from the sheet. The moisture evaporates and is then transferred from

the sheet to the surrounding atmosphere by the mass transfer process. Multi-cylinder drying is the most common way in the paper and paperboard industry.

SUMMARY OF THE INVENTION

As discussed above in the chapter “wood cell structure”, wood as well as non-wood fibers comprise tracheids, having a cylindrical shell surrounding a hollow lumen and closed ends. Only small bordered pit holes along a longitudinal line in the tracheids allow passage of liquids in and out of the fiber lumen. In soft-woods the tracheids are 90+% of the wood volume and 94+% of the pulp mass, whereas hardwood fiber tracheid volume ranges from 40 to 70%, while the vessel elements occupy 10 to 40% of the wood.

The tracheids remain closed through all the present technology processing steps in the pulp and paper industry from digesting through washing, bleaching and drying. Only in mechanical refining of chemical pulp, for improving paper sheet formation and its strength characteristics, some fiber cell walls are opened, but due to concomitant cutting of the fibers refining is used only to a limited extent leaving most of the tracheids closed.

The closed tracheids create a number of problems to a broad range of the pulp and paper industry processes. For pulp washing, only the free liquid outside between the fiber cells is washable to recover the dissolved organic matter and chemicals in the spent cooking liquor, or to remove the dissolved organic matter and spent bleaching chemicals from the pulp before the next bleaching or final drying stage. For pulp bleaching, all bound liquid inside the closed fiber lumen carries already dissolved organic matter and spent cooking or bleaching chemicals into the next stage. This carry-over consumes fresh bleaching chemicals leaving less for further bleaching reactions in the cell wall. Also, the closed cylindrical fiber wall allows the bleaching chemicals access to the desired organic matter, mainly lignin, and in specialty pulps also the hemicelluloses, in the cell wall only through the outside wall surface. The miniscule open area of the bordered pit holes does not allow practically any transfer of bleaching chemicals into the fiber lumen and simultaneously transfer of any dissolved organic matter out of the same holes.

All bound liquid inside the closed fiber lumen, after the unbleached pulp washer or after the last bleach plant washer, carries already dissolved organic matter, spent cooking liquor, or bleaching chemicals into the market pulp or paper mill pulp storage chest. There some of the bound liquid has time to leach out from the fiber lumen into the free wash liquid of the last washing stage surrounding the fibers.

In case of market pulp drying the wet end filtrate from the sheet formation before the pulp dryer carries a large COD load, the leached amount, into the pulp mill effluent system. Any dissolved organic matter and chemicals that were not leached out of the fibers will be carried with the market pulp to the customers mill, where it eventually will add to that mill's COD load after repulpers and the refining action free most of the remaining carry-over to the mill's effluent system.

For recycled paper, there are a variety of undesirable materials bound inside the fibers, such as ink particles, paper filler materials, glue, dissolved organic matter, digesting and bleaching chemicals etc. All these undesirable materials are carried over in the bound liquid inside the fiber lumen to the final end products.

For drying, the closed fiber structure with lumen filled with liquid retards and adds to the burden of removing the liquid from pulp or paper mechanically or by evaporation. This bound liquid is a major factor behind the massive pressing and drying sections of the present-day paper and board machines, and the high energy consumption for obtaining the final dried product.

The present invention has the aim of solving the problems as discussed above by longitudinal splitting of the cylindrical hollow cellulosic fibers in a controlled manner, thereby opening the lumen inside the fiber for the various operations in the pulp and paper industry. According to a first aspect of the invention, a method of splitting the fibers comprises the steps of (i) wetting the fibers, (ii) feeding the wet fibers to a gaseous flow, and (iii) conducting the gaseous flow carrying the fibers through a venturi tube, so that (iv) the pressure drop in the venturi tube throat brings a pressure difference between the inside and the outside of the fibers and causes the fibers to split in their longitudinal direction.

According to a second aspect of the invention, an apparatus for splitting the fibers comprises (i) a flow channel for conducting a gaseous flow, said flow

channel issuing in a venturi tube, (b) a container for fibers in a wetted condition, (c) means for pressurizing said container, and (iv) supply means for feeding the wet fibers from said container to said flow channel upstream of the venturi tube.

According to a third aspect of the invention, a method of washing fibrous pulp comprises the steps of (i) feeding wet cellulosic fibers of the pulp to an above atmospheric pressure gaseous flow, (ii) conducting the gaseous flow carrying the fibers through a venturi tube, so that (iii) the pressure drop in the venturi tube brings a pressure difference between the inside and the outside of the hollow cellulosic fibers and causes the fibers to split in their longitudinal direction, and (iv) subjecting the longitudinally split fibers to treatment with washing liquors.

According to a fourth aspect of the invention, a method for the bleaching of fibrous pulp comprises the steps of (i) feeding wet cellulosic fibers to an above atmospheric pressure gaseous flow, (ii) conducting the gaseous flow carrying the fibers through a venturi tube, (iii) the pressure drop in the venturi tube bringing a pressure difference between the inside and the outside of the hollow cellulosic fibers and causing the fibers to split in their longitudinal direction, and (iv) subjecting the longitudinally split fibers to treatment with bleaching chemicals.

As a modification of the method according to the fourth aspect above, at least one bleaching chemical can be fed to the gaseous flow together with the wet fibers, so that the bleaching chemical is present already at the moment of splitting the fibers and can affect the lumen, i.e. the inside wall of the fiber immediately.

As another modification the treatment may be a chemical treatment other than bleaching, using respective chemical reactants for affecting the fibers opened by longitudinal splitting.

Furthermore, the method may be used for deinking of recycled paper, which starts with repulping the paper to obtain fibers in a wetted condition, followed by the steps for splitting the fibers as brought forward above, and final treatment of the split fibers to remove the ink particles by washing.

According to a fifth aspect of the invention, a method for the pretreatment of recycled paper for papermaking comprises the steps of (i) repulping the paper to obtain cellulosic fibers in a wet condition, (ii) feeding the wet fibers to an above atmospheric pressure gaseous flow, (iii) conducting the gaseous flow carrying the fibers through a venturi tube, (iv) the pressure drop in the venturi tube bringing a pressure difference between the inside and the outside of the fibers and causing the fibers to split in their longitudinal direction, and (v) subjecting the longitudinally split fibers to cleaning by removal of glue and/or organic or inorganic filler materials freed from the inside of the fiber lumen.

According to a sixth aspect of the invention, a method for the pretreatment of fibrous pulp for a papermaking process comprises the steps of (i) wetting the hollow cellulosic fibers of the pulp, (ii) feeding the wet fibers to an above atmospheric pressure gaseous flow, (iii) conducting the gaseous flow carrying the fibers through a venturi tube, (iv) the pressure drop in the venturi tube bringing a pressure difference between the inside and the outside of the fibers and causing the fibers to split in their longitudinal direction, and (v) bringing the longitudinally split fibers to a furnish for supply to the wet end forming fabric of a papermaking machine.

By use of the longitudinally split fibers for papermaking there are substantial advantages to be gained in the drying of the paper, including changes in the drying section of the papermaking machine. These advantages will be discussed in the next chapters below. Another important advantage is that the freeness of the paper can be reduced while the strength of the finished paper product is preserved as the controlled splitting does not cut the fibers in the longitudinal direction. The fiber splitting according to the invention thus forms a useful substitute for conventional refining, which aims at reducing the freeness but is handicapped by its tendency to cut the fibers shorter and thereby weaken the final paper.

According to a seventh aspect of the invention, a method for the preparation of dried paper comprises the steps of (i) wetting hollow cellulosic fibers, (ii) feeding the wet fibers to an above atmospheric pressure gaseous flow, (iii) conducting the gaseous flow carrying the fibers through a venturi tube, (iv) the pressure drop in the venturi tube bringing a pressure difference between the inside and the outside of the fibers and causing the fibers to split in their longitudinal direction, (v) bringing the longitudinally split fibers to a furnish, (vi) sup-

plying the furnish to the wet end forming fabric of a papermaking machine, (vii) forming a fibrous web on said forming fabric, (viii) pressing the fibrous web for removal of water in the pressing section of said papermaking machine, and (ix) drying the fibrous web on a sequence of steam heated drying cylinders in the drying section of said papermaking machine.

Splitting of the fibers frees the water and brings it into direct contact with the surfaces of the drying cylinders, thus adding to the efficiency of drying and allowing the drying section of the papermaking machine to be drastically shortened. The contact between liquid water and drying cylinder surface may be maintained substantially at each one of the cylinders in the sequence. This is in sharp contrast with the present-day drying processes, in which such direct contact is lost in the course of the drying, the latter drying stages seeking to remove residual water and moisture from the lumen of the un-split fibers through the fiber cell wall. Such conventional drying requires a progressively increasing temperature and vapor pressure along the sequence of drying cylinders as each dry fiber builds up an insulating layer on both outside surfaces of the paper to resist heat transfer into the wetter interior of the paper sheet. Consequently the cost savings won by the invention are remarkable.

According to a preferred embodiment the cylinders at the opposite ends of the drying sequence have vapor pressures that stand in a relation of at most 2 to 1, preferably at most 1.5 to 1, to each other. The invention may even allow a substantially equal vapor pressure to be maintained within each cylinder of the drying sequence. A suitable vapor pressure within each cylinder of said sequence may be 4 bar at most, preferably within the range of 3 to 4 bar. In comparison, in conventional drying processes dealing with predominantly unsplit fibers and therefore predominantly bound water inside the fibers said relation between the initial and the final vapor pressures in the sequence of cylinders is typically about 3 to 1, increasing from about 3 bar in the wet end cylinders to about 8–10 in the dry end cylinders.

In terms of temperature, a suitable temperature on the surface of each cylinder of the sequence may be 150°C at most, preferably about 135 to 145°C, while the steam temperature inside the dry end cylinders in prior art is typically in the 180°C range.

According to an eighth aspect of the invention, there is provided a paper product comprising at least one fibrous layer, in which at most 50% of the fibers have a hollow cylindrical unsplit configuration, the rest of the fibers having been split in their longitudinal direction. Preferably the share of such unsplit fibers is at most 10%, and most preferably substantially all of the fibers in the at least one fibrous layer are split in their longitudinal direction. The paper product may be made by use of the pretreated fibrous pulp made in accordance with the sixth aspect of the invention discussed above. In prior art papers based on conventionally refined pulps, failing to fulfill the characteristics of the present invention, refining has cut the fibers shorter but has not markedly changed their hollow cylindrical configuration.

The paper according to the invention may consist of a single layer, or it may be a multilayer paper, there being a separate headbox and forming fabric for each of the layers in the papermaking machine. In case of a multilayer paper at least one layer and preferably each one of the layers has at least 50%, preferably at least 90%, and most preferably substantially all of the fibers split in their longitudinal direction.

In papermaking it is possible to prepare a furnish exclusively from a pulp pretreated according to the invention to comprise longitudinally split fibers, or by blending such pretreated pulp with a conventional pulp of un-split fibers. In this way the share of split fibers in each paper layer may be controlled if desired.

The invention benefits pulp washing by making all liquor bound inside the fiber lumen at the previous treatments, such as cooking liquors or bleaching chemicals, washable to recover the dissolved organic matter and chemicals in the spent liquor. Washing away any cooking liquors prevent undesirable carry-over of such liquors to a subsequent bleaching or other chemical treatment stage. At the same time the displacement washing process is made more efficient, reducing the number of washing steps and use of washing water.

There is no dissolved organic matter or spent process chemicals carried over in bound liquid inside the fiber lumen as residues contaminating a final pulp product such as market pulp. When used for papermaking the pulp has no COD load carried over into the paper mill effluent system.

Regarding the bleaching the benefits are quite similar. Bleaching chemicals have an immediate access to the opened inside of the longitudinal fibers, and

harmful carry-over of chemicals to the next processing step in a typically multi-step bleaching process is avoided. The consumption of bleaching chemicals is reduced and the entire process is simplified together with reduction of the bleaching pressure, temperature, time and the amount of chemicals used, and even the number of the bleaching steps in some cases can be reduced.

The longitudinally split fiber wall thus allows effective removal of the target organic matter, mainly lignin, and for specialty pulps also the hemicelluloses, from both sides of the fiber cell wall. In case of recycled paper the variety of undesirable materials bound inside the recycled fibers, such as ink particles, paper filler materials, glue, dissolved organic matter, digesting and bleaching chemicals etc. are immediately accessible to removal after the fibers are split longitudinally.

Since splitting the fiber wall longitudinally open is an efficient refining action in itself, very little, if any, mechanical refining is necessary to form a strong and smooth paper sheet with good printing properties. This reduces the continuous weakening of recycled fibers due to repeated refining actions.

Splitting the fiber wall longitudinally open is also an efficient refining action in itself, resulting in better paper or board properties than the conventional mechanical refining can produce. The main target of refining, to improve the bonding ability of fibers, is improved by 65–70 percent due to doubled contact surface area for bonding between the individual fibers. All the negative mechanical refining effects are eliminated, such as no cutting and shortening of fibers, no fines production, no curling of the fibers, no nodes, kinks, slip planes, or micro-compressions in the cell wall are created.

For pulp and paper drying the longitudinally opened fiber structure is a major advantage, allowing more effective removal of residual moisture by pressing and by heated cylinders. Especially the paper or board machine drying section may be made shorter and less massive with reduced energy consumption. As conventional market pulp is used for papermaking, the splitting of the fibers according to the invention is a useful pretreatment to be carried out before the preparation of the aqueous furnish, bringing the advantages in the pressing and drying sections of the machine.

Since the volumetric flow is the same in both the flow channel upstream of the venturi tube and the substantially reduced cross sectional area in the venturi

throat, the average velocity of the gas and fiber mixture must increase as it passes through the throat. Therefore, the gas pressure drops according to Bernoulli's conservation of energy equation. The point of smallest flow cross section in a venturi tube is termed the "vena contracta", and corresponds to the point of lowest pressure. It can be sized small enough to drop the entering gas or steam vapor pressure even to half of its original value in a fraction of a second as the gas and fiber mixture passes through the vena contracta.

For controlled splitting of the fibers in the venturi throat the pressure difference between the outside and the inside of the hollow fibers must be sufficient to split the fibers longitudinally, like a pea pod, while preventing an uncontrolled explosive splitting that would rupture the fiber shells and weaken the mechanical strength of the pulp. The pressure in the gaseous flow, which also prevails in the liquid inside the fibers, may be in the range of 1 to 20 bar, preferably 5 to 10 bar. The selection of this operating pressure is dependent on many variables such as the desired flow velocity through the venturi throat, size of the feed fiber particles, fiber moisture, discharge line back pressure, production capacity, and transporting gas. The preferred transporting gases are compressed air and steam, the latter being more lubricating than the former and cheaper to produce.

A sudden pressure drop occurs as the gas together with the fibers flows through the venturi throat, and due to the closed structure of the fibers a corresponding pressure difference is suddenly created between the opposite sides of the fiber wall. The magnitude of the pressure drop, as well as the pressure difference that causes the fiber to split, is governed by the geometry of the venturi throat. The venturi throat may constrict the flow to a cross-sectional area of 2 to 40%, preferably 5 to 10% of the cross-section of the flow channel upstream of the venturi tube. The pressure downstream of the venturi tube is by necessity lower that upstream of the same, preferably the normal atmospheric pressure.

For example, if both the gas flow pressure and the liquid pressure inside the fiber lumen are 8 bars upstream of the venturi tube, the gas pressure surrounding the fibers may drop to 4 bars in the venturi throat, while the liquid pressure in the interior of the fiber lumen is still 8 bars. The 4 bar pressure difference is sufficient to break the fiber cell wall along a longitudinal line where the cell wall is the weakest. Since the liquid inside the fiber lumen is a non-compressible

and non-flashing fluid its pressure is released immediately to the pressure of the surrounding gas when the fiber shell splits. No changes to the fiber morphology have been found to take place other than the longitudinal split.

An apparatus according to the invention may comprise a container defining a pressure chamber (first embodiment) or an atmospheric feed chamber (second embodiment), which chambers contain the wet pulp fibers, and a flow channel receiving the fibers and carrying them in an above atmospheric pressure gaseous flow to the venturi tube. There are means to pressurize the pressure chamber to an above atmospheric pressure level. Input means are provided to supply wet pulp fibers into the pressure chamber or feed chamber in a continuous manner. The pressure chamber is operated as a batch process where its pressure is relieved to load a new batch of wet pulp fibers and then repressurized for operation. The atmospheric feed chamber is operated as a continuous process where a rotary valve between the feed chamber and the pressurized flow chamber maintains a good air/steam lock between the chambers.

The pressurized flow channel may be provided with a gas or steam vapor entrance pipe and issues in a discharge venturi tube section. Input means are provided to feed the pressurized flow chamber with above atmospheric pressure gas or steam vapor as well as with wet pulp fibers from the pressure chamber (first embodiment) or feed chamber (second embodiment). Discharge means are provided to let the pressurized gas or steam and fiber mixture flow through a venturi tube into a receiving tank, e.g. an atmospheric pressure cyclone chamber for fiber and gas or steam separation.

In the preferred form the consistence of the wet pulp fed from the pressure container to the flow channel is maintained in the 5 to 50% range, more preferably in the range of 15 to 30%.

Other features of the present invention will be apparent from the following detailed description of preferred examples.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1, already discussed in connection with the background of the invention, shows a diagram of the ultra structure of typical softwood cells;

FIG. 2 is an assembly diagram of the apparatus of the first embodiment of the present invention;

FIG. 3 is an assembly diagram of the apparatus of the second embodiment of the present invention showing reference numbers for general description of the apparatus;

FIG. 4 is an assembly diagram of the apparatus of the third embodiment of the present invention showing reference numbers for general description of the apparatus;

FIG. 5 is a SEM photograph of bleached softwood pulp fibers at magnification 200;

FIG. 6 shows the center of the same SEM photograph of **FIG. 5** at magnification 1000;

FIG. 7 is a SEM photograph of unbleached softwood pulp fibers at magnification 600 processed with a pilot scale laboratory apparatus of the present invention;

FIG. 8 shows the center of the same SEM photograph of **FIG. 7** at magnification 2000;

FIG. 9 shows longitudinally split unbleached softwood pulp fibers at magnification 1300;

FIG. 10 shows longitudinally split unbleached softwood pulp fibers at magnification 1300;

FIG. 11 shows two parallel lines of bordered pit holes in the same fiber cell at magnification 700;

FIG. 12 shows micro-fibril bridges between split fiber cells at magnification 700;

FIG. 13 shows the fiber structure of dried reference pulp paper of unbleached softwood pulp at magnification 250;

FIG. 14 shows the fiber structure of dried reference pulp paper of unbleached softwood pulp at magnification 250;

FIG. 15 shows the fiber structure of dried modified split-fiber-pulp paper of unbleached softwood pulp at magnification 250;

FIG. 16 shows the fiber structure of dried modified split-fiber-pulp paper of unbleached softwood pulp at magnification 250;

FIG. 17 shows a typical paper drying machine;

Fig. 18 is a cross-section of a conventional sheet of paper under drying;

FIG. 19 shows the same cross-section after water removal; and

FIG. 20 corresponds to **FIG. 18** but shows a sheet of paper according to the invention.

BRIEF DESCRIPTION OF THE TABLES

TABLE 1 shows the filling, pressurizing, emptying, and depressurizing sequences of the pressure chambers and the compressed air accumulator pressurizing air source;

TABLE 2 shows a laboratory report on testing of conventional un-split ECF bleached softwood pulp fibers;

TABLE 3 shows a laboratory report on testing of longitudinally split ECF bleached softwood pulp fibers;

TABLE 4 shows a laboratory report on testing of conventional unbleached softwood pulp fibers.

DESCRIPTION OF THE FIRST EMBODIMENT

It is believed that a clearer understanding of the present invention will be obtained by first describing somewhat briefly the main components of the apparatus of the first embodiment of the present invention, followed by a general description of its operation. After this there will be a more detailed description of the first embodiment and also more specifics of its operation. Then there will be descriptions of further embodiments.

(a) Main Components of the Apparatus

With reference to **FIG. 2**, the apparatus of the first embodiment of the present invention comprises three pressure chambers for the wet pulp fibers, a compressed air accumulator for pressurizing the pressure chambers, a compressor for pressurizing the air accumulator, three mechanical feeders to ration out the pulp fibers from the pressure chambers, a pressurized flow chamber pipe assembly to receive the fibers through the mechanical feeders, a steam valve to feed and pressurize the pressurized flow chamber pipe assembly, and a venturi tube section and blow valve to discharge the fiber-air-steam mixture from the pressurized flow chamber pipe assembly.

The three pressure chambers are operated as a batch process, where one chamber is being filled with pulp fibers at atmospheric pressure, while the fibers in another chamber are being rationed out at the operating pressure into the flow chamber pipe assembly, and the third chamber is being either relieved of its operating pressure after all fibers have been rationed out or pressurized for operation after the chamber has been filled with fibers.

(b) General Description of the Apparatus

With reference to **FIG. 2**, the apparatus **10** of the present invention comprises three elongate pressure chambers **12**, **14** and **16** which are alternatively filled with wet pulp fibers **18** at atmospheric pressure, then pressurized to operating pressure with compressed air from the compressed air accumulator **20**, emptied from wet pulp fibers **18** through a rationing device **22** to the pressurized flow chamber **24**, and finally depressurized to atmospheric pressure by use of compressor **26** to recover all pressurized air energy back to the compressed air accumulator **20**. All three pressure chambers **12**, **14** and **16** have an upper end **13** and lower end **15**.

There are four valve connections to the upper end **13**. Valve **28** controls the filling of wet pulp fibers **18** into the pressure chamber. Air bleed valve **30** enables the excess air in the pressure chamber to be displaced into the atmosphere by the incoming wet fibers during the filling phase. Pressurizing valve **32** is used to pressurize the pressure chamber to operating pressure with compressed air from the compressed air accumulator **20**. Depressurizing valve **34** is used to recover the energy of the pressurized air in the pressure chamber back to the air accumulator **20** by use of the compressor **26** after the pressure chamber has been emptied of wet pulp fibers. On the suction side of the compressor **26** there are two valves; recycle valve **36** which is open when the pressure energy in any of the pressure chambers is being recovered, and; fresh air intake valve **38** for compressed air make-up when recycle valve **36** is closed. On the pressure side of the compressor **26** there is a check valve **25** in the line **27** between the compressor **26** and the air accumulator **20**.

The lower end **15** comprises a false bottom funnel **38** to direct the wet pulp fibers **18** to the rationing device **22,** and a discharge valve **40** to let the wet pulp fibers **18** into the pressurized flow chamber **24**. A pressure equalizing pipe **42** connects the space under the false bottom funnel **38** to the upper end **13** of the pressure chambers **12**, **14** and **16**.

The apparatus **10** can be considered as having two main operating sections that cooperate with one another to accomplish the major functions of the present invention. First, there are the above described three pressure chambers **12**, **14** and **16**, and second, there is the pressurized flow chamber **24**. The pressurized flow chamber **24** has two main sections; a pipe assembly **44** to receive the wet pulp fibers **18** alternatively through three nozzle locations **46** on the top of the pipe assembly **44** and; a venturi tube section **48**. The inlet end **43** of the pipe assembly **44** is connected to a feed valve **50** for feeding and pressurizing the pressurized flow chamber **24** with gas or steam vapors. The discharge end **49** of the venturi tube section **48** is connected to a blow valve **52** to discharge the fiber-air-steam mixture from the pressurized flow chamber **24** through a blow line **54** into a cyclone **56** on top of a high density storage tank **58**.

The apparatus **10** is supplied with wet pulp fibers typically at 25 to 30 percent consistency. **FIG. 2** shows a typical thickening apparatus **60** in the form of a screw press. A pipeline **62** from a pulp storage tank or a pipeline **64** from a re-

pulper feed the thickening apparatus **60** typically with 2 to 5 percent pulp slurry. A pipeline **66** from a decker or **68** from a pulp washer will supply the thickening apparatus **60** typically with pulp at 10 to 15 percent consistency. A chute assembly **70** distributes the thickened wet pulp fibers **18** alternatively into any of the three pressure chambers **12**, **14** and **16**. Actuator controlled baffle boards **72** are used to direct the wet pulp fibers **18** from the discharge end **74** of the thickening apparatus **60** into either pressure chamber **12**, **14** or **16**, whichever is in the filling phase of the operation. **FIG. 15** shows that pressure chamber **14** is being filled.

In some instances there may be advantages to use lower feed consistencies, such as 10 to 25 percent or higher consistencies, such as 30 to 45 percent. When 10 to 15 percent feed consistency is desired then the pipeline **66** from the decker and/or **68** from a pulp washer can be used directly to feed the pressure chambers **12**, **14** and **16** bypassing the thickening apparatus **60**.

Depending on what kind of pulp fibers are being processed with the apparatus of the present invention the processed pulp in the high density storage tank **58** will be diluted and pumped out either through line **76** to a rewasher, line **78** to screen room, line **80** to bleach plant, line **82** to refiners, or line **84** to a paper machine.

All carry-over chemicals and already dissolved organic matter in unbleached pulp can be recovered for recycling due to the longitudinal fiber split making the bound liquor inside the fiber lumen available for displacement washing in a rewasher. It follows that all carry-overs to any bleaching stage after the fiber split process will be practically nil after each intermediate washer in the bleach plant.

Screen room rejects and refiner energy consumption will be reduced substantially due to the longitudinal fiber split, and all bound ink particles inside the fiber lumen in recycled paper will be available for removal. Other benefits of the fiber split will be discussed in detail later. There will also be further descriptions of how conventional apparatuses and methods can be modified to utilize these benefits.

(c) Brief Description of the Overall Operation of the Invention

With the foregoing detailed description of the apparatus in mind, there will now be a brief description of the overall operation of the present invention.

The preferred range of the operating pressure in the pressurized flow chamber of the first embodiment is typically 5 to 10 bars. In some instances there may be advantages to use higher pressures, such as 10 to 20 bars. In some instances there may be advantages to use lower pressures, such as 1 to 5 bars. In such a case it is preferable to use the second embodiment of the present invention as described later below.

There are four separate phases in the operation of the present invention.

EMPTYING PHASE

Initially, one of the three pressure chambers **12**, **14** or **16** has been filled with wet pulp fibers **18**, pressurized to operating pressure, and is being gradually emptied into the pressurized flow chamber **24**.

FIG. 2 shows pressure chamber **12** at this phase of operation. Wet fiber filling valve **28**, air bleed valve **30** and depressurizing valve **34** are all closed. Pressurizing valve **32** is open to maintain the operating pressure in pressure chamber **12** the same as the pressure in the pressurized flow chamber **24** by feeding compressed air from the accumulator **20**. Feed valve **50** for feeding and pressurizing the pressurized flow chamber **24** with gas or steam vapor is open together with the blow valve **52** at the end of the venturi tube section **48**. Discharge valve **40** at the lower end **15** of pressure chamber **12** is open and the rationing device **22** is turned on to feed the wet pulp fibers **18** into the gas or steam vapor stream in the pressurized flow chamber **24**. This emptying phase of operation continues until the pressure chamber **12** is emptied of all wet pulp fibers **18**.

FILLING PHASE

While pressure chamber **12** is being emptied, pressure chamber **14** is being filled with wet pulp fibers **18** from the chute assembly **70** under the thickening apparatus **60** as shown in **FIG. 15**. Discharge valve **40** at the lower end **15** of pressure chamber **14** is closed and the rationing device **22** is turned off. At the upper end **13** of pressure chamber **14** the wet fiber filling valve **28** and air

bleed valve **30** are open while depressurizing valve **34** and pressurizing valve **32** are closed to maintain the pressure chamber **14** at atmospheric pressure. The open air bleed valve **30** lets the excess air out of the pressure chamber **14** as the air is being displaced by the volume of the wet pulp fibers **18** entering the pressure chamber **14**. This filling phase of operation continues until the pressure chamber **14** is full with wet pulp fibers **18**.

DEPRESSURIZING PHASE

Once a pressure chamber is emptied it will be depressurized to atmospheric pressure. **FIG. 2** shows pressure chamber **16** in such depressurizing phase. Discharge valve **40** at the lower end **15** of pressure chamber **16** is closed and the rationing device **22** is turned off. At the upper end **13** of pressure chamber **16** the wet fiber filling valve **28**, air bleed valve **30** and the pressurizing valve **32** are closed and the depressurizing valve **34** and the recycle valve **36** at the suction side of the compressor **26** are open to recover all pressurized air energy from the pressure chamber **16** back to the compressed air accumulator **20** with the aid of compressor **26**. The fresh air intake valve **38** is closed during the depressurizing phase. This depressurizing phase of operation continues until the pressure in the pressure chamber **16** is brought down to atmospheric pressure.

At this point the pressure chamber **16** is ready to begin the next filling phase. The depressurizing valve **34** and the recycle valve **36** at the suction side of the compressor **26** are closed and the fresh air intake valve **38** at the suction side of compressor **26** is opened to allow the compressor **26** to continue its compressed air make-up phase into the compressed air accumulator **20**. As described in the filling phase section above, at the upper end **13** of pressure chamber **16** the wet fiber filling valve **28** and air bleed valve **30** are opened. When the previous pressure chamber **14** being filled with wet pulp fibers **18** is full then the baffle boards **72** in the chute assembly **70** are turned into such new positions that the wet pulp fibers **18** are directed from the thickening apparatus **60** into the chute feeding pressure chamber **16**.

PRESSURIZING PHASE

Once the pressure chamber **14** has been filled with wet pulp fibers **18** then its wet fiber filling valve **28** and air bleed valve **30** are closed. Pressurizing valve **32** is opened to raise the pressure in the pressure chamber **14** to the same

operating pressure that is in the pressurized flow chamber **24**. This completes the pressurizing phase and the pressure chamber 14 is now ready for the next emptying phase.

TIMING OF OPERATING PHASES

TABLE 1 shows the timing of all the operating phases in a table format. Initially, pressure chamber **12** is filled with wet pulp fibers **18**. Pressure chamber **14** filling starts when pressure chamber **12** is full, and then pressure chamber **16** filling starts when pressure chamber **14** is full. By the time pressure chamber **16** is full, pressure chamber **12** has already been pressurized, emptied, and depressurized. Therefore, filling of pressure chamber **12** can start again and this filling sequence continues until there is an interruption in the production.

Once the pressure chamber **12** is full with wet pulp fibers **18** it will be pressurized with compressed air from accumulator **20**. Pressurizing does not take as much time as the filling, so emptying the pressure chamber **12** will start while pressure chamber **14** is still being filled. By the time pressure chamber **12** is empty, pressure chamber **14** has already been filled and pressurized, and is ready for emptying. Again, by the time pressure chamber **14** is empty, pressure chamber **16** has been filled and pressurized and is ready for emptying. This emptying sequence continues until there is an interruption in the production.

Once the pressure chamber **12** is empty it will be depressurized by using air compressor **26** to recover the pressure energy in chamber **12** back into the compressed air accumulator **20**. Depressurizing does not take as much time as emptying a pressure chamber from wet pulp fibers **18**, so at the end of depressurizing the air compressor's **26** air intake will be shifted to fresh atmospheric air by opening the fresh air intake valve **38** and closing the recycle valve **36**. The fresh air intake valve **38** is kept open until pressure chamber **14** is ready for depressurizing. Again, by the time pressure chamber **16** is empty, it will be depressurized in the above manner. This depressurizing and fresh compressed air makeup sequence continues until there is an interruption in the production.

DESCRIPTION OF THE SECOND EMBODIMENT

(a) Main Components of the Apparatus

With reference to **FIG. 3**, the apparatus of the second embodiment of the present invention comprises one or more feed chambers for the wet pulp fibers, one or more rotary valves to ration out the pulp fibers from the feed chambers while maintaining a good steam lock condition , a pressurized flow chamber pipe assembly to receive the fibers through the rotary valves, a steam valve to feed and pressurize the pressurized flow chamber pipe assembly, and a venturi tube section and blow valve to discharge the fiber-steam mixture from the pressurized flow chamber pipe assembly. **FIG. 3** shows three feed chambers.

The feed chambers are operated on a continuous basis, and more than one feed chamber are used in cases where more than one pulp grade is processed simultaneously to provide a desired mix of fibers.

(b) General Description of the Apparatus

With reference to **FIG. 3**, the apparatus **10b** of the present invention comprises three elongate atmospheric pressure feed chambers **112**, **114** and **116** being fed with wet pulp fibers **18**, which are rationed out with rotary valves **122** to the pressurized flow chamber **124**. The rotary valves **122** maintain a good steam lock condition between the feed chambers and the pressurized flow chamber. All three feed chambers **112**, **114** and **116** have an upper end **113** and lower end **115**.

There are two nozzle connections at the upper end **113**. Valve **128** controls the inlet stream of wet pulp fibers **18** into the feed chamber. Air bleed nozzle **130** ensures atmospheric pressure condition in the feed chambers at all times during the operation.

The lower end **115** comprises a conical section **138** to direct the wet pulp fibers **18** to the flow rationing rotary valve **122,** and a discharge valve **140** to let the wet pulp fibers **18** into the pressurized flow chamber **124**. The amount of steam flow transferred in the pockets of the rotary valve **122** on the return side from the pressurized flow chamber **124** to the feed chamber will be cooled by the wet pulp fibers **18** and condensed to water, or will escape through the upper end **113** air bleed nozzle **130**.

The apparatus **10b** can be considered as having two main operating sections that cooperate with one another to accomplish the major functions of the present invention. First, there are the above described three feed chambers **112**, **114** and **116**, and second, there is the pressurized flow chamber **124**. The pressurized flow chamber **124** has two main sections; a pipe assembly **144** to receive the wet pulp fibers **18** alternatively through three nozzle locations **146** on the top of the pipe assembly **144** and; a venturi tube section **148**. The inlet end **143** of the pipe assembly **144** is connected to a feed valve **150** for feeding and pressurizing the pressurized flow chamber **124** with gas or steam vapors. The discharge end **149** of the venturi tube section **148** is connected to a blow valve **152** to discharge the fiber-steam mixture from the pressurized flow chamber **124** through a blow line **154** into a cyclone **156** on top of a high density storage tank **158**.

The apparatus **10b** is supplied with wet pulp fibers typically at 25 to 30 percent consistency. **FIG. 3** shows a typical thickening apparatus **160** in the form of a screw press. A pipeline **162** from a pulp storage tank or a pipeline **164** from a repulper feed the thickening apparatus **160** typically with 2 to 5 percent pulp slurry. A pipeline **166** from a decker or **168** from a pulp washer will supply the thickening apparatus **160** typically with pulp at 10 to 15 percent consistency. A chute assembly **170** directs the thickened wet pulp fibers **18** from the discharge end **174** of the thickening apparatus **160** into feed chamber **114**. Feed chambers **112** and **116** have their own similar thickening apparatuses which are not shown in **FIG. 3**.

In some instances there may be advantages to use lower feed consistencies, such as 10 to 25 percent or higher consistencies, such as 30 to 45 percent. When 10 to 15 percent feed consistency is desired then the pipeline **166b** from a decker and/or **168b** from a pulp washer can be used to feed directly the feed chambers **112** and/or **116**.

As was already described in connection with the first embodiment of the present invention, depending on what kind of pulp fibers are being processed with the apparatus of the present invention, the processed pulp in the high density storage tank **158** will be diluted and pumped out either through line **176** to a rewasher, line **178** to screen room, line **180** to bleach plant, line **182** to refiners, or line **184** to a paper machine.

All benefits of the fiber spitting operation as described in connection with the first embodiment of the present invention apply also to this second embodiment of the present invention.

(c) Brief Description of the Overall Operation of the Invention

With the foregoing detailed description of the apparatus in mind, there will now be a brief description of the overall operation of the present invention.

The operation of this second embodiment of the present invention is continuous but the fiber splitting takes place in exactly the same manner as was already described in connection with the first embodiment.

The preferred range of the operating pressure in the pressurized flow chamber of the second embodiment is typically 5 to 10 bars. In some instances there may be advantages to use lower pressures, such as 1 to 5 bars. If operating pressures above 10 bars are desirable, then it is preferable to use the first embodiment of the present invention as described above. Its batch operation with the pressure chambers eliminates the high demand on the rotary valves to provide a good steam/air lock condition between the feed chambers of the second embodiment and the pressurized flow chamber.

DESCRIPTION OF THE THIRD EMBODIMENT

(a) Main Components of the Apparatus

With reference to **FIG. 4**, the apparatus of the third embodiment of the present invention is used for fibrous feedstock that is already dry, typically from 35 percent consistency to air dry at 90%, and typically in the form of rolls or bales of cut sheets. It comprises one or more moisturizing feed lines, one or more feed chambers for the wet pulp fibers, one or more rotary valves to ration out the pulp fibers from the feed chambers while maintaining a good steam lock condition , a pressurized flow chamber pipe assembly to receive the fibers through the rotary valves, a steam valve to feed and pressurize the pressurized flow chamber pipe assembly, and a venturi tube section and blow valve to discharge the fiber-steam mixture from the pressurized flow chamber pipe assembly. **FIG. 4** shows three processing lines, two for processing dry pulp or paper webs in roll form and one line for processing cut and baled pulp or paper sheets.

The moisturizing liquid is typically water but other liquids can be used as well. In some applications it can be desirable to penetrate the fibers with liquid bleaching agents before the fiber splitting takes place. This ensures hundred percent mixing of chemicals with the fibers during the passage through the venturi throat. When chemicals are used in the moisturizing process, all or part of the moisturizing line will be enclosed and ventilated to contain volatile vapors.

Another application for using chemicals in the moisturizing line of the present invention is for production of sodium carboxyl methyl cellulose (CMC), hydroxyl ethyl cellulose (HEC), methyl ethyl cellulose (MEC) and cellulose diacetate.

The processing lines are operated on a continuous basis. Only the moisturizing feed lines will be described in more detail below since the rest of the apparatus and method of the third embodiment of the present invention is essentially same as in the second embodiment.

(b) General Description of the Apparatus

With reference to **FIG. 4**, the apparatus **10c** of the third embodiment of the present invention comprises three atmospheric pressure feed chambers **212**, **214** and **216** being fed with wet pulp fibers **18** from moisturizing lines **220**, **240** and **260**. The wet pulp fibers are rationed out with rotary valves **122** to the pressurized flow chamber **124**. The rotary valves **122** maintain a good steam lock condition between the feed chambers and the pressurized flow chamber. Since from this point on the third embodiment remains essentially the same as already described in connection with the second embodiment, its description will not be repeated. All three feed chambers **212**, **214** and **216** have a cyclone **210** on the top for fiber separation from the air stream of the pneumatic conveyor system **218** that is the preferred way of delivering the wet fibers from the moisturizing lines to the feed chambers **212**, **214** and **216**.

The apparatus **10c** is supplied with dry pulp or paper typically at air dry consistency of 90 percent.

Moisturizing line **220** comprises a roll feeder **222**, plurality of rotating slitter blades **224**, a liquid filled dip pan **226**, in which immersion rolls **228** keep the moving fiber web **230** submersed in the moisturizing liquid, a cylinder press **232** for final moisturizing liquid penetration and end moisture control, a shred-

der **234**, a blower **236**, and a pneumatic conveying pipe **238** which transports the shredded wet fibers into cyclone **210** on top of the feed chamber **212**.

Moisturizing line **240** comprises a roll feeder **242**, plurality of rotating slitter blades **244**, a moisturizing liquid collector pan **246**, liquid spray nozzles **248** across the moving fiber web **250**, a cylinder press **252** for final moisturizing liquid penetration and end moisture control, a shredder **254**, a blower **256**, and a pneumatic conveying pipe **258** which transports the shredded wet fibers into cyclone **210** on top of the feed chamber **214**.

Moisturizing line **260** comprises a cut sheet feed table **262**, plurality of rotating slitter blades **264**, a moisturizing liquid collector pan **266**, liquid spray nozzles **268** across the moving fiber sheets **270**, a cylinder press **272** for final moisturizing liquid penetration and end moisture control, a shredder **274**, a blower **276**, and a pneumatic conveying pipe **278** which transports the shredded wet fibers into cyclone **210** on top of the feed chamber **216**.

The overall operation of the third embodiment of the present invention is similar to the overall operation of the second embodiment and therefore its description will not be repeated.

As was described earlier in the section BACKGROUND OF THE INVENTION, Fiber Morphology, there are differences between softwoods and hardwoods. Softwoods are dominated by one fiber type, the tracheid, while hardwoods have fiber tracheids and vessel elements. However, the apparatus and method of the present invention works equally well to split both softwood and hardwood tracheids longitudinally.

(b) Method of Washing

All conventional pulp washing methods displace spent liquor with clean wash liquid only from the space outside and between the pulp fibers, but leave practically all spent liquor, containing the already dissolved organic matter and spent processing chemicals inside the fiber lumen. Only some leaching of the inside bound liquor happens during the dilution/extraction stages between multiple washing steps in series. A substantial amount of spent liquor, typically 1.5–2 times the weight of the pulp fibers is, after the washing, still carried over inside the hollow fiber lumen to the next processing stage. In case of unbleached pulp, all already dissolved organic matter and spent chemicals in the

carry-over liquid end up later in the papermaking process as effluent into the waterways, instead of being recovered through evaporation and recovery boiler for fuel and chemical make-up, as happens to all organic matter and spent chemicals, when they are recovered with the washer discharge filtrate. A large portion of the carry-overs in bleach plant washing also contribute to the environmental pollution as effluent. Some pulp mills recycle wash liquids from downstream washers as wash liquids to be used as wash liquids in the upstream washers for chemical recovery in case of oxygen and peroxide bleaching. However, worldwide the majority of bleaching is done with chlorine dioxide and all filtrates from those washers end up as effluent.

FIG. 5 is a SEM photograph of bleached softwood pulp fibers at magnification 200 and **FIG. 6** shows the center of the same SEM photograph at magnification 1000. As can be seen in **FIG. 6**, the bordered pit holes **310** are clearly visible as tiny round circles e.g. in the top two fibers running in the direction from 10 o'clock to 4 o'clock and from 8 o'clock to 2 o'clock.

Attention is here drawn to the fact that the cross sectional area of the bordered pit holes **310** represents such a miniscule percentage of the total surface area of the pulp fibers, that it is hard to imagine any transfer of wash liquid through these holes into the fiber lumen to displace any dissolved organic matter and processing chemicals inside the lumen during the washing stage, and then at the same time transfer them out through these same passage ways.

FIG. 7 is a SEM photograph of unbleached softwood pulp fibers at magnification 600. The fibers were processed with a pilot scale laboratory apparatus of the present invention using 8 bar pressure steam vapors as the process gas. **FIG. 8** shows the center of the same SEM photograph at magnification 2000. As can be seen in **FIG. 7**, and in more detail in **FIG. 8** the fibers have been split longitudinally and the bordered pit holes **310** are clearly visible from the inside of the fiber lumen.

The same processing method with a pilot scale laboratory apparatus of the present invention was used again with 8 bar pressure compressed air as the process gas. **FIG. 9** is a SEM photograph of such unbleached softwood pulp fibers at magnification 1300 and **FIG. 10** another at magnification 1100.

As can be seen in both of these SEM photographs the bordered pit holes **310** are predominantly lined up in a singly row parallel to the fiber cell longitudinal

axis, and the longitudinal split has happened along the fiber cell wall opposite to the line of the bordered pit holes.

An interesting exception is shown in **FIG. 11** at magnification 700, where there are two parallel lines of bordered pit holes in the same fiber cell. **FIG. 12**, at magnification 700, shows valuable, paper strengthening micro-fibril bridges between individual fiber cells, such as the narrow ones in the upper right hand corner, and a wide bridge connection slightly left and below the center of the photograph.

By examining **FIG. 7–12** one can draw the conclusion that all the bound liquor inside the fiber lumen has become free and washable due to the longitudinal fiber split accomplished with the apparatus and method of the present invention.

SUMMARY OF METHOD OF WASHING

A method to remove dissolved organic matter and chemicals from the interior of hollow fibrous cells consists of means to subject the wet fibers first to a sudden pressure drop by feeding the fibers into an above atmospheric pressure flow chamber, where pressure is maintained with gas or steam vapors at high enough pressure to force the mixture of wet fibers and gas or steam vapors to flow through a substantially reduced cross-sectional area, such as through a venturi throat, in said flow chamber into another chamber at substantially lower pressure, preferably atmospheric, causing said sudden pressure drop between the liquor filled interior of the fibers and the gas or steam vapor surrounding the fibers, to split the fiber cell wall along a longitudinal line, and then use other means, such as conventional washers, to rewash the split fibers to displace the dissolved organic matter and chemicals from the pulp mat with clean liquid
.

(c) Method of Bleaching

Again, reference is made to **FIG. 5** and **FIG. 6**.

Bleaching chemicals can reach the residual lignin in the fiber cell only through the outside surface of the cell wall leaving the inside surface of the lumen unbleached.

As can be seen in **FIG. 6**, the cross sectional area of the bordered pit holes represents such a miniscule percentage of the total surface area of the pulp fiber, that it is hard to imagine any transfer of bleaching chemicals through these holes into the fiber lumen and then at the same time any dissolved organic matter to diffuse out through these same passage ways.

Again, with reference to **FIG. 7–12**, one can draw the conclusion that the longitudinally split fibers will allow the bleaching chemicals to reach the residual lignin in the fiber cells from both sides of the cell wall reducing bleaching time to half. It follows, that required bleaching chemical charge, chemical consumption, process temperature, and pressure will also drop. Bleach plant capacity will increase substantially, and in some cases, the amount of bleaching stages can be reduced.

Since all bleaching stages also include a washing process, where the dissolved organic matter and the spent bleaching chemicals are removed, it follows that with split fibers the carry-over to the next processing stage will be nil.

The following laboratory test results are in support of the earlier statement that "bleaching chemicals can reach the residual lignin in the fiber cell only through the outside surface of the cell wall leaving the inside surface of the lumen unbleached".

Bleached softwood fibers were first processed with a pilot scale laboratory apparatus of the present invention. Then the brightness (ISO%) of both the reference pulp without fiber splitting and the split-fiber-pulp was measured after subjecting them to different levels of refining at 0, 50, 100, 150 and 200 kWh/t.

The brightness % reduction in the reference pulp is only modest (1.9 units at 200 kWh/t) from 89.4 at 0 refining to 88.5, 88.0, 87.7 and 87.5 at 50, 100, 150 and 200 kWh/t of refining energy respectively. The mechanical refining action separates fibrils and fines away mainly from the bleached outside surface of the reference pulp fibers as well as breaks some of the fibers across their cross section, but leaves most of the fiber interiors unexposed.

The brightness % reduction in split-fiber-pulp is markedly larger (6.2 units at 200 kWh/t) from 83.9 at 0 refining to 81.5, 80.1, 78.8 and 77.7 at 50, 100, 150 and 200 kWh/t of refining energy respectively.

In the split-fiber-pulp samples the fibers are split longitudinally and the unbleached interior surfaces of the lumen are exposed (see **FIG. 7–12**). Even without any mechanical refining (0 kWh/t) the brightness of the split-fiber-pulp has already dropped (5.5 units) to 83.9% from 89.4% in reference pulp. When this 5.5 units brightness % drop, due to plain fiber splitting, is added to the additional drop of 6.2 units, due to 200 kWh/t refining energy, the total brightness drop is 11.7 units compared to 1.9 units in the reference pulp.

Fiber splitting and additional refining of course expose more and more of the unbleached interior fiber wall surfaces dropping the brightness accordingly. This pronounced drop in brightness supports the recommendation that the best position for the use of the apparatus and method of the present invention is in the unbleached pulp washing line. Not only will the split fibers release all the bound liquor in the fiber lumen, allowing recovery of practically all cooking chemicals, but also all carry-over to and between the following bleaching stages will be reduced to practically nil, allowing more economical and environmentally friendlier operation of pulp and paper mills.

SUMMARY OF METHOD OF BLEACHING

A method to bleach hollow fibrous cells consists of means to subject the wet fibers first to a sudden pressure drop by feeding the fibers and bleaching chemicals into an above atmospheric pressure flow chamber, where pressure is maintained with gas or steam vapors at high enough pressure to force the mixture of wet fibers, bleaching chemicals, and gas or steam vapors to flow through a substantially reduced cross-sectional area, such as through a venturi throat, in said flow chamber into a bleaching chamber at substantially lower pressure, either atmospheric or pressurized, causing said sudden pressure drop between the liquor filled interior of the fibers and the gas or steam vapor surrounding the fibers, to split the fiber cell wall along a longitudinal line exposing the interior surface of the fibers to direct contact with the bleaching chemicals, and then allowing time for the bleaching chemicals to react with the organic matter, such as lignin, in the fibers under controlled temperature and pressure conditions, until the desired bleaching target has been reached. Thereafter the bleached fibers are discharged from the bleaching chamber and washed by conventional means and delivered to the next processing step. Conventional means are provided to maintain the proper bleaching tempera-

ture and pressure in the bleaching chamber, e.g. with steam or liquor circulation.

(d) Method of Chemical Treatment

Some end products in chemical pulping require additional chemical treatment after the conventional bleaching stages. This method of chemical treatment is similar to the above method of bleaching in the way that the apparatus is practically the same but the feedstock fibers have already been bleached to a desired extent before the chemical treatment begins.

Again, reference is made to **FIG. 5** and **FIG. 6**.

Chemical treatment chemicals can reach the residual lignin and hemicelluloses in the bleached fiber cell only through the outside surface of the cell wall when the bleached fiber cells have been processed with conventional pulping technologies.

As can be seen in **FIG. 6**, the cross sectional area of the bordered pit holes represents such a miniscule percentage of the total surface area of the pulp fiber that it is hard to imagine any transfer of treatment chemicals through these holes into the fiber lumen to react with the lignin and hemicelluloses also from inside out.

Again, with reference to **FIG. 7–12**, one can draw the conclusion that the longitudinally split fibers will allow the treatment chemicals to reach the residual lignin and hemicelluloses in the fiber cells from both sides of the cell wall reducing reaction time to half. It follows, that required treatment chemical charge, chemical consumption, process temperature, and pressure will also drop. Treatment plant capacity will increase substantially, and in some cases, the amount of treatment stages can be reduced.

There is a practical reason why the high purity dissolving pulps have a final cellulose content of 96% in the sulfite process and 98% in the Kraft process, even after several special alkaline purification treatments. Trying to get the last 2% of the hemicelluloses out would drop the final cellulose yield substantially. However, the longitudinally split fibers would allow the remaining 2% of the residual hemicelluloses to be extracted, most likely even at a higher final cellulose yield than in present processes.

SUMMARY OF METHOD OF CHEMICAL TREATMENT

A method to chemically treat bleached hollow fibrous cells consists of means to subject the bleached wet fibers first to a sudden pressure drop by feeding the bleached fibers and treatment chemicals into an above atmospheric pressure flow chamber, where pressure is maintained with gas or steam vapors at high enough pressure to force the mixture of bleached fibers, treatment chemicals, and gas or steam vapors to flow through a substantially reduced cross-sectional area, such as through a venturi throat, in said flow chamber into a reaction chamber at substantially lower pressure, either atmospheric or pressurized, causing said sudden pressure drop between the liquor filled interior of the bleached fibers and the gas or steam vapor surrounding the bleached fibers, to split the fiber cell wall along a longitudinal line exposing the interior surface of the fibers to direct contact with the treatment chemicals, and then allowing time for the treatment chemicals to react with the residual lignin and hemicelluloses in the bleached fibers under controlled temperature and pressure conditions, until the desired chemical treatment target has been reached. Thereafter, the treated end product is discharged from the reaction chamber by conventional means and delivered to the next processing step. Conventional means are provided to maintain the proper temperature and pressure in the reaction chamber.

(e) Method of Refining

As described earlier refining or beating of chemical pulps is the mechanical treatment and modification of fibers so that they can be formed into paper or board of the desired properties. It is one of the most important operations when preparing papermaking fibers for high-quality papers or paperboards.

The main target of refining is to improve the bonding ability of fibers so that they form a strong and smooth paper sheet with good printing properties. Since the final bonding of fibers is a result of drying to form a paper sheet its impact on the paper properties will be described in detail in the next section **(f) Method of Drying** rather than here.

TABLE 2 shows a laboratory report on testing of conventional ECF bleached softwood (pine: Pinus sylvestris) pulp fibers: reference pulp. (ECF stands for elemental chlorine free.)

TABLE 3 shows a laboratory report on testing of the same ECF bleached softwood (pine: Pinus sylvestris) pulp fibers after they were first processed with a pilot scale laboratory apparatus of the present invention to split the fibers longitudinally: modified pulp.

Both reference and modified pulp samples were refined using 50, 125 and 200 kWh/t refining energy and the interpolated test results are shown in table format in **TABLE 2** and **TABLE 3**. There are several clear indicators of substantial morphological changes in the modified split-fiber-pulp.

The fiber splitting is a refining action evidenced by the change in the freeness values. At 0 kWh/t of refining the reference pulp freeness in Schopper-Riegler scale is 14 while the modified pulp SR value is 14.5. Mild refining at 50 kWh/t increases the SR value of both pulps by 3, to 17 in reference pulp and to 17.5 in modified pulp. Thereafter, refining at 125 kWh/t energy level, the reference pulp SR has increased 3.5 to 20.5 but the modified pulp SR has increased 6.5 to 24. Further refining at 200 kWh/t level increases the reference pulp SR by an additional 7 to 27.7 and the modified pulp SR climbs an additional 12.5 to 36.5.

It is a well known factor in the pulping industry that fibers with the same coarseness, but different diameters, will have different collapsing tendencies in refining. Of course the coarseness is the same in both the reference and modified pulp, being of the same wood specie. The principal value to the tendency for a fiber to collapse in refining comes from the relationship of fiber diameter and wall thickness. Both the reference and modified pulp have the same cell wall thickness but the modified pulp fiber periphery is almost double the periphery of the reference pulp, due to the longitudinal split, and represents therefore a double size “diameter”.

TABLE 2 and **TABLE 3** support this finding as well. With the reference pulp, 78 kWh/t of refining energy produced 600 ml CSF while the modified pulp required only 50 kWh/t of refining energy for the same freeness. Further, to reach 500 ml CSF the reference pulp required 150 kWh/t of refining energy while the modified pulp reached that target with 108 kWh/t of refining energy. That means that the reference pulp consumed 56% and 39% more refining energy than the modified pulp to reach 600 and 500 ml CSF respectively.

Reference is now made to the prior art explosion pulping, which also performs a kind of refining action, called defibrillation. The process was described earlier under Pulping in section BACKGROUND OF THE INVENTION. Explosion pulping is an ultra-high-yield pulping process based on short time vapor-phase cooking at temperatures in the range of 180 to 210°C, followed by explosive decompression. This process is very effective as a means of fiber separation with low energy consumption, but the resulting fibers are mostly un-collapsed, rigid, and unsuitable for papermaking. None of the fibers are split open.

SUMMARY OF METHOD OF REFINING

A method to refine hollow fibrous cells consists of means to subject the wet fibers first to a sudden pressure drop by feeding the fibers into an above atmospheric pressure flow chamber, where pressure is maintained with gas or steam vapors at high enough pressure to force the mixture of fibers and gas or steam vapors to flow through a substantially reduced cross-sectional area, such as through a venturi throat, in said flow chamber into a chamber at substantially lower pressure, preferably atmospheric, causing said sudden pressure drop between the liquor filled interior of the fibers and the gas or steam vapor surrounding the fibers, to split the fiber cell wall along a longitudinal line, and then use other means, such as conventional refiners, to further refine the fibers to the final desired freeness.

(f) Method of Drying Pulp, Paper and Paperboard

MULTI-CYLINDER DRYING

No other test values in **TABLE 2** and **TABLE 3** will be analyzed in this connection since laboratory paper sheets do not represent well paper that is dried over steam heated cylinders. Lab sheets are dried without restrictions to the shrinkage. The fibers are most of the time in random directions giving false readings if compared to paper formed with a Fourdrinier section and dried over dryer cylinders. That's why **TABLE 2** and **TABLE 3** do not show separately any machine direction (MD) or cross direction (CD) values. As an example, typically paper MD tensile is 2.5 times CD tensile. As another example, one cannot compare a lab sheet's tear, with fibers in random directions, to tear of a real paper machine paper, where most of the fibers are oriented in the MD and substantially less in the CD.

However, **TABLE 4** brings extra light to the superior characteristics of the split-fiber pulp. **TABLE 4** shows a laboratory report on testing of conventional unbleached softwood pulp fibers. The reference pulp was not processed with a pilot scale laboratory apparatus of the present invention, but the modified pulp was processed to split the fibers longitudinally. Both the reference and modified (split-fiber) pulp were refined at 100 kWh/t energy and then dried to paper with a laboratory cylinder dryer paper machine using a Fourdrinier wire section for the sheet formation.

Two SEM photos, **FIG. 13** and **FIG. 14**, at magnification 250, show the fiber structure of the reference pulp paper and two SEM photos, **FIG. 15** and **FIG. 16**, also at magnification 250, show the fiber structure of the modified pulp paper. The differences in the fiber morphology between the reference and modified pulp papers are obvious and support well the findings in the test results as described earlier in section **(e) Method of Refining** regarding the ECF bleached softwood (pine: Pinus sylvestris) pulp fibers.

The modified pulp is more refined and has substantially more nano-scale fibrils reaching out and bonding with other fibers. The micro-fibril connections are not just between the fibers at the same level in the paper, but they reach even deeper into the paper, bonding with fibers several layers below. That leaves the reference pulp paper clearly more permeable than the modified pulp paper.

Once again reference is made to **FIG. 12**, at magnification 700, which shows valuable, paper strengthening micro-fibril bridges between individual fiber cells even without refining, such as the narrow ones in the upper right hand corner, and a wide bridge connection slightly left and below the center of the photograph. The molecules of the hemicelluloses are primarily responsible for the bonding of fibers together. The bonding takes place during the drying phase, when heat is transferred into the paper during its passage over the steam-heated dryer cylinders.

By comparing the test results in **TABLE 4** one can see that the following paper characteristics are superior in the modified pulp paper:

- tensile (over 10%) and stretch (over 20% in cross machine direction (CD))

- tensile energy absorption (17% in machine direction (MD) and 43% in CD)

- TEA index (19% in MD and 45% in CD)

- tensile stiffnes and index (12-13% in CD)

- modulus of elasticity (14% in MD and 24% in CD)

- burst strength and index (9-10%).

The most improved characteristic in the modified pulp paper is the internal bonding strength increase by 71% in MD and 66% in CD. This becomes obvious when examining **FIG. 15** and **FIG. 16**. The increased internal bonding strength also improves substantially the bonding between the unbleached bottom and bleached top layer of liner board even when the top layer is not formed with the modified pulp. The fibrils on the top surface of the unbleached modified pulp bottom layer will reach several fiber layers deep into the bottom of the bleached top layer bonding the layers together during drying.

Other values in **TABLE 4** are about the same in both the reference and modified pulp paper within the accuracy of the test equipment.

FLASH DRYING

As was described earlier in BACKGROUND OF THE INVENTION under section Pulp processing, in flash drying the entrapped water in the fiber lumen immediately turns to steam (one cc of water becoming 1700 cc of steam) creating an uncontrolled internal explosion due to the 1700-fold expansion of vapors in the interior of the fiber lumen.

This does not happen in the apparatus and method of the present invention. The gas in the above atmospheric pressure flow chamber is not heated and the steam is saturated. The short time the wet unheated pulp fibers are exposed to the gas or steam vapors in the above atmospheric pressure flow chamber, typically less than one second, will not cause any measurable increase in the temperature of the liquid inside the fiber lumen. In the apparatus and method of the present invention the fiber lumen is full of non-compressible liquid, which will immediately lose its pressure, when the fiber cell wall splits open, and the freed liquid remains liquid. No flashing of the liquid takes place.

However, the receiving cyclone chamber after the discharge venturi of the present invention can be on top of a spray dryer system. Drying of the longitudi-

nally split fibers will be very efficient due to the doubling of the contact surface area in the fibers with the hot drying gas, and due to the bound liquor inside the fiber lumen being freed to receive the evaporative heat input from the drying gas directly onto the liquor droplet's exposed outside surface, thus allowing heat transfer to bypass the fiber wall boundary layers.

PRESENT INVENTION'S IMPACT ON PULP, PAPER AND PAPERBOARD DRYING

The economics of transportation defines the manner in which pulp will be prepared for shipment. As described earlier in the Pulp processing section of the FIELD OF THE INVENTION, two basic systems are employed in the production of dry market pulp: the conventional system, and the flash-drying system.

The conventional system of producing dry market pulp parallels conventional papermaking: a thick pulp mat is formed with a Fourdrinier wet end, most remaining free water between the fibers is removed mechanically in the press section, and evaporative drying is employed with either a steam-heated cylinder dryer section or an air-float dryer section.

Flash or spray drying refers to the process whereby the fibrous material is introduced as a spray or an analogous form into a stream of hot gases. The high-temperature heat content of the gas stream causes the bound liquid inside the fiber lumen to flash violently to vapor causing substantial damage to the fiber cell wall.

These misshapen fibers have made flash-dried pulps recognized as being ideally suited to the needs of those mills producing filter papers and latex-saturated paper and board but not for high strength paper or board production.

However, drying of the longitudinally split fibers will not cause any flashing expansion inside the fiber lumen. Drying will be very efficient due to the doubling of the contact surface area in the fibers with the hot drying gas, and due to the bound liquor inside the fiber lumen being freed to receive the evaporative heat input from the drying gas directly onto the liquor droplet's exposed outside surface, thus allowing heat transfer to bypass the fiber wall boundary layers.

In drying a sheet of paper two basic physical processes are involved, heat transfer and mass transfer. Heat is transferred from some source such as

steam to the wet sheet in order to provide the energy required to drive the moisture from the sheet. The moisture evaporates and is then transferred from the sheet to the surrounding atmosphere by the mass transfer process.

Multi-cylinder drying is the most common way in the paper and paperboard industry.

Reference is made to **FIG. 17** which shows schematically a paper drying machine **420** typical in the prior art, which is divided typically to several sections of varying steam pressures. For example, first 6 cylinders are shown as the wet end section **422** and operated e.g. at 4 bar steam pressure. The last 17 cylinders are shown as the dry end section **428** and operated e.g. at 10 bar steam pressure. The condensate from the dryer cylinders of this end section **428** is flashed to steam at e.g. 8 bar pressure in the flash tank **427** and used to heat the previous 10 cylinders which form the dryer section **426**. Again, the condensate from the dryer cylinders of this section **426** is flashed to steam at e.g. 6 bar pressure in the flash tank **425** and used to heat the previous 6 cylinders which form the dryer section **424**. Finally the condensate from the dryer cylinders of this section **424** is flashed to steam at 4 bar pressure in the flash tank **423** and used to supply heat to the wet end dryer section **424**.

The reason for this cascading use of higher steam pressure at the dry end and lower steam pressure at the wet end is the fact that it is easier to provide the heat transfer from the dryer surface to the paper web when there is still free water between the paper web fibers in direct contact with the typically cast iron surface of the dryer cylinders. Once the free water has been evaporated, it takes a higher temperature differential between the dryer cylinder surface and the paper surface to get the heat transferred through the fiber cell wall into the bound liquid inside the fiber lumen, and a higher temperature differential between the paper surface and the surrounding air to get the moisture mass transfer into balance with the heat input.

The further the paper dries, the more effective the already dried outer fiber layers in the paper become as an insulating layer to resist the heat transfer to the interior of the paper web. The dry outer fiber layers also slow down the moisture mass transfer out from the interior fiber cells that are still full of bound liquid. There are hundreds of layers of individual fibers to form the desired paper weight per square meter of paper surface.

Reference is made to **FIG. 18**, which shows schematically at the top the cross section of a sheet of paper **430a** representing wet paper according to the prior art, where there is still plenty of free water left between the Individual fibers **431** in random directions and multiple layers. The middle sheet of paper **430b** represents the cross section of paper where most of free water between the Individual fibers **432** has been removed by evaporation.

As can be seen from diagrams **430a** and **430b** there is free water all the time at the outside boundary layer of the paper sheets. The space between the individual fibers **431** and **432** allows free passage of the free water to fill the space left by evaporation as long as there is water to move freely. The bottom sheet of paper **430c** represents the paper cross section where all free water has been removed and only the bound water remains inside the lumen of the fibers **433**. As paper dries its logical that its thickness is being reduced accordingly.

Reference is now made to **FIG. 19**, which shows schematically at the top the same cross section of a sheet of paper **430c** representing the paper cross section where all free water has been removed but all bound water still remains. Next cross section of a sheet of paper **430d** represents paper where some of the bound water inside the top and bottom layers of the individual fibers **434** and **435** has started to dry and shrink the fibers in cross direction. Next sheet of paper **430e** represents the cross section of paper where most of the free water between the individual fibers **436** and **437** has been removed by evaporation. The bottom sheet of paper **430f** represents the paper cross section where almost all bound water has been removed and the sheet of paper is dry.

As the drying progresses from outside surfaces inward it becomes evident that the dried outer layers will start to slow down the heat transfer rate to the wet interior of the sheet. Each dried and collapsed fiber forms a double wall layer of insulation between the dryer and paper surfaces.

However, as can be seen in **FIG. 20**, where the bottom sheet of paper **430g**, which represents the cross section of paper made with split fibers according to the present invention, is compared to the top sheet of paper **430a** of **FIG. 18**, it is clear that all water in the paper sheet **430g** is free to flow toward the outside surface in contact with the dryer cylinder until the paper sheet is dry. Therefore, there is no need to increase the steam pressure in the dryer cylinders to-

ward the dry end. All cylinders can be heated with the lower steam pressure, e.g. 4 bars, which will dramatically reduce the paper machine energy consumption, increase its drying capacity, and reduce the amount of cylinders required for any particular capacity. Dryer cylinders can also be built with reduced wall thicknesses due to lower operating pressure rating.

It is also evident from the **FIG. 20** that it takes almost double amount of individual split fiber layers to form a paper sheet of the same basis weight as paper formed with flat double-walled un-split fibers. This means also that the bonding surface areas between individual fibers will practically double thus increasing the paper bonding and other strength characteristics.

It is to be recognized that the above possible apparatuses, methods and modifications are given by way of example, and yet other possible apparatuses, methods and modifications could be made without departing from the basic teachings of the present invention.

Time →																		
Chamber 12	Filling		Press.	Emptying		Depr.	Filling		Press.	Emptying		Depr.						
Chamber 14		Filling		Press.	Emptying		Depr.	Filling		Press.	Emptying		Depr.					
Chamber 16			Filling		Press.	Emptying		Depr.	Filling		Press.	Emptying		Depr.				
Accumulator 20 pressurizing air source	With fresh air			From chamb. 12	With fresh air	From chamb. 14	With fresh air	From chamb. 16	With fresh air	From chamb. 12	With fresh air	From chamb. 14	With fresh air	From chamb. 16				

TABLE 1

Z-strength kPa	Hp-kone index Index	Hp-kone index Index	Fiber length index Index	Zero-Span wet dry Ratio	Zero-Span wet Ratio	Sheet density index kOsm³/g	Sheet Bulk cm³/g	Tear index mNm²/g	Elastic mod. GPa	Tear index mNm²/g	ISO index %/g	Porosity ml/min	Tens. index Nm/g	Stretch %	ISO index %/g	T.SEA index kNm/kg	Elastic mod. GPa	Tear index mNm²/g	SEC kWh/t
531								4,22	3,64	21,8	1,51	1,53	41,2	4,9	1,51	4,22	3,64	21,8	0
256								6,11	4,26	16,4	1,58	1,73	49,3	4,2	1,58	6,11	4,26	16,4	20
910								7,26	6,35	12,6	2,44	1,97	57,2	4,2	2,44	7,26	6,35	12,6	128
1019								7,92	6,10	11,3	2,76	2,02	58,7	4,3	2,76	7,92	6,10	11,3	282
764								6,2	4,85	16,3	2,0	1,74	78	4,2	2,0	6,2	4,85	16,3	67
842								7,8	5,57	12,4	2,5	1,91	90	4,2	2,5	7,8	5,57	12,4	148
938								6,5	4,69	15,1	2,3	1,78	75,3	4,2	2,3	6,5	4,69	15,1	78
945								7,4	5,09	12,4	2,5	1,92	90,2	4,3	2,5	7,4	5,09	12,4	150
997								7,1	5,26	13,4	2,4	1,85	84,5	4,2	2,4	7,1	5,26	13,4	114
960								7,6	5,83	11,9	2,6	1,97	93,3	4,3	2,6	7,6	5,83	11,9	175
992								6,9	4,89	14,1	2,3	1,82	80,9	4,2	2,3	6,9	4,89	14,1	100
946								7,4	5,58	12,4	2,5	1,92	90,3	4,2	2,5	7,4	5,58	12,4	150
1018								7,6	6,08	11,8	2,7	2,02	96,5	4,3	2,7	7,6	6,08	11,8	200

Grammage g/m²			Sheet MIT g/m²	Sh-length mm	CIELAB			L-abs coeff. m²/kg	Light scatt. m²/kg	Kappa mm	Air perm Gurley µm/Pa	Air res Gurley s	Bulk dm³/kg	Den-sity kg/m³	SEC kWh/t
62,8				3807				0,05	28,6		69	2,3	1,88	625	6
66,1				1118				0,05	28,5		26	6,6	1,43	697	89
65,3				1128				0,04	28,2		14	9,5	1,35	739	125
65,9				1090				0,04	27,7		10	10	1,28	780	282
66,0				1119				0,05	23,2		28,3	6,6	1,48	701	67
66,4				1117				0,04	19,5		7,2	33,5	1,63	781	148
66,8				1128				0,05	22,3		21,2	8,2	1,48	712	78
66,6				1116				0,04	19,4		7,0	35,1	1,33	752	150
65,4				1127				0,04	20,7		13,1	12,7	1,37	703	114
65,7				1103				0,04	18,8		4,8	56,4	1,31	765	175
66,5				1125				0,04	21,3		15,7	10,9	1,38	725	100
65,6				1116				0,04	19,4		7,0	35,4	1,33	762	150
65,9				1091				0,04	17,8		1,9	78,2	1,28	779	200

TABLE 2

	Z-sample pcs	Aperture index mm	Fat ash index g/kg	Developed at 30 °C min	Developed at 30 °C dry	Bark area ratio dm²/kg	Bark thickness mm	Density index kg/m³	Elastic modulus GPa	Tensile index MPa	Tensile strain %	Breaking length km	Bulk density kg/m³	SEC kWh/t
1	500							21,9	2,84	4,42	1,59	43,5	670	14,5
2	503							15,0	4,41	6,07	2,08	55,6	630	17,5
3	504							11,7	5,44	7,02	2,50	58,9	475	24,8
4	505							9,66	6,83	8,30	2,68	57,8	465	36,5
5	525							14,5	4,43	6,2	2,1	70	537	17,5
6	502							11,3	5,83	7,4	2,6	66	436	26,6
7	501							16,0	4,41	6,2	2,1	65,9	600	17,5
8	506							12,5	5,28	6,8	2,5	65,8	500	22,5
9	507							10,6	5,67	7,6	2,6	62,2	400	29,1
10	10							13,7	4,80	6,5	2,3	78,7	520	18,5
11	11							11,5	5,84	7,2	2,6	66,8	462	25,5
12	16							10,7	6,68	7,7	2,7	62,7	385	36,1
13	508							12,6	5,30	6,9	2,4	61,9	513	21,8
14	509							11,0	5,85	7,5	2,6	61,2	435	28,1
15	510							9,7	6,66	8,3	2,7	57,7	382	36,3

	Density kg/m³	Bulk density kg/m³	Air flow Gurley s	Air flow Gurley ml/min	Klemm mm	Light scat. m²/kg	Light coef. m²/kg	Opacity %	Bright ness %	CIELAB L*	CIELAB a*	CIELAB b*	Sp. surface mm²/g	Surface roughness µm		Caliper mm/100
1	643	1,36	2,7	30		27,4	0,18	71,4	83,9				342			65,4
2	715	1,48	6,7	20		21,8	0,20	66,5	81,8				1044			64,9
3	784	1,31	36	3,6		18,6	0,20	62,5	79,4				1032			64,6
4	807	1,28	680	0,26		16,6	0,22	56,6	77,6				944			65,0
5	715	1,48	7,4	15,6		21,8	0,20	66,4	81,5				1034			64,9
6	773	1,39	136,3	3,8		17,8	0,22	62,0	79,8				1014			64,7
7	713	1,48	6,7	20,0		21,6	0,20	66,0	81,6				1044			64,9
8	768	1,33	31,6	7,3		18,2	0,22	63,6	79,6				1038			64,7
9	785	1,28	260,3	2,1		17,6	0,20	61,3	78,6				966			64,6
10	730	1,37	19,1	12,7		20,5	0,23	65,0	80,7				1060			64,9
11	768	1,30	75,8	6,2		18,2	0,22	62,8	79,3				1026			64,8
12	785	1,27	274,7	1,9		17,3	0,22	61,1	78,6				980			64,8
13	747	1,34	26,2	9,8		19,6	0,21	63,9	80,1				1036			64,7
14	778	1,29	208,5	2,4		17,8	0,22	61,8	78,8				1003			64,7
15	807	1,24	521,6	0,3		16,1	0,22	56,5	77,7				946			65,0

TABLE 3

Sample	Side and direction	Number of tests	Reference pulp	Modified pulp
Grammage, g/m² *)			59.5	58.9
Bulking thickness, µm *)		5	84.8	76.8
Standard deviation, µm			2.9	0.9
Apparent bulk density, kg/m³ *)		5	702	767
Standard deviation, kg/m³			17	8
Bulk, cm³/g *)			1.43	1.30
Standard deviation, cm³/g			0.03	0.02
Tensile strength, kN/m *)	MD	10	5.09	5.85
Standard deviation, kN/m			0.18	0.32
Tensile strength, kN/m *)	CD	10	2.29	2.51
Standard deviation, kN/m			0.10	0.12
Tensile index, Nm/g *)	MD	10	85.7	99.2
Standard deviation, Nm/g			3.1	5.4
Tensile index, Nm/g *)	CD	10	37.8	41.6
Standard deviation, Nm/g			1.7	2.0
Stretch, % *)	MD	10	1.7	1.9
Standard deviation, %			0.1	0.2
Stretch, % *)	CD	10	2.5	3.1
Standard deviation, %			0.3	0.3
Tensile energy absorption, J/m² *)	MD	10	64.2	75.6
Standard deviation, J/m²			6.5	10.3
Tensile energy absorption, J/m² *)	CD	10	41.1	50.0
Standard deviation, J/m²			3.7	7.7
TEA index, J/g *)	MD	10	1.08	1.28
Standard deviation, J/g			0.11	0.17
TEA index, J/g *)	CD	10	0.691	1.00
Standard deviation, J/g			0.086	0.13
Tensile stiffness, kN/m *)	MD	10	659	678
Standard deviation, kN/m			13	18
Tensile stiffness, kN/m *)	CD	10	277	311
Standard deviation, kN/m			12	13
Tensile stiffness index, kNm/g *)	MD	10	11.1	11.5
Standard deviation, kNm/g			0.3	0.3
Tensile stiffness index, kNm/g *)	CD	10	4.66	5.30
Standard deviation, kNm/g			0.20	0.20
Modulus of elasticity, N/mm²(of bulking thickn.) *)	MD	10	7773	8832
Standard deviation, N/mm²			177	228
Modulus of elasticity, N/mm²(of bulking thickn.) *)	CD	10	3369	4049
Standard deviation, N/mm²			139	157
Bursting strength, kPa		20	345	388
Standard deviation, kPa			39	19
Burst index, kPam²/g		20	4.12	4.94
Standard deviation, kPam²/g			0.49	0.33
Tearing strength, mN *)	MD	10	462	397
Standard deviation, mN			13	23
Tearing strength, mN *)	CD	10	624	466
Standard deviation, mN			38	15
Tear index, mNm²/g *)	MD	10	7.77	6.08
Standard deviation, mNm²/g			0.25	0.43
Tear index, mNm²/g *)	CD	10	10.5	7.91
Standard deviation, mNm²/g			0.8	0.25
Internal bonding strength, modifScott, J/m²	MD	10	335	572
Standard deviation, J/m²			25	28
Internal bonding strength, modifScott, J/m²	CD	10	330	540
Standard deviation, J/m²			17	35
Ring crush resistance (RCT), kN/m	MD	10	0.257	0.229
Standard deviation, kN/m			0.021	0.023
Ring crush resistance (RCT), kN/m	CD	10	0.305	0.268

TABLE 4

Claims

1. A method of splitting hollow cellulosic fibers, comprising the steps of:

   - wetting the fibers;

   - feeding the wet fibers to a gaseous flow;

   - conducting the gaseous flow carrying the fibers through a venturi tube;

   - the pressure drop in the venturi tube throat bringing a pressure difference between liquid inside the fibers and gas outside of the fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers.

2. A method according to claim 1, wherein the wet fibers are fed to an above atmospheric pressure gaseous flow.

3. A method according to claim 1 or 2, wherein the fibers are brought into a liquid suspension of 5 to 50 % consistency and fed to said gaseous flow under pressure.

4. A method according to claim 3, wherein (i) the fibers are brought into a liquid suspension, (ii) the suspension is compressed by means of compressed air or steam, (iii) the suspension is dewatered to a consistency range of 5 to 50%, preferably of 15 to 30%, and (iv) the wet fibers are fed to said gaseous flow under pressure.

5. A method according to claim 3, wherein the fibers in a liquid suspension are dewatered to a consistency range of 5 to 50%, preferably of 15 to 30%, fed alternatively to a plurality of atmospheric pressure tanks, which are pressurized alternatively to above atmospheric pressure with compressed air, and the wet fibers are fed to the said gaseous flow as a batch process, where one tank is being filled with wet fibers while another is being pressurized or depressurized and yet another tank is being emptied of wet fibers into the said gaseous flow.

6. A method according to any one of the preceding claims, wherein said gaseous flow is air or steam.

7. A method according to any one of the preceding claims, wherein the gaseous flow together with the wet fibers is discharged through the venturi tube to an atmospheric pressure.

8. A method according to any one of the preceding claims, wherein the pressure inside the fibers before entering the throat of the venturi tube is in the range of 1 to 20 bar, preferably of 5 to 10 bar.

9. A method according to any one of the preceding claims, wherein the fibers are pressurized in a liquid suspension to a pressure in the range of 1 to 20 bar, preferably of 5 to 10 bar.

10. A method according to any one of the preceding claims, wherein the gaseous flow at the throat of the venturi tube is constricted to a cross-sectional area of 2 to 40%, preferably of 5 to 10%, of the flow cross-section upstream of the venturi tube.

11. A method according to any one of the preceding claims, wherein the fibers are selected from the group consisting of unbleached or bleached chemical pulp, unbleached or bleached CTMP or TMP, and recycled fibrous material.

12. An apparatus for the splitting of hollow cellulosic fibers, comprising

- a flow channel for conducting a gaseous flow, said flow channel issuing in a venturi tube;
- a container for fibers in a wetted condition;
- means for pressurizing said container; and
- supply means for feeding the wet fibers from said container to said flow channel upstream of the venturi tube.

13. An apparatus according to claim 12, comprising

- a container defining a pressure chamber for fibers in a wetted condition;
- means for the supply of the wet fibers to said container;
- means for pressurizing said container;

- a flow channel for conducting a gaseous flow;

- supply means for feeding the wet fibers from said container to the gas eous flow in said flow channel;

- a venturi tube downstream of said flow channel, bringing a pressure drop and a pressure difference between liquid inside and gas outside of the hollow fibers carried by the gaseous flow, and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers; and

- a receiving tank downstream of the venturi tube, for collecting the longitudinally split fibers.

14. An apparatus according to claim 12 or 13, wherein the throat of the venturi tube has a cross-sectional area of 2 to 40%, preferably of 5 to 10% of the cross-sectional area of the flow channel upstream of the venturi tube.

15. A method of washing fibrous pulp, comprising the steps of:

- feeding wet cellulosic fibers of the pulp to an above atmospheric pressure gaseous flow;

- conducting the gaseous flow carrying the fibers through a venturi tube;

- the pressure drop in the venturi tube bringing a pressure difference between liquid inside and gas outside of the hollow cellulosic fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers; and

- subjecting the longitudinally split fibers to treatment with washing liquors.

16. A method according to claim 15, wherein the fibrous pulp is unbleached chemical pulp from a cooking process or unbleached CTMP or TMP.

17. A method according to claim 15, wherein the fibrous pulp is bleached chemical pulp, bleached CTMP or TMP, or bleached recycled pulp.

18. A method for the bleaching of fibrous pulp, comprising the steps of:

- feeding wet cellulosic fibers to an above atmospheric pressure gaseous flow;

- conducting the gaseous flow carrying the fibers through a venturi tube;

- the pressure drop in the venturi tube bringing a pressure difference between liquid inside and gas outside of the hollow cellulosic fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers; and

- subjecting the longitudinally split fibers to treatment with bleaching chemicals.

19. A method for the bleaching of fibrous pulp, comprising the steps of:

- feeding wet cellulosic fibers and at least one bleaching chemical to an above atmospheric pressure gaseous flow;

- conducting the gaseous flow carrying the fibers through a venturi tube;

- the pressure drop in the venturi tube bringing a pressure difference between liquid inside and gas outside of the hollow cellulosic fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers; and

- allowing the at least one bleaching chemical to react with the longitudinally split fibers.

20. A method according to claim 18 or 19, wherein unbleached cellulosic pulp from a cooking process, unbleached CTMP or TMP, or unbleached recycled pulp is washed and the fibers of the pulp in a wetted condition are fed to said above atmospheric pressure gaseous flow.

21. A method according to claim 20, wherein the washed pulp is dewatered to a consistency range of 5 to 50%, preferably of 15 to 30%, and fed to said above atmospheric pressure gaseous flow under pressure.

22. A method for the chemical treatment of a fibrous pulp, comprising the steps of:

- feeding wet cellulosic fibers and at least one reactive chemical to an above atmospheric pressure gaseous flow;
- conducting the gaseous flow carrying the fibers through a venturi tube;
- the pressure drop in the venturi tube bringing a pressure difference between liquid inside and gas outside of the hollow cellulosic fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers; and
- allowing the at least one chemical to react with the longitudinally split fibers.

23. A method for the pretreatment of fibrous pulp for a papermaking process, comprising the steps of:

- wetting the hollow cellulosic fibers of the pulp;
- feeding the wet fibers to an above atmospheric pressure gaseous flow;
- conducting the gaseous flow carrying the fibers through a venturi tube;
- the pressure drop in the venturi tube bringing a pressure difference between liquid inside and gas outside of the fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers; and
- bringing the longitudinally split fibers to a furnish for supply to the wet end forming fabric of a papermaking machine.

24. A method according to claim 23, wherein dry pulp is brought into an aqueous suspension, the suspension is dewatered to a consistency range of 5 to 50%, preferably of 15 to 30%, and the wet fibers are fed to said gaseous flow under pressure.

25. A method according to claim 20 or 21, wherein the fibrous pulp is unbleached or bleached chemical pulp, or unbleached or bleached CTMP or TMP.

26. A method according to claim 20 or 21, wherein the fibrous pulp comprises recycled cellulosic fibers.

27. A method for the deinking of recycled paper, comprising the steps of:

- repulping the paper to obtain cellulosic fibers in a wet condition;
- feeding the wet fibers to an above atmospheric pressure gaseous flow;
- conducting the gaseous flow carrying the fibers through a venturi tube;
- the pressure drop in the venturi tube bringing a pressure difference between liquid inside and gas outside of the fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers; and
- subjecting the longitudinally split fibers to treatment to remove the ink particles.

28. A method for the pretreatment of recycled paper for papermaking, comprising the steps of:

- repulping the paper to obtain cellulosic fibers in a wet condition;
- feeding the wet fibers to an above atmospheric pressure gaseous flow;
- conducting the gaseous flow carrying the fibers through a venturi tube;
- the pressure drop in the venturi tube bringing a pressure difference between liquid inside and gas outside of the fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers; and
- subjecting the longitudinally split fibers to cleaning by removal of glue and/or organic or inorganic filler materials freed from the inside of the fiber lumen.

29. A method for the preparation of dried paper, comprising the steps of:

- wetting hollow cellulosic fibers;

- feeding the wet fibers to an above atmospheric pressure gaseous flow;
- conducting the gaseous flow carrying the fibers through a venturi tube;
- the pressure drop in the venturi tube bringing a pressure difference between liquid inside and gas outside of the fibers and causing the fibers to split in their longitudinal direction, to open the lumen inside the fibers;
- bringing the longitudinally split fibers to a furnish;
- supplying the furnish to the wet end forming fabric of a papermaking machine;
- forming a fibrous web on said forming fabric;
- pressing the fibrous web for removal of water in the pressing section of said papermaking machine; and
- drying the fibrous web on a sequence of steam heated drying cylinders in the drying section of said papermaking machine.

30. A method according to claim 29, wherein a contact between liquid and the drying cylinder surface is maintained substantially at each one of the cylinders in said sequence.

31. A method according to claim 29 or 30, wherein the cylinders at the opposite ends of said sequence have vapor pressures in a relation of at most 2 to 1, preferably at most 1.5 to 1, to each other.

32. A method according to claim 31, wherein a substantially equal vapor pressure is maintained within each cylinder of said sequence.

33. A method according to claim 31 or 32, wherein the vapor pressure within each cylinder of said sequence is at most 5 bar, preferably within the range of 3 to 4 bar.

34. A method according to any one of claims 29–33, wherein the temperature of the steam inside each cylinder of said sequence is at most 150℃, preferably within the range of 135 to 145℃.

35. A paper product comprising at least one fibrous layer, in which at most 50% of the fibers have a hollow cylindrical configuration, the rest of the fibers being split in their longitudinal direction.

36. A paper product according to claim 35, wherein at most 10% of the fibers in said fibrous layer have a hollow cylindrical configuration, the rest of the fibers being split in their longitudinal direction.

37. A paper product according to claim 36, in which substantially all of the fibers in said fibrous layer are split in their longitudinal direction.

38. A multilayer paper product according to any one of claims 35–37, in which at least one fibrous layer, preferably each fibrous layer, has at least 50%, preferably at least 90% of the fibers split in their longitudinal direction.

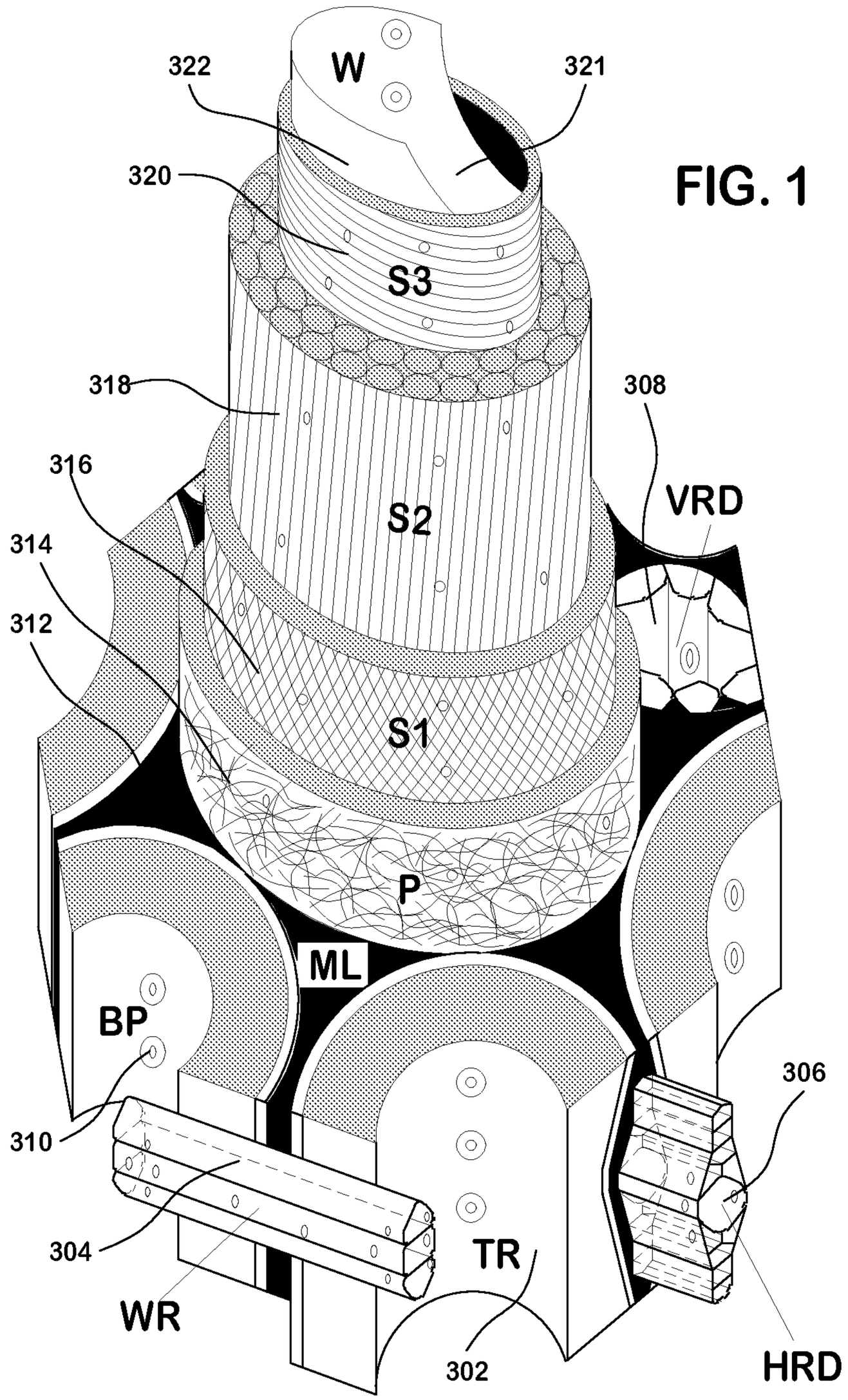

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FIG. 1

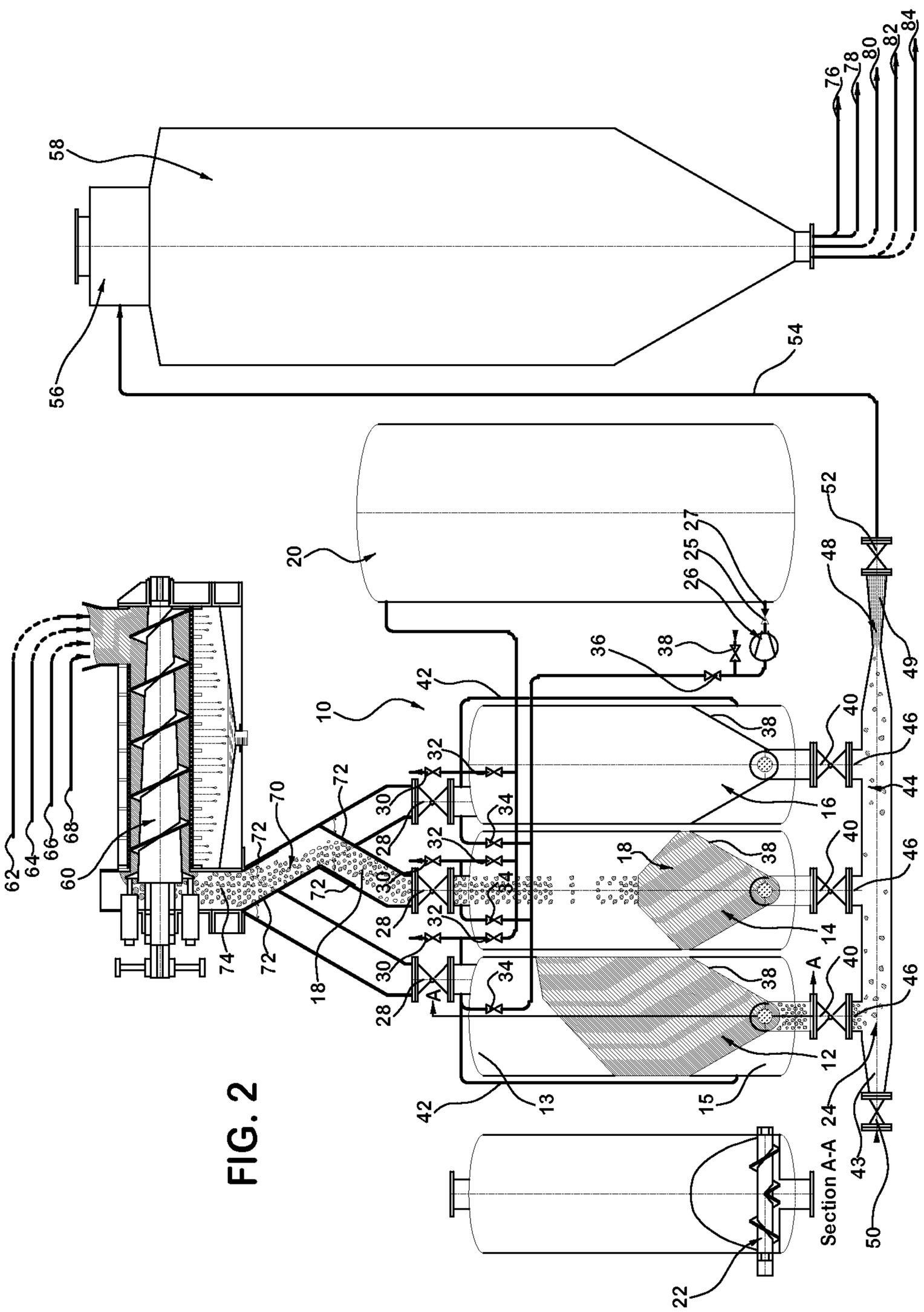

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Section A-A

FIG. 2

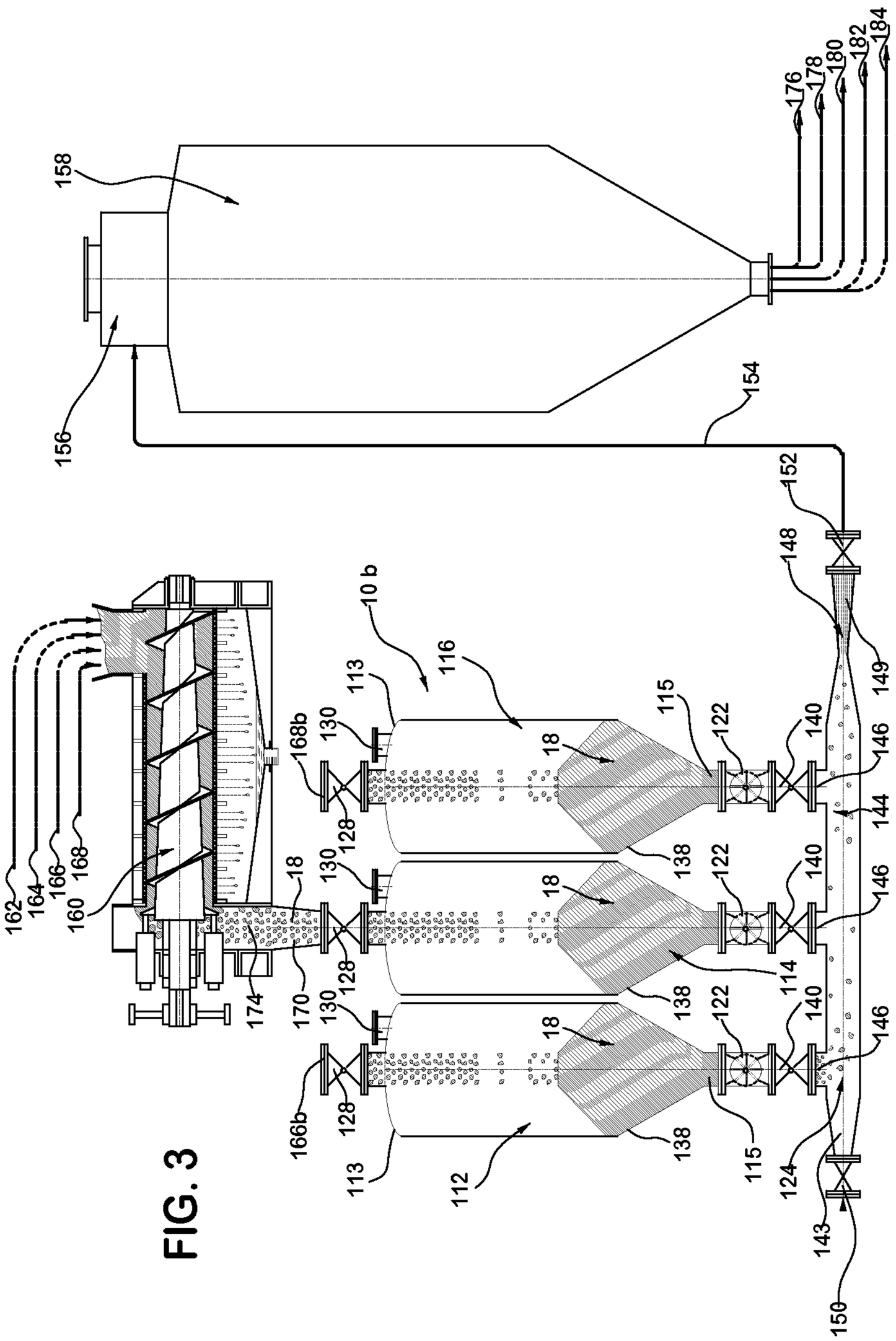

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FIG. 3

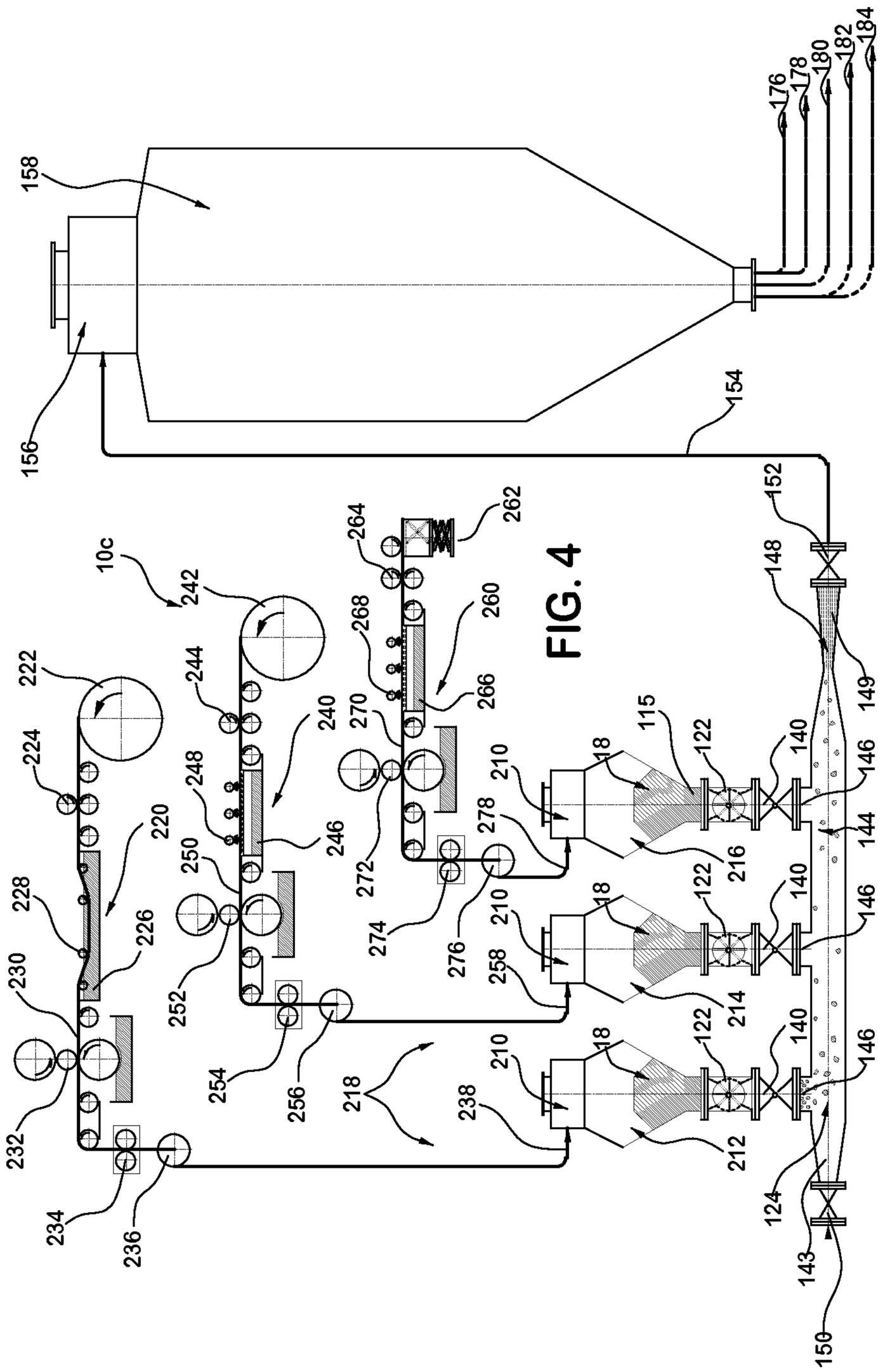

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FIG. 4

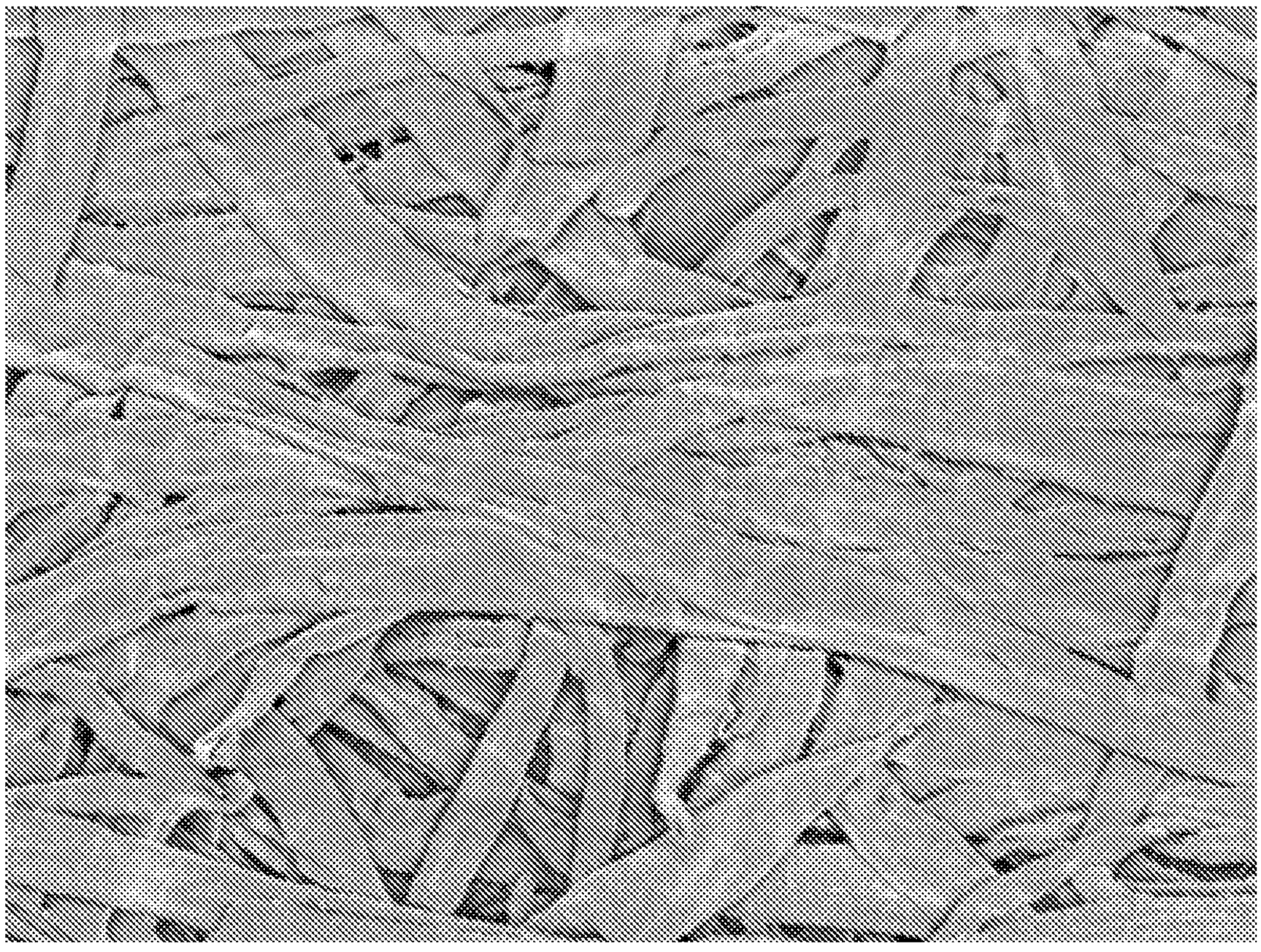


FIG. 5

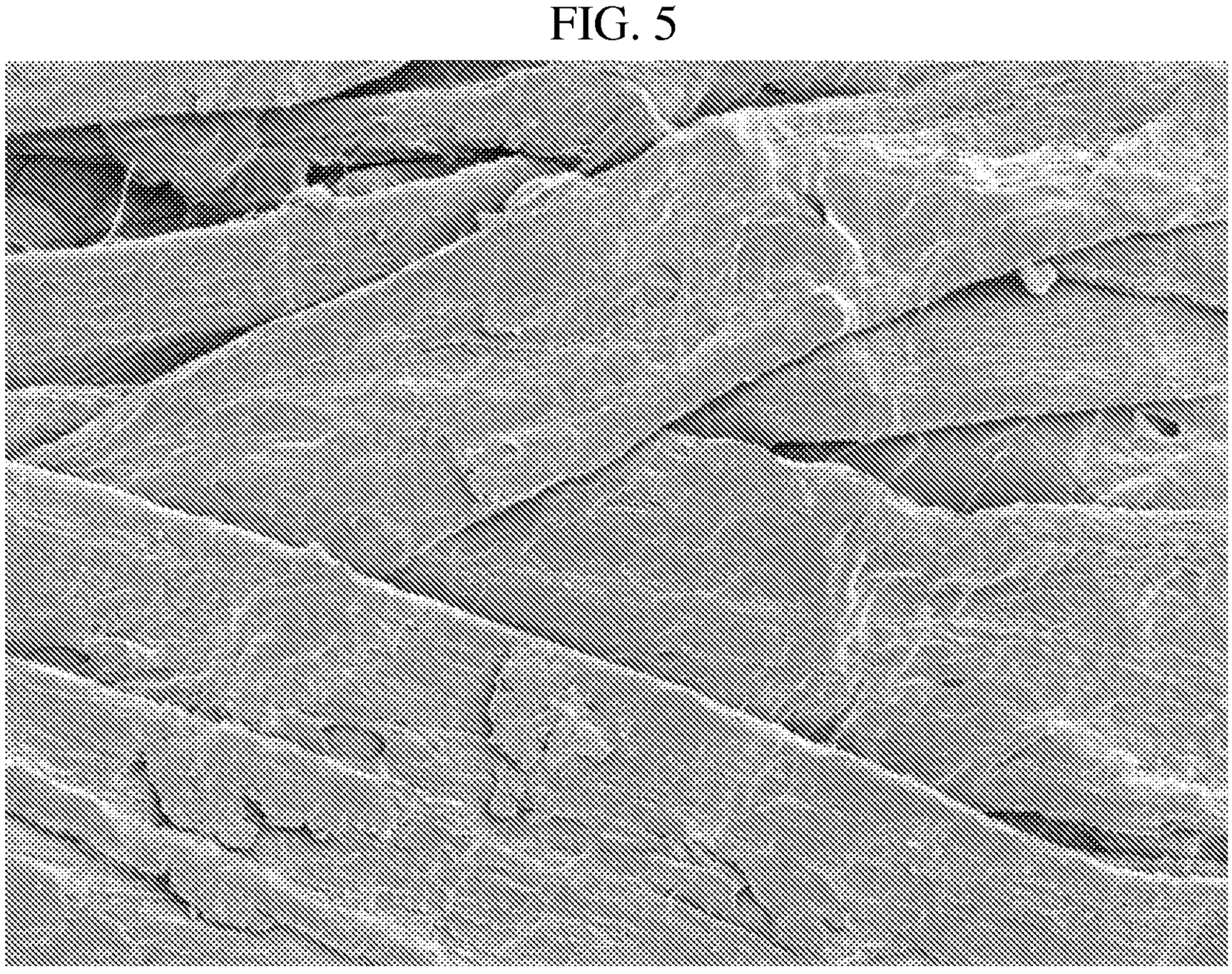


FIG. 6

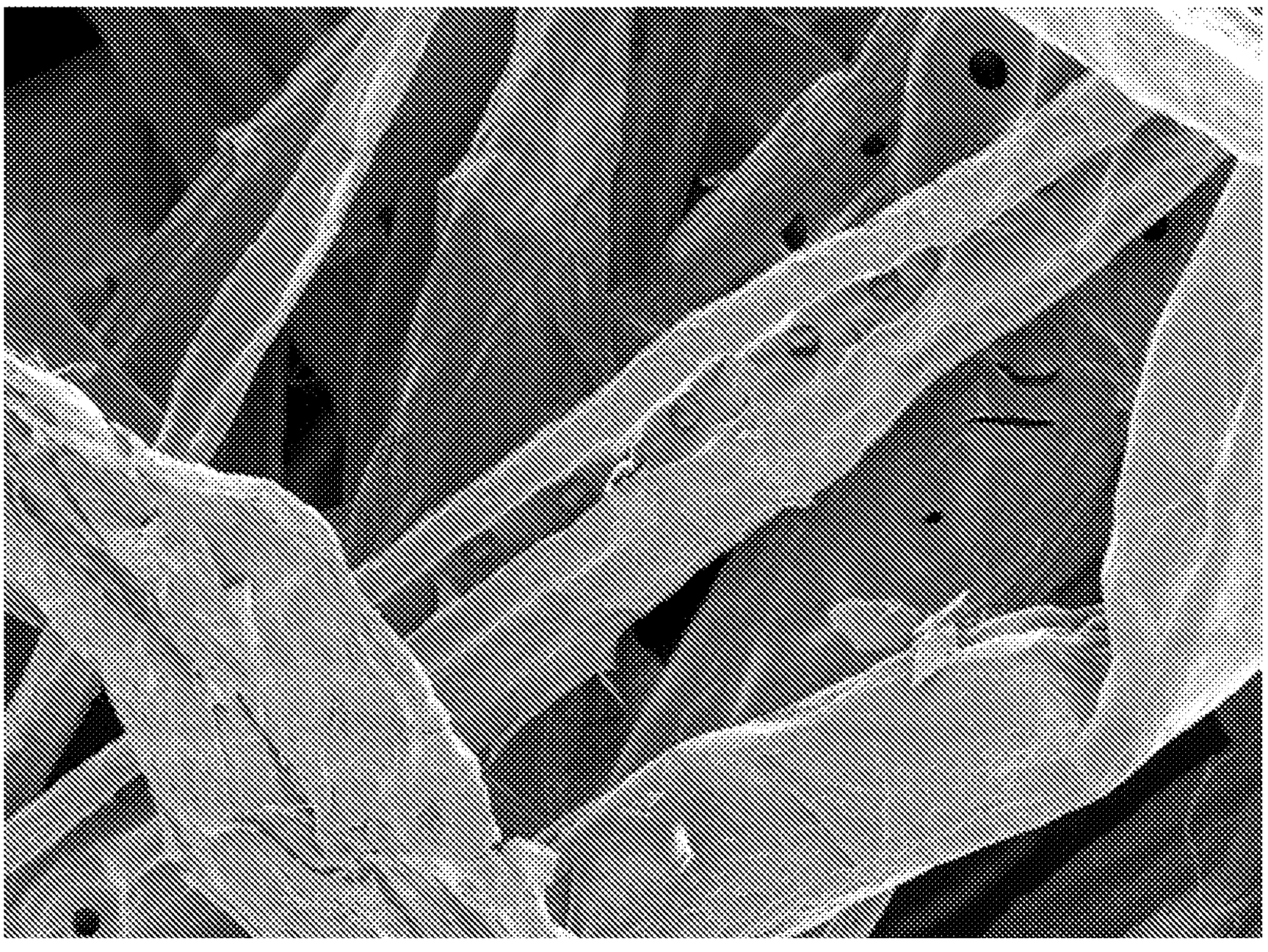


FIG. 7

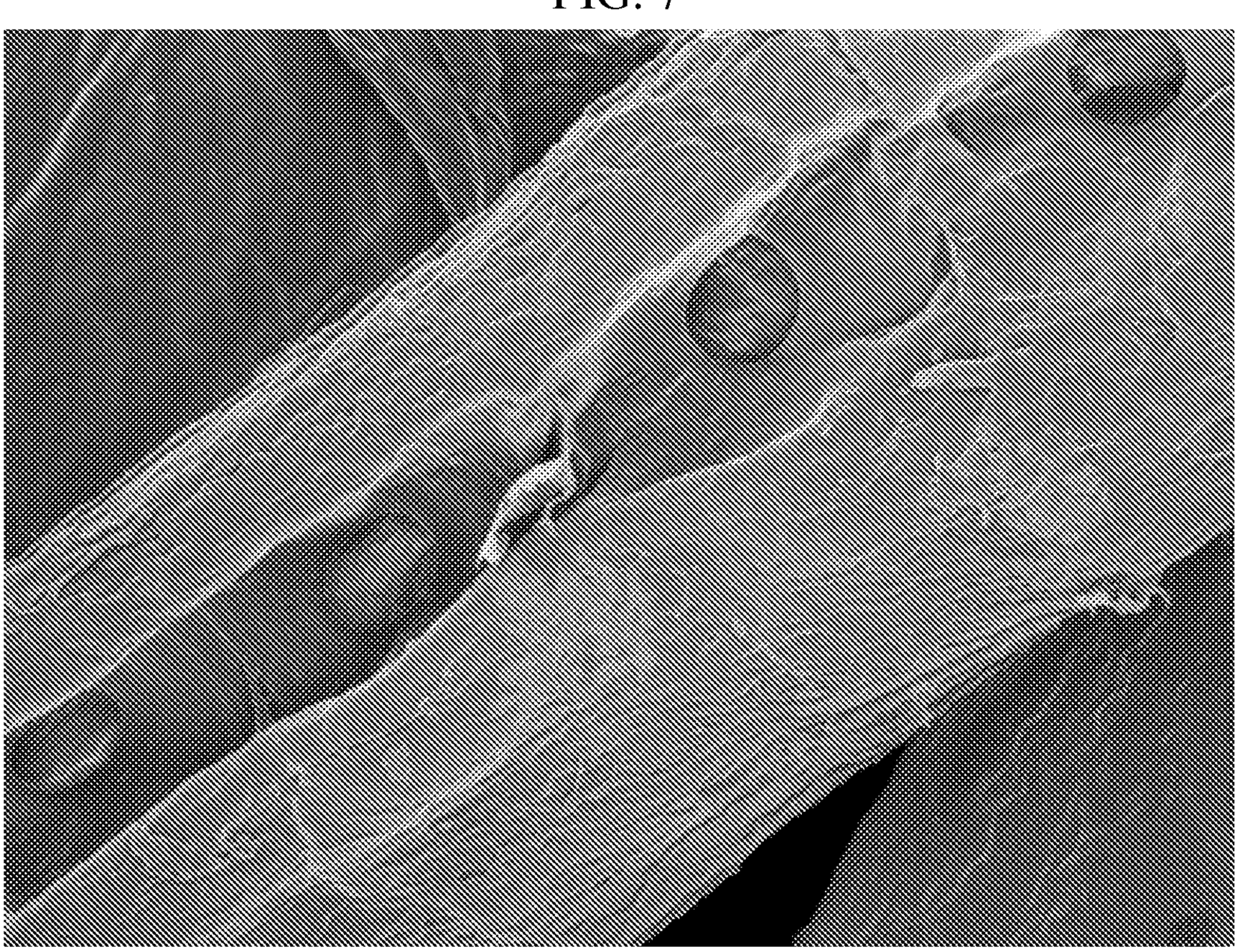


FIG. 8

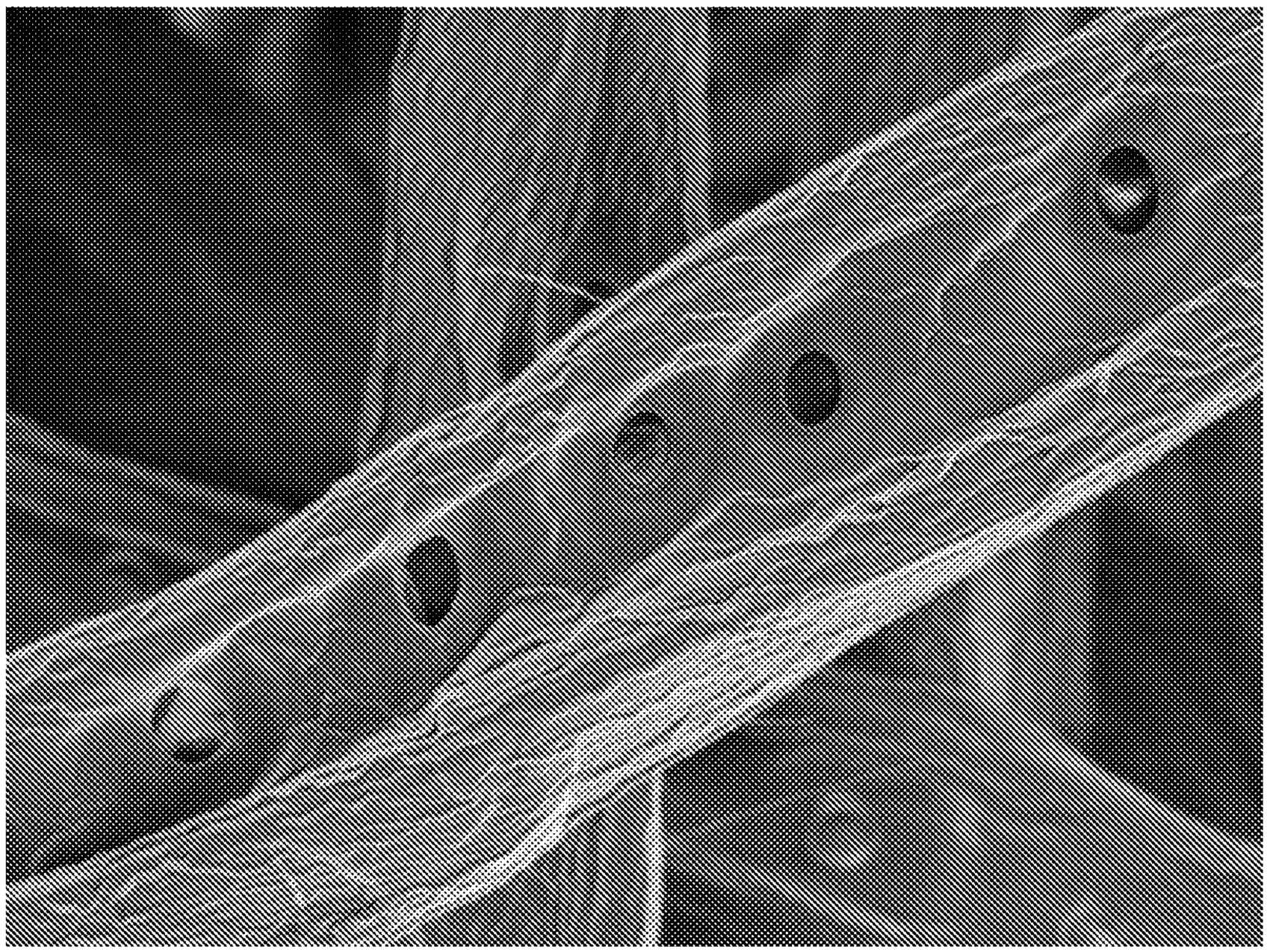


FIG. 9

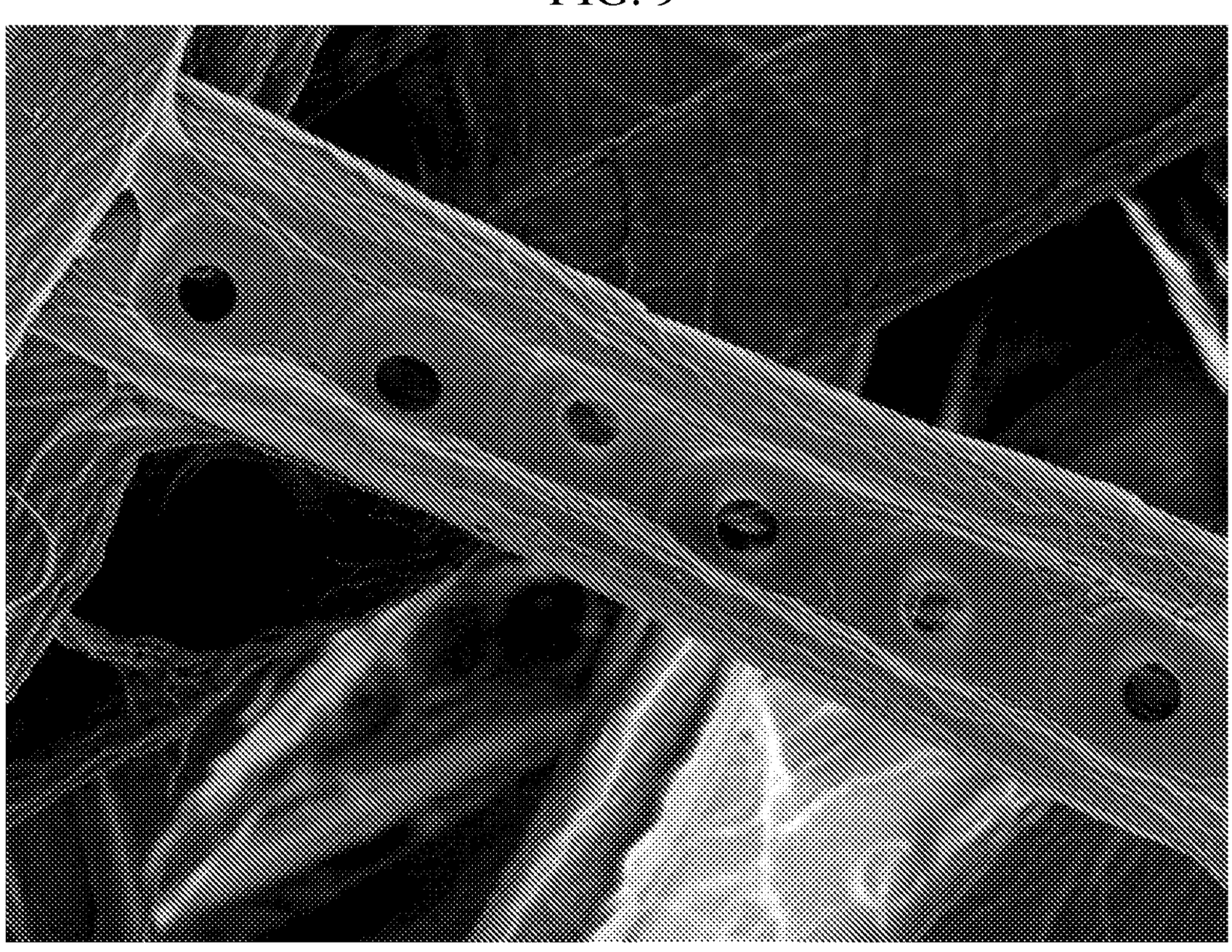


FIG. 10

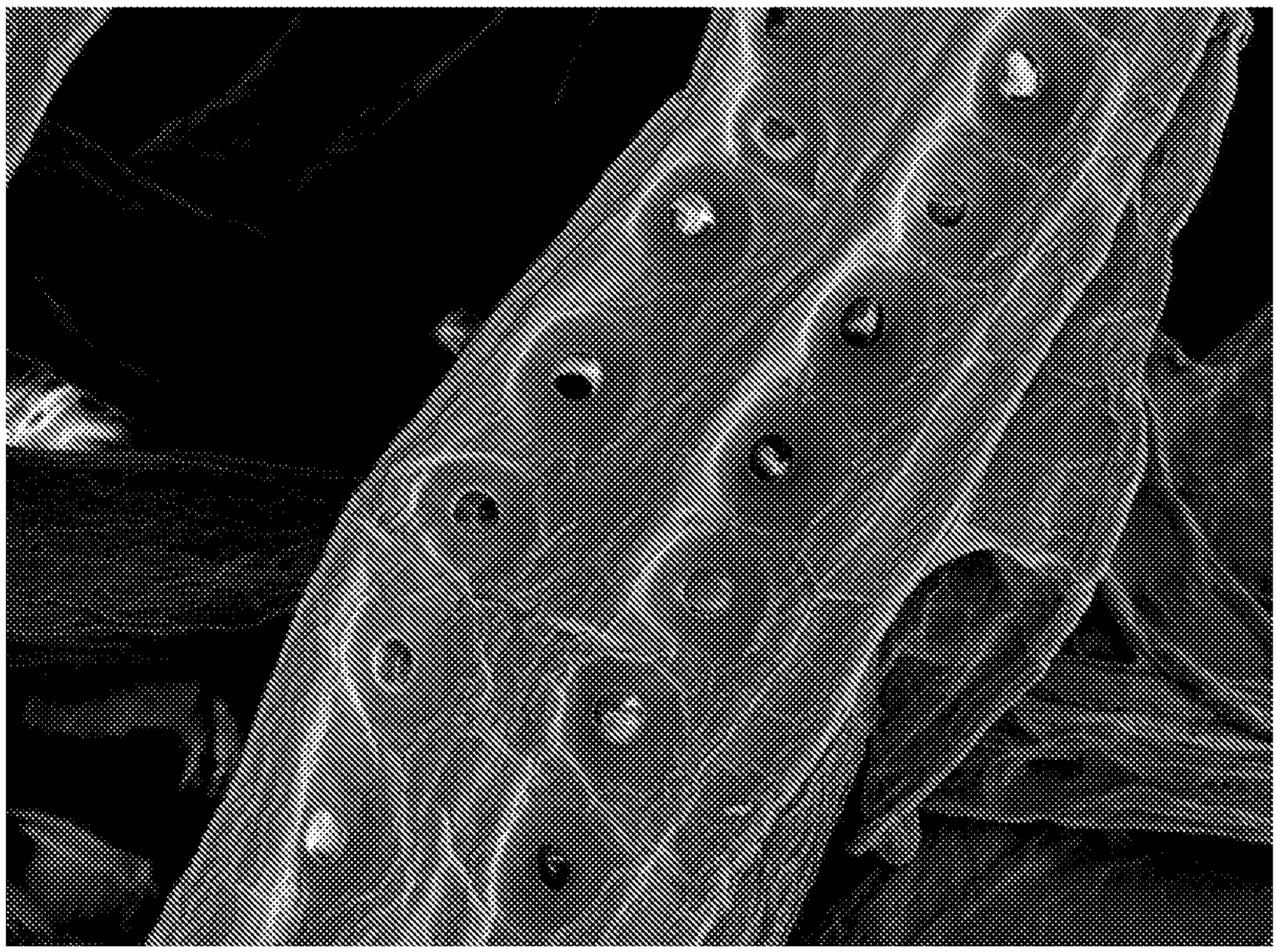


FIG. 11

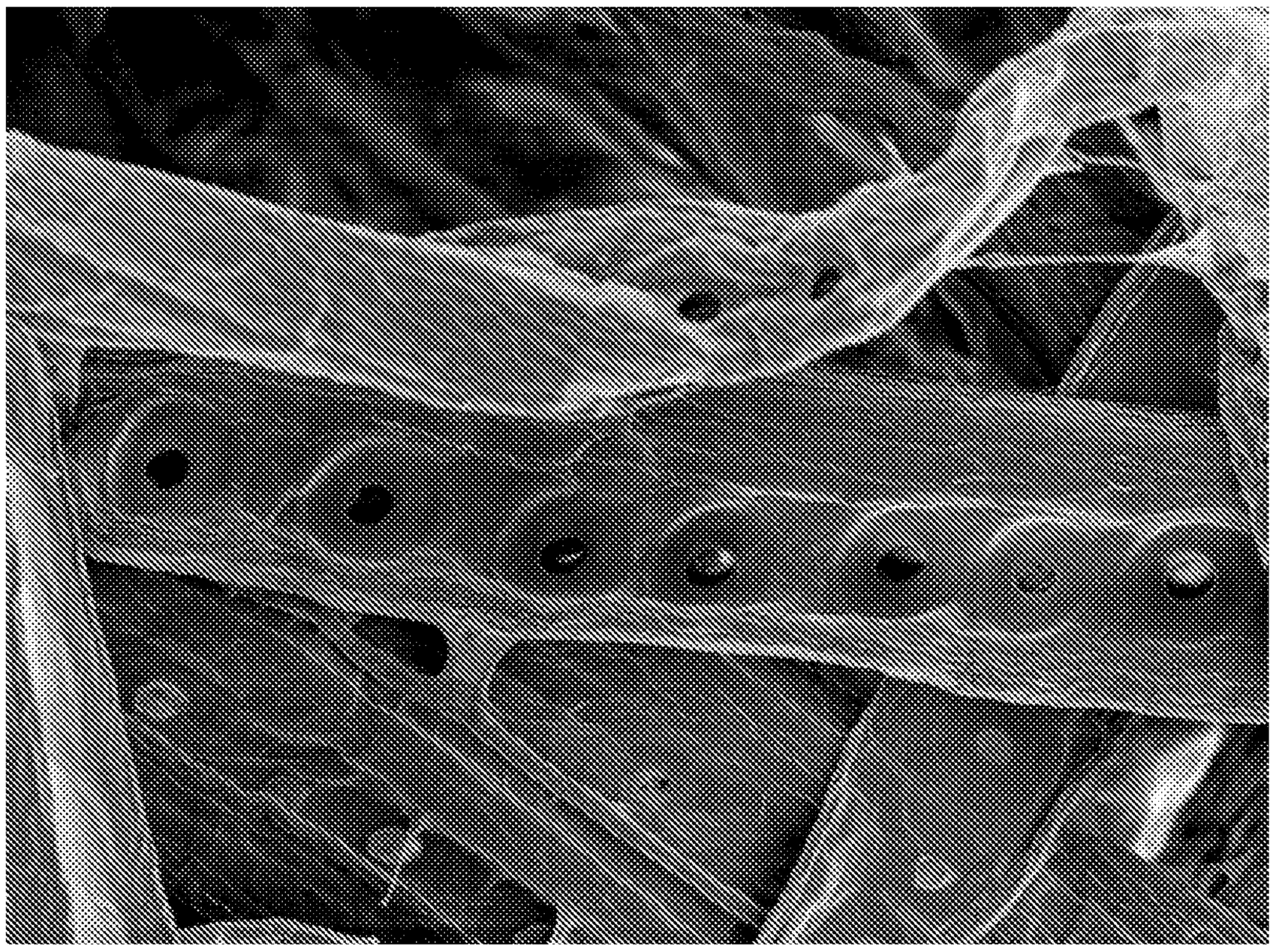


FIG. 12

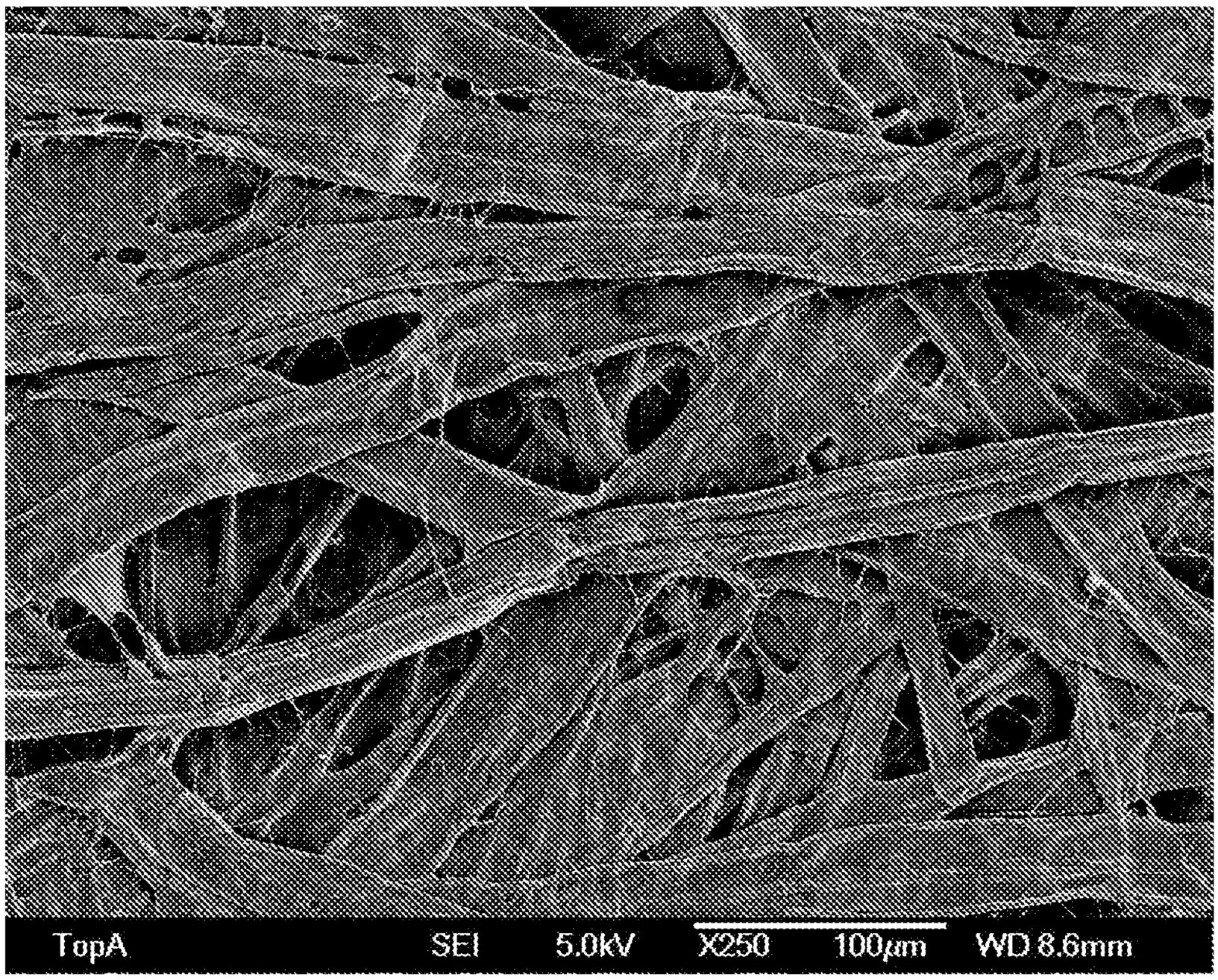

TopA
SEI
5.0kV
X250
100µm
WD 8.6mm

FIG. 13

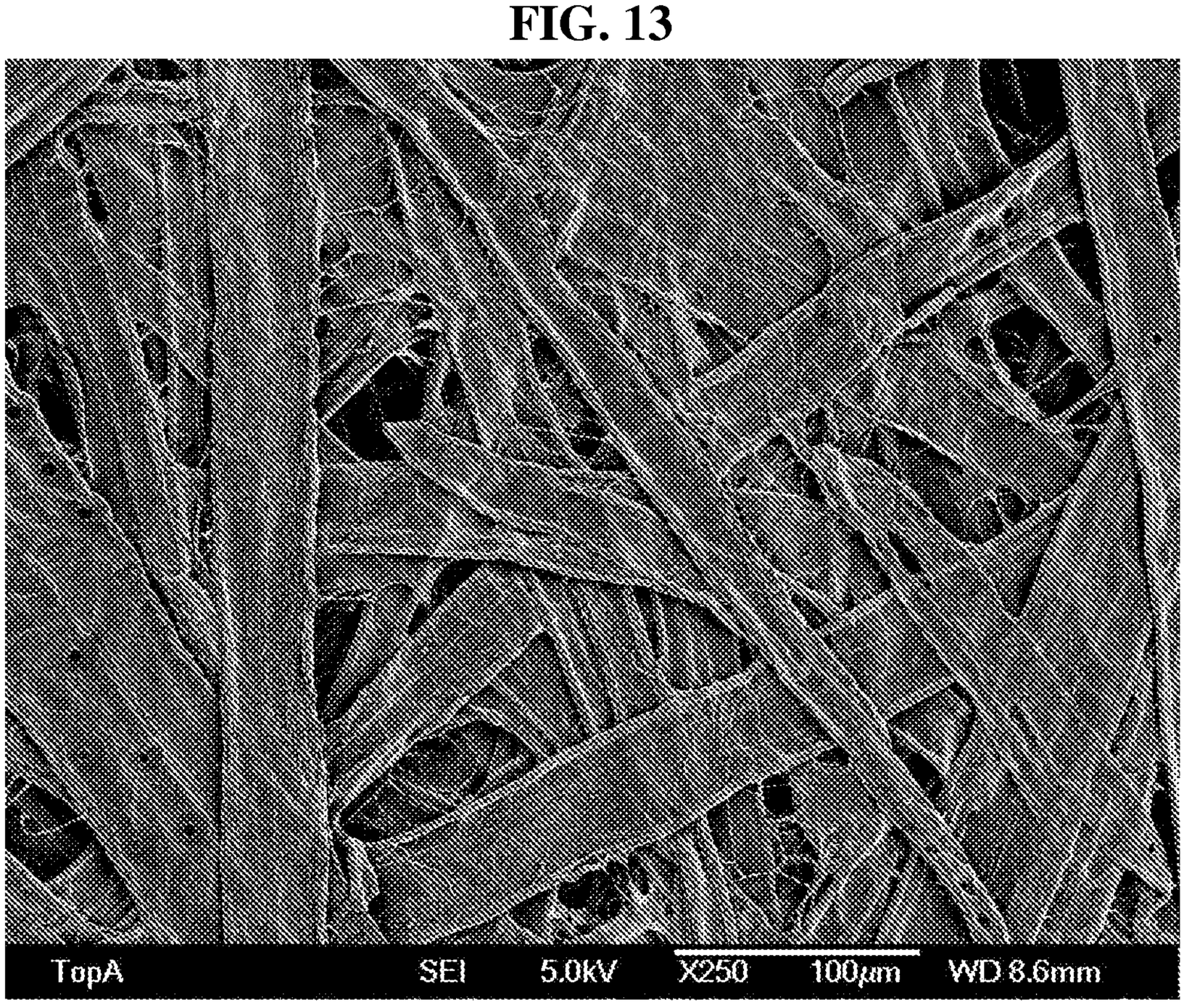

TopA
SEI
5.0kV
X250
100µm
WD 8.6mm

FIG. 14

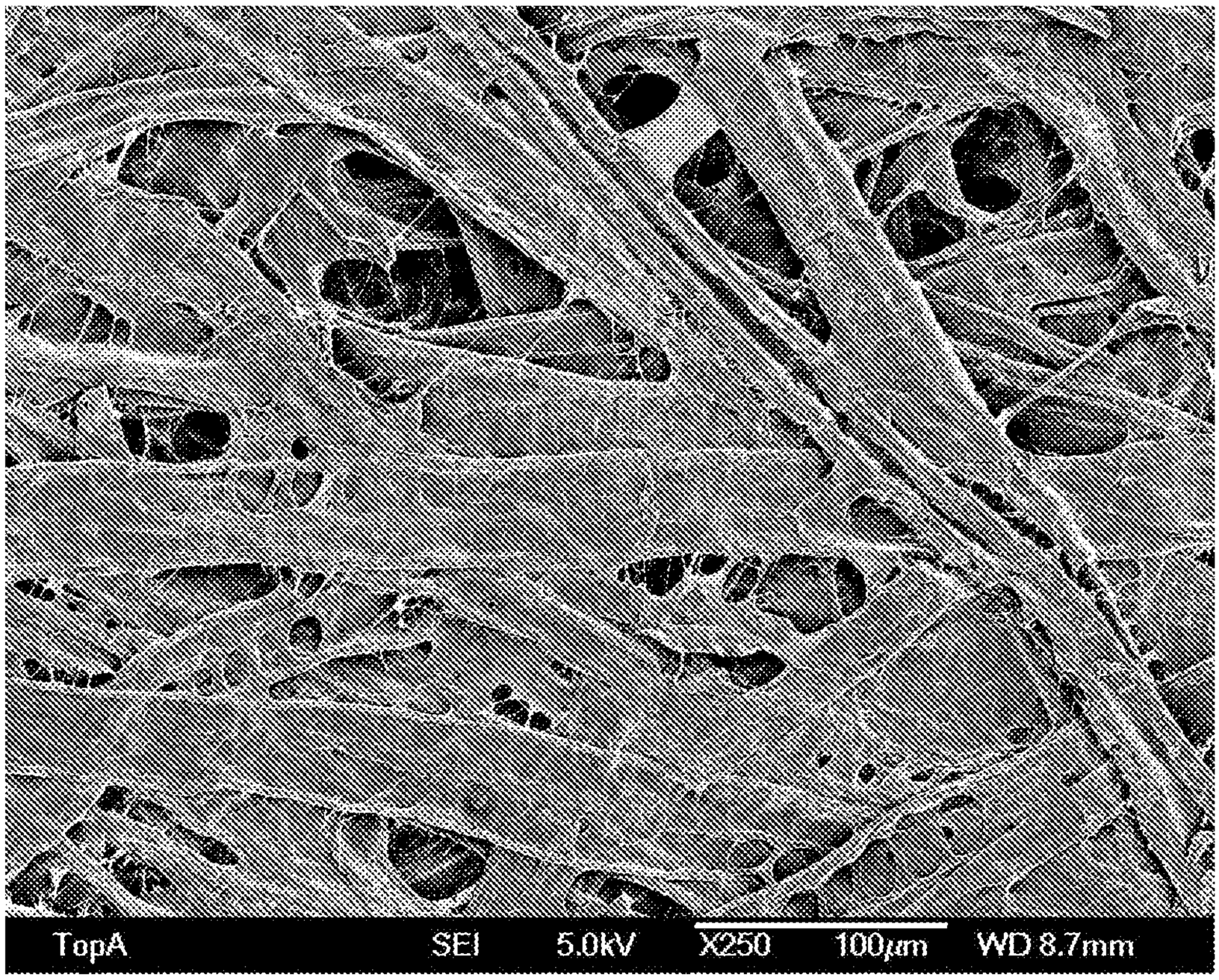

TopA
SEI
5.0kV
X250
100µm
WD 8.7mm

FIG. 15

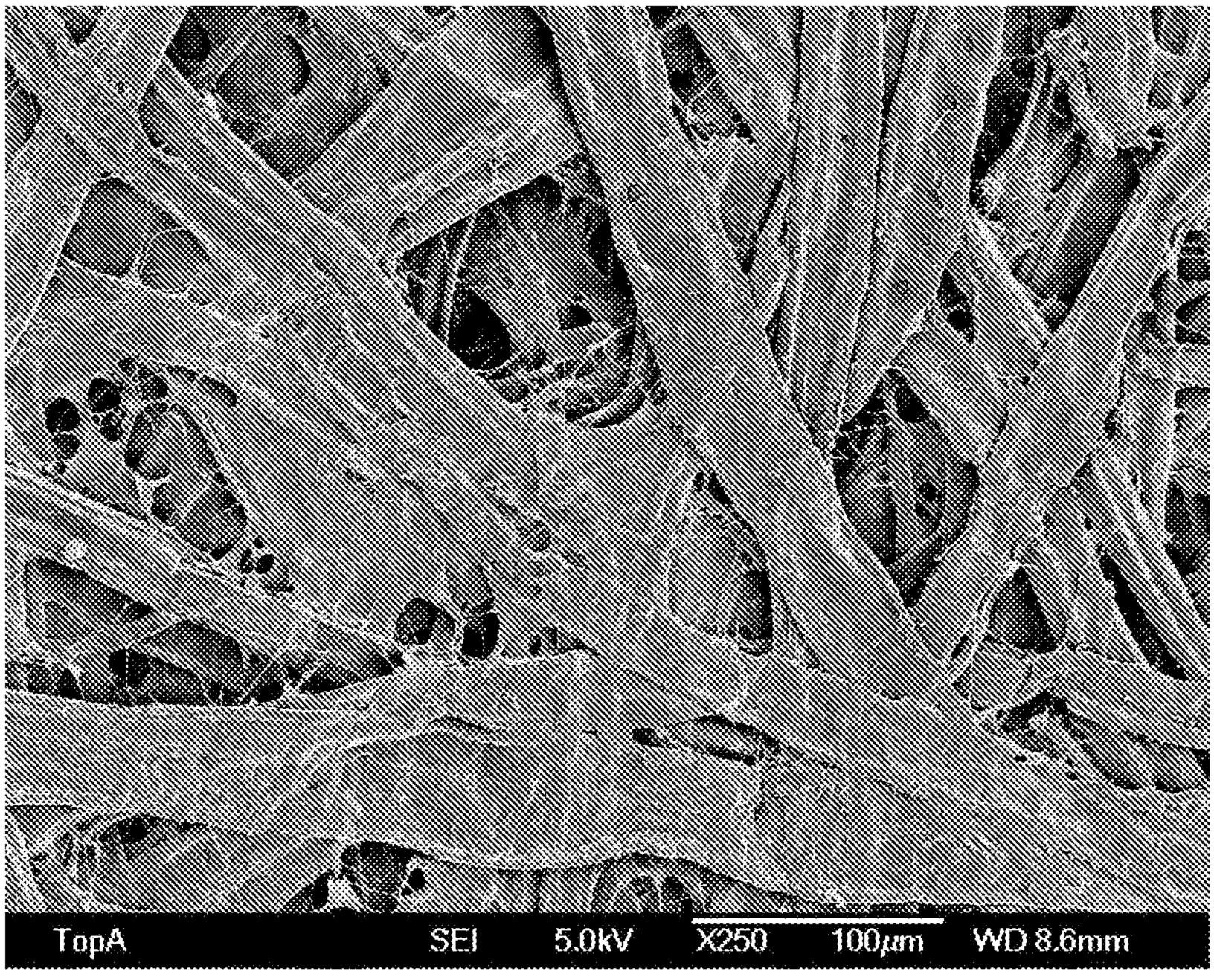

TopA
SEI
5.0kV
X250
100µm
WD 8.6mm

FIG. 16

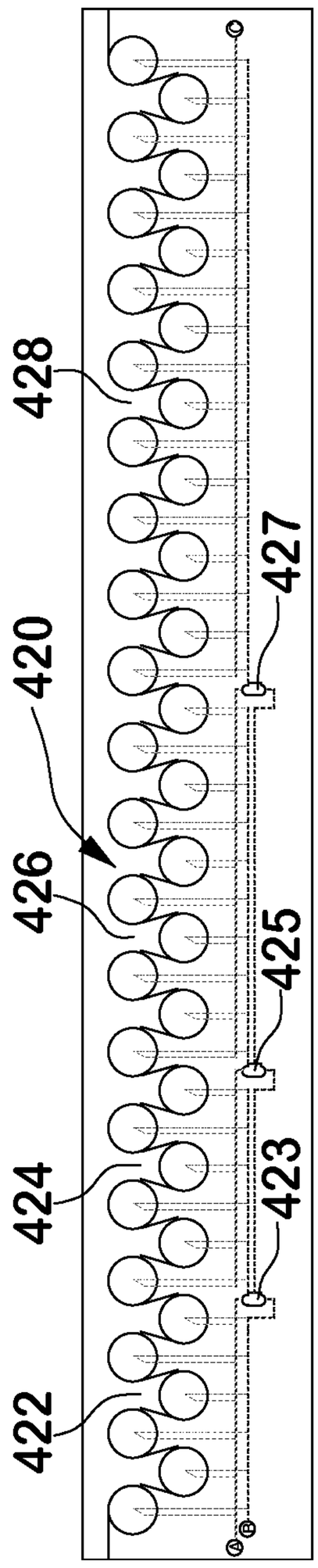


FIG. 17

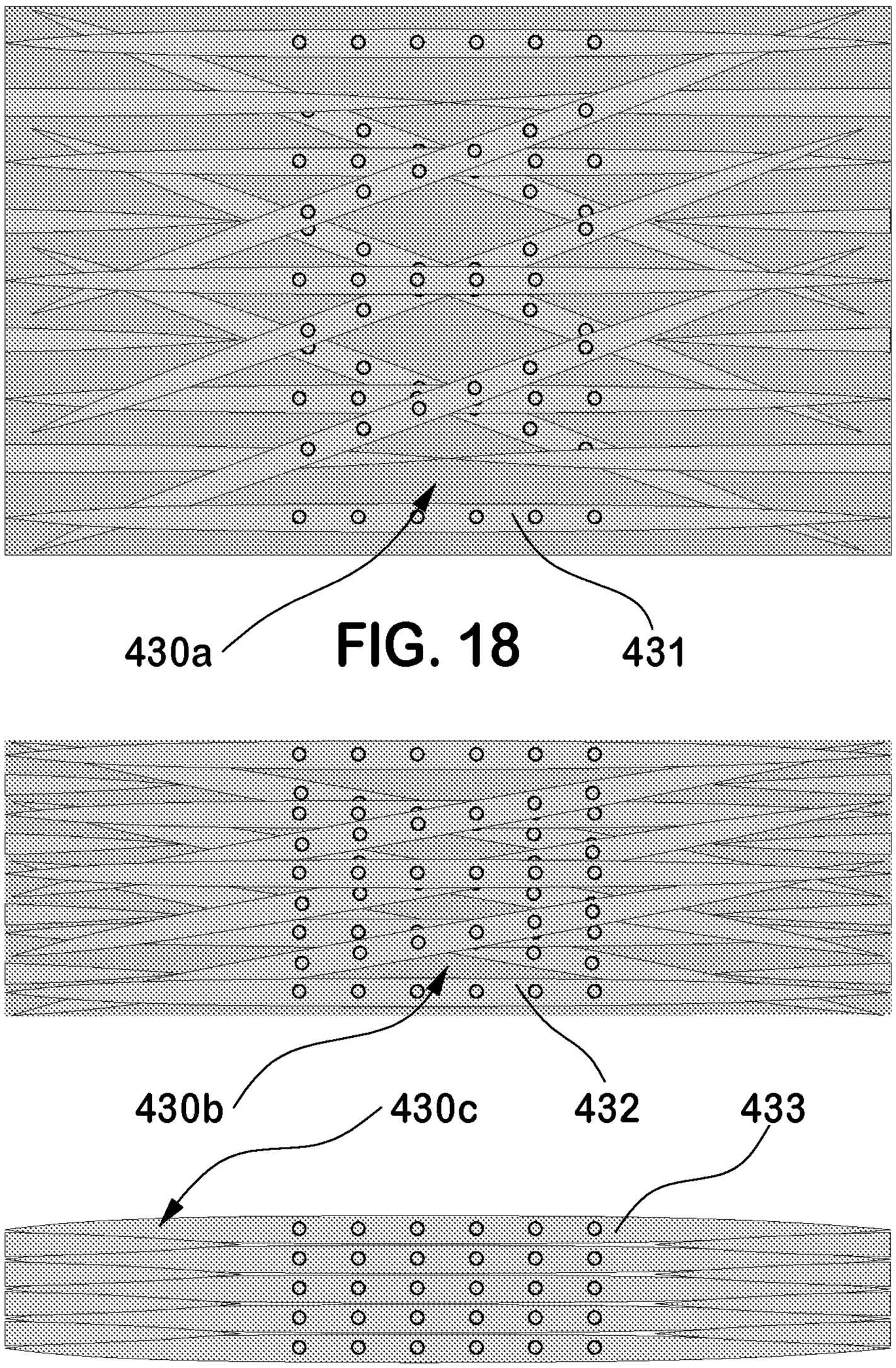


FIG. 18

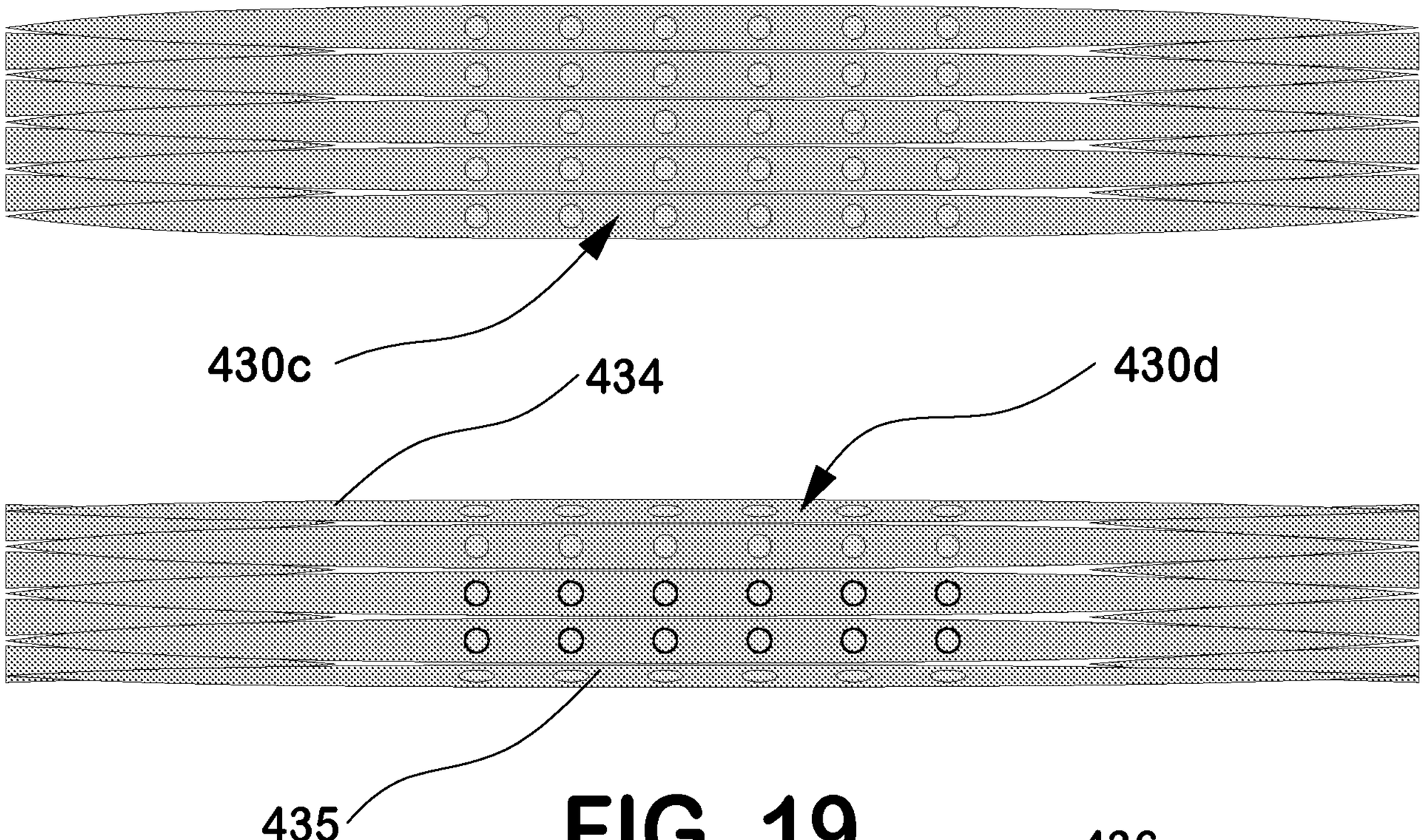
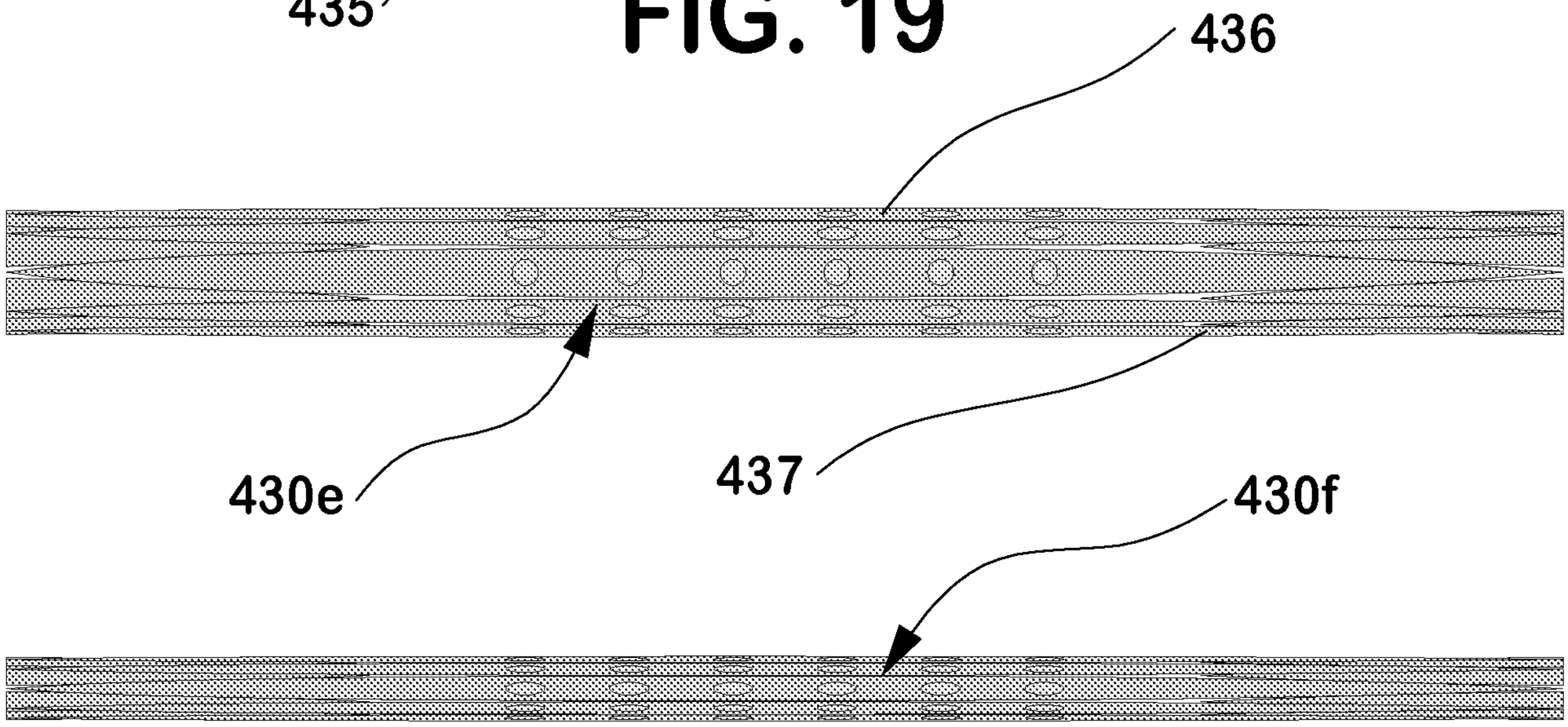


FIG. 19



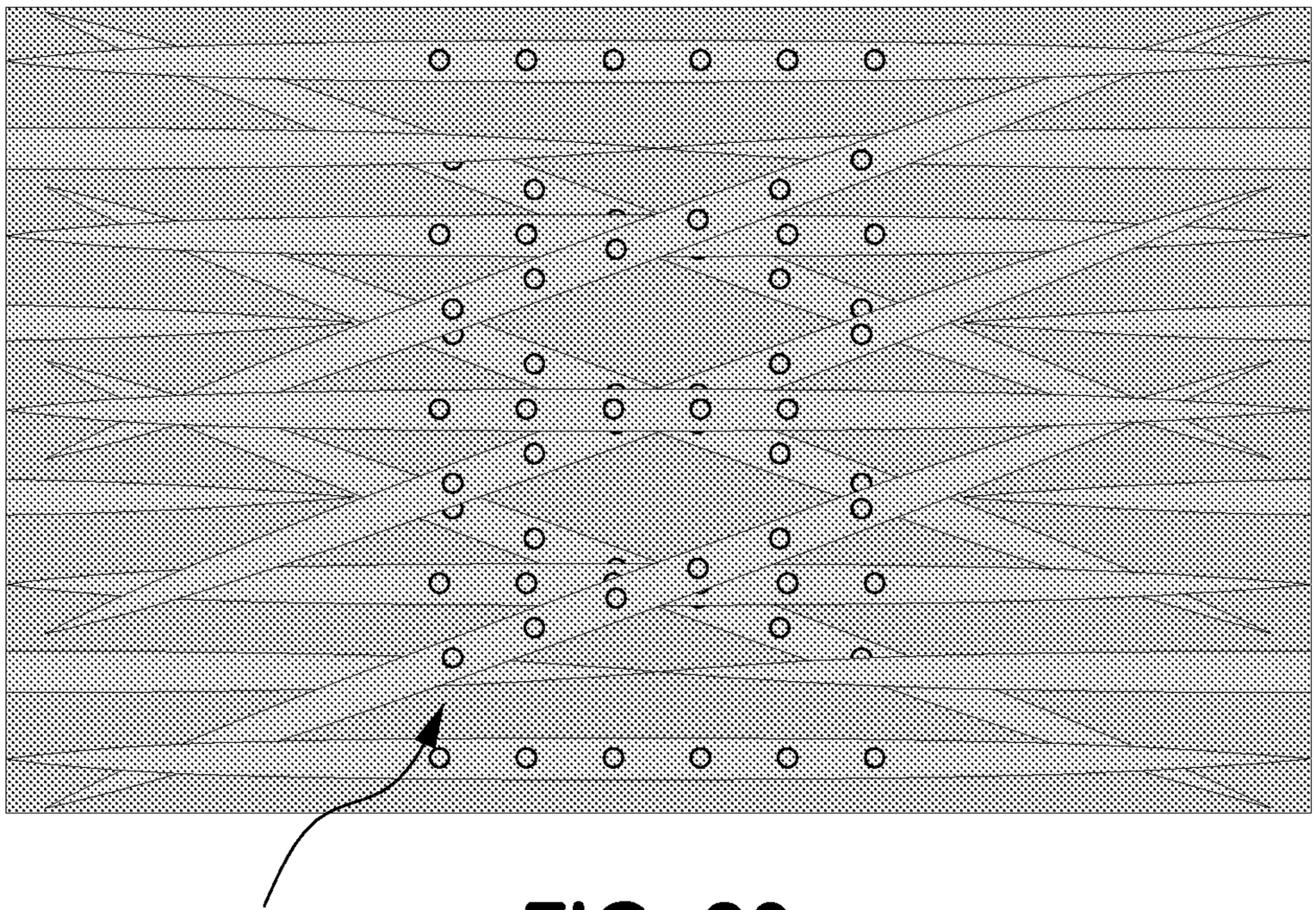
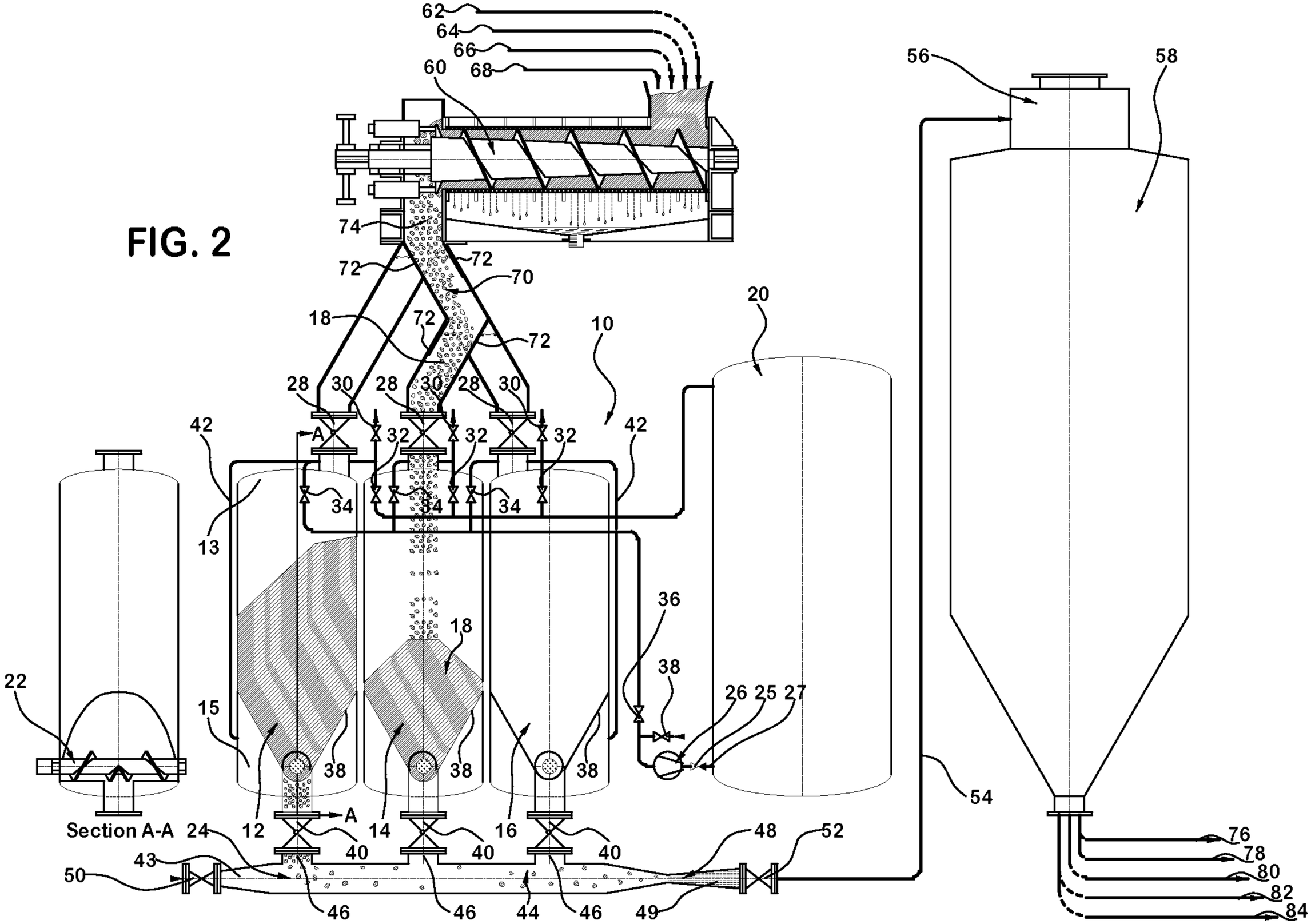


FIG. 20

FIG. 2


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Section A-A
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