Title: METHOD AND APPARATUS FOR BLEACHING PULP WITH A GASEOUS BLEACHING REAGENT

Abstract

A method and apparatus for bleaching pulp with a gaseous bleaching reagent. The pulp (18) is intensively mixed in the presence of the bleaching reagent within an upstream vessel comprising a blower/blower (12). Next, the pulp is agitated in the presence of the bleaching reagent within an intermediate vessel comprising an agitated mixer reactor (14). The pulp is then discharged to a downstream vessel, comprising a porous bed reactor (16), where it is further reacted with the bleaching reagent. The concentration of the gaseous bleaching reagent supplied to each vessel is separately controlled which, in combination with a controlled pulp residence time within at least the agitated mixer reactor and the porous bed reactor, results in an economy of energy utilization, a minimization of pulp particle damage due to mechanical mixing, and uniformity of pulp bleaching.
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METHOD AND APPARATUS FOR BLEACHING PULP WITH
A GASEOUS BLEACHING REAGENT

CROSS-REFERENCES

The subject application is a continuation-in-part of
60/001,447 filed on July 26, 1995, entitled: "Method And
Apparatus For Bleaching Pulp".

BACKGROUND OF THE INVENTION

1.0 Field of the Invention

The present invention relates generally to the
bleaching of lignocellulosic materials for use in the pulp
and paper industry, and more particularly to a method and
apparatus for bleaching pulp with a gaseous bleaching
reagent.

2.0 Related Art

The use of gaseous reagents, including ozone, for the
bleaching of lignocellulosic materials including wood pulp
is well known in the art. It is further known,
particularly with respect to the bleaching of high
consistency wood pulp, that mechanical mixing of the pulp
in the presence of the bleaching reagent is required to
enhance the rate of reaction between the bleaching reagent
and the pulp and to achieve uniformity of the resultant
bleached pulp. As known in the art, wood pulp is obtained
from the digestion of wood chips from repulping of
recycled paper or from other sources and is commonly
processed in pulp and paper mills in slurry form in water.

SUBSTITUTE SHEET (RULE 26)
As used herein, the term "consistency" is used to express the measured ratio of dry pulp fibers to water, or more specifically, the weight of dry pulp fibers in a given weight of pulp slurry or "pulp stock" as a percentage. Various definitions are used, such as air-dry consistency (a.d.%), or oven-dry (o.d.%), or moisture-free consistency (m.f.%). The laboratory techniques for measuring these values can be found in references well known in the art, such as the TAPPI Standards Manual. Terms widely used to describe ranges of stock consistency useful in pulp and paper plants follow:

- Low Consistency - below about 4-6% o.d.
- Medium Consistency - about 9-18% o.d.
- High Consistency - above about 18-20% o.d., but more commonly above about 25% o.d.

The primary characteristics of pulp slurries which changes with consistency is the fluidity. Low consistency slurries flow like water and can easily be pumped through pipelines using normal centrifugal pumps. In contrast, medium consistency pulp slurries have a paste-like character, do not flow by gravity, and can only be pumped in pipelines by using specially designed pumps. Also in contrast, wood pulp in the high consistency range does not have a slurry-like character, but is better described as a damp, fibrous, solid mass. Upon superficial examination, high consistency wood pulp appears to be and act like a dry solid. Accordingly, high consistency wood pulp generally cannot be pumped through any great distance in pipelines because the pipe wall friction is very high, resulting in uneconomic pumping horsepower requirements. However, this
characteristic is used to advantage in some prior art bleaching systems which feed high consistency pulp to a gas-filled vessel through a short length of pipe in which the pulp forms a plug sufficiently impermeable to prevent loss of reaction gas in the reverse direction. High consistency wood pulp has an additional characteristic which is that it can be fluffed, in the same way that dry fibrous solids such as cotton or feathers can be fluffed, to give a light and porous mass, the inner fibers of which are accessible to a chemical reagent in gaseous form. Fluffed, high consistency pulp can be blown with air or bleaching gases through pipelines provided sufficient velocity is used to prevent the wet fibers from settling out of the gas suspension. It is understood in the art that the agitation of pulp, for the aforementioned reasons, requires the expenditure of energy and increases the pulp processing costs both with regard to the initial capital investment and with regard to equipment maintenance costs in proportion to the degree of mechanical effort expended.

Recently, there have been many efforts to utilize ozone as the bleaching reagent for high consistency wood pulp, and other lignocellulosic materials, to avoid the use of chlorine (and the attendant environmental problems) in such bleaching processes. Although ozone may initially appear to be an ideal material for bleaching lignocellulosic materials, the exceptional oxidative properties of ozone and its relatively high cost have limited the development of satisfactory devices and
processes for ozone bleaching of lignocellulosic materials.

One known system for bleaching high consistency pulp with ozone includes a device commonly referred to as a fluffer/blower. The pulp is mechanically fluffed within the fluffer/blower in the presence of the ozone and the associated carrier gas (either oxygen or air) so as to form a gas-suspended mixture for transport and initiation of the bleaching reaction. The gas-suspended pulp is then transported through a conduit to the top of a reactor tower, of the porous-bed type. The pulp then drops into the reactor tower to form a porous bed of fluffed pulp which continuously moves downward through a cylindrical reaction tower toward an expanded section which acts as a gas separation chamber. The ozone and carrier gas flow downward through the porous bed at a substantially higher velocity than that at which the pulp bed moves downward through the reactor. The carrier gas then flows into the gas separation chamber within the reactor and is subsequently recycled to an ozone generator.

Although porous-bed reactors of the type just described, have proven to be highly efficient with respect to removing or "stripping" the ozone from its carrier gas, reactors of this type are subject to the following limitations. Although the fluffed pulp contains a considerable fraction of individual fibers, a majority of the pulp is present in agglomerated particles called flocs, with each floc containing a substantial number of intertwined individual fibers. These flocs are subject to
varying permeability which may result in non-uniform bleaching within the reactor due to increased bleaching of outer fibers as compared to that of the inner fibers. This problem may be exacerbated due to local areas of increased pulp density within the reactor. Additionally, the ozone/pulp reaction is very fast, with the reaction rate being directly proportional to the ozone concentration. This aggravates the non-uniformity of bleaching since a large fraction of the ozone may be consumed prior to reaching the fibers in high density regions within the pulp bed. Other factors contributing to the non-uniformity of pulp bleaching within the reactor include channeling of the gas between pulp particles and the time required for dissolution of the reagent gas in the liquor which surrounds the fibers in the pulp particles.

It is further noted that prior systems of this type exhibit limited "turn-down" ratios, i.e. limited flexibility in adjusting to the varying bleaching requirements of different types of pulp (for instance hardwoods versus softwoods) and of varying production rates. The pulp residence time within the fluffer/blower is substantially fixed and is controlled by the fluffer speed required to achieve the desired shredding and fluffing of the pulp. The pulp residence time within the transport conduit interconnecting the fluffer/blower and the bed reactor is also substantially fixed (without an impractical increase in conduit length) due to the transport velocity required within the conduit. Accordingly, the ozone concentration at the inlet to the bed reactor is established by the ozone concentration and
flow rate, as well as the pulp input rate, supplied to the fluffer/blower.

The foregoing illustrates limitations known to exist in present wood pulp bleaching operations. Thus, it is apparent that it would be advantageous to provide an alternative directed to overcoming one or more of the limitations set forth above. Accordingly, a suitable alternative is provided including features more fully disclosed hereinafter.

SUMMARY OF THE INVENTION

In one aspect of the present invention, this is accomplished by providing a method for bleaching pulp with a gaseous bleaching reagent comprising the steps of: supplying high consistency pulp to a first, upstream vessel; intensively mixing the pulp within the upstream vessel in the presence of a contacting gas including the gaseous bleaching reagent, a carrier gas, and reaction by-product gases, so as to suspend the pulp in the contacting gas and to initiate a reaction of the gaseous bleaching reagent with the pulp;

discharging the gas-suspended pulp to a second, intermediate vessel;

agitating the pulp within the intermediate vessel in the presence of the contacting gas so as to maintain the pulp in suspension in the contacting gas and to further react the gaseous bleaching reagent with the pulp;

discharging the gas-suspended pulp and the contacting gas to a third, downstream vessel so as to substantially
complete the reaction of the gaseous bleaching reagent
with the pulp;
controlling pulp residence time within at least the
intermediate and downstream vessels, and controlling
separate supplies of the gaseous bleaching reagent to each
of the vessels so that about 10% to about 70% of the
reaction of the gaseous bleaching reagent with the pulp
occurs in the upstream vessel, about 10% to about 70% of
the reaction occurs in the intermediate about 10% to about
70% of the reaction occurs in the downstream vessel,
wherein the step of controlling includes the steps of:
providing a first countercurrent flow of the
contacting gas between the downstream vessel and the
intermediate vessel, and a second countercurrent flow
of the contacting gas between the intermediate vessel
and the upstream vessel;
enriching the first and second countercurrent
flows of the contacting gas with fresh bleaching gas
so as to provide first, second and third
predetermined concentrations of the gaseous bleaching
reagent supplied to the upstream, intermediate and
downstream vessels, respectively.

According to a second aspect of the present
invention, this is accomplished by providing a system for
bleaching pulp with a gaseous bleaching reagent, with the
system comprising:
means for intensively mixing the pulp within the
presence of a contacting gas including the gaseous
bleaching reagent, a carrier gas and reaction by-product
gases, wherein said means for intensively mixing comprises a first, upstream vessel having a pulp inlet, a pulp outlet and a gas inlet;

means for agitating the pulp in the presence of the contacting gas, wherein the means for agitating comprises a second, intermediate vessel having a pulp inlet, a pulp outlet, a gas inlet and a pair of gas outlets, wherein the pulp outlet of the upstream vessel is in fluid communication with the pulp inlet of said intermediate vessel;

a third, downstream vessel having a pulp inlet, a pulp outlet, a gas inlet and a gas outlet, wherein the pulp outlet of the intermediate vessel is in fluid communication with the pulp inlet of the downstream vessel; and

means for supplying a first, countercurrent flow of enriched contacting gas between the downstream vessel and the intermediate vessel and for supplying a second countercurrent flow of enriched contacting gas between the intermediate vessel and the upstream vessel, wherein the means for supplying includes:

a first proportioning valve having a first inlet in fluid communication with the gas outlet of the downstream vessel, a second inlet in fluid communication with a first source of fresh bleaching gas, and an outlet in fluid communication with the gas inlet of the intermediate vessel; and

a second proportioning valve having a first inlet in fluid communication with one of the pair of the gas outlets of the intermediate vessel, a second
inlet in fluid communication with a second source of fresh bleaching gas, and an outlet in fluid communication with the gas inlet of the upstream vessel.

**BRIEF DESCRIPTION OF THE DRAWING**

The foregoing and other aspects of the present invention will become more apparent from the subsequent Detailed Description of the invention when considered in conjunction with the accompanying drawing figure, wherein:

The Figure illustrates a system for bleaching pulp with a gaseous bleaching reagent according to the present invention.

**DETAILED DESCRIPTION**

Referring now to the drawing, The Figure illustrates a system 10 for bleaching lignocellulosic materials, such as high consistency wood pulp, with a gaseous bleaching reagent, according to the present invention. System 10 includes an upstream vessel 12, an intermediate vessel 14 and a downstream vessel 16 which are disposed relative to one another so that lignocellulosic materials, such as high consistency wood pulp, may be reacted with a gaseous bleaching reagent within each of the vessels in succession according to the method of the present invention. As described herein, the apparatus of the present invention depicted in the illustrative embodiment shown in The Figure, will be described in conjunction with a method for bleaching high consistency wood pulp utilizing ozone as the gaseous bleaching reagent, according to the present
invention. The apparatus and method of the present invention are not intended to be utilized for the bleaching of either medium consistency or low consistency wood pulp, with the terms high consistency, medium consistency and low consistency referring to the definitions set forth in the Background of this application. However, the method and apparatus of the present invention may be advantageously utilized in conjunction with gaseous bleaching reagents other than ozone, such as chlorine monoxide, chlorine dioxide, and others. As is known in the art, due to the manner in which ozone is generated, ozone is typically available at a relatively low concentration within a carrier gas, such as oxygen or air. Typically, commercially available ozone has a concentration of about 6% to about 10%, by weight, when using oxygen as the carrier gas. As used herein, the term “contacting gas” will refer to the mixture of ozone in an oxygen carrier gas, as well as other gases and vapors, such as by-product gases of reaction, which are present at equilibrium conditions. The term “fresh bleaching gas” will be used to denote a mixture of ozone in an oxygen carrier gas supplied from a conventional source, such as a dryer/cleaner and ozone generator, which has not been reacted with the pulp and accordingly does not include reaction by-product gases.

High consistency wood pulp 18 is supplied from a conventional dewatering press (not shown) to a compaction feed auger 20. Auger 20 includes a housing 22 having an inlet 24 which is adapted to receive the pulp 18. Feed auger 20 further includes a shaft 26 which is rotatably
mounted within housing 22. A screw flight 28 is attached to shaft 26, for rotation therewith, and is effective for compacting the pulp 18 supplied to housing 22 so as to form an impervious pulp plug which is effective for preventing the backflow of gas through feed auger 20. The rotating action of screw 28 causes the pulp plug to advance to a pulp inlet 30 of the upstream vessel 12. In the illustrative embodiment shown in the Figure, upstream vessel 12 comprises a conventional fluffer/blower which functions in a manner well known in the art. The pulp plug entering inlet 30 is disintegrated by a screw 32 attached to a shaft 34 rotatably mounted within a housing 36 of the fluffer/blower 12. Shaft 34 is driven by a conventional source of motive power (not shown). Fluffer/blower 12 further includes a means (not shown) for further breaking-up, or fluffing, the disintegrated pulp. This means for fluffing is known in the art and may comprise radially spaced, inner and outer rings of arcuately spaced apart, rotary pins (not shown), mounted for rotation with shaft 34, and a ring of arcuately spaced apart, stationary pins (not shown) attached to housing 36. The disintegrated and fluffed pulp is intensively mixed within fluffer/blower 12 in the presence of a contacting gas, received by a multi-port gas inlet 38. The contacting gas is supplied to inlet 38 from the intermediate vessel 14, in a manner discussed subsequently in greater detail, and includes ozone, oxygen carrier gas, and by-product gases of the reaction occurring within vessel 14. The mixture of the contacting gas and the pulp within fluffer/blower 12 suspends the pulp in the contacting gas and initiates the
reaction of the ozone with the pulp. The gas-suspended pulp discharges fluffer/blower 12 through pulp outlet 40 with sufficient velocity so that it is transported to a pulp inlet 42 of the intermediate vessel 14, via conduit 44. The gas-suspended pulp enters an upper portion 41 of the intermediate vessel 14 through inlet 42 in a tangential manner so that the gas-suspended pulp swirls around an inner wall of the upper portion 41 of vessel 14 in a cyclonic fashion. Hence, the upper portion 41 of vessel 14 may be referred to in the art as a cyclone. The operation of the fluffer/blower 12 and the gas transport of pulp through conduit 44 to the pulp inlet 42 of vessel 14 requires a volume of gas which is much larger than the total flow of fresh bleaching gas supplied to system 10 from a variety of subsequently discussed sources. As an illustration of this fact, it is noted that for a pulp processing rate of about 500 tons/day, the flowrate of the contacting gas through conduit 44 is about 8,000 cu. ft./min., while the total flowrate of the fresh bleaching gas supplied to system 10 is about 1,500 cu. ft./min. In order to accommodate this requirement, the upper portion 41 of vessel 14 includes a gas separator 43 having a generally centrally disposed pipe or conduit 45 which communicates with an upper gas outlet 47 of vessel 14. A significant portion of the contacting gas entering cyclone 41 of vessel 14 is separated from the pulp within separator 43 and is recirculated to one of the ports of the multi-port inlet 38 of the fluffer/blower 12 via conduit 49. It is noted that enriched contacting gas is supplied to a second port of inlet 38 as subsequently
described in greater detail. A portion of the contacting gas discharging through outlet 47 of vessel 14, which is denoted by flow arrow 51 and is approximately equal to the amount of fresh bleaching gas added to system 10, is discharged from system 10 via conduit 53 and valve 55 so as to avoid overpressurization of vessels 12 and 14. Portion 51 of the contacting gas may be supplied to another portion of the associated bleaching plant for further processing.

The intermediate vessel 14 comprises an agitated mixer reactor having a housing 46 and a shaft 48 which is rotatably mounted within housing 46 and driven by conventional means such as a variable speed motor 50. Shaft 48 is sealed as it passes through housing 46 so as to prevent any undesirable leakage of gas externally of reactor 14. The generally centrally disposed pipe 45 of separator 43 is generally concentrically disposed about an upper portion of shaft 48. The agitated mixer reactor 14 further includes a plurality of arms, or paddles 52 which are attached to shaft 48 for rotation therewith, and extend radially outwardly from shaft 48. Additional contacting gas is supplied to the agitated mixer reactor 14 through gas inlet 54 from the downstream vessel 16, in a subsequently described manner. The pulp is agitated within the agitated mixer reactor 14 so as to maintain the pulp in suspension in the contacting gas and to further react the pulp with the ozone present in reactor 14. In the illustrative embodiment shown in the Figure, the contacting gas flows in co-current relationship with the pulp through the agitated mixer reactor 14, which is
preferable. However, the contacting gas may alternatively flow in countercurrent relationship with the pulp through the agitated mixer reactor 14. Additionally, although the agitated mixer reactor 14 is depicted in a vertical orientation in the Figure, reactor 14 may alternatively be disposed in a horizontal configuration. As discussed previously, a significant portion of the contacting gas entering reactor 14 through inlet 42 is separated from the pulp via separator 43 and recirculated to the fluffer/blower 12 via conduit 49. The remaining portion of the contacting gas entering reactor 14, flows through reactor 14. The gas-suspended pulp, and a first portion of the contacting gas flowing through reactor 14 discharge reactor 14 through a pulp outlet 56 to a pulp inlet 58, comprising an inlet conduit, of the downstream vessel 16 via a conduit 60. The centrifugal action of paddles 52 causes the pulp particles to be flung outward through outlet 56 with a sufficient velocity to travel through conduit 60, which is relatively short in length and horizontally disposed, and into the pulp inlet 58 of vessel 16. The pulp is then gravity-fed through inlet 58. The remaining portion of the contacting gas flowing through reactor 14 discharges through a gas outlet 62 of reactor 14, for subsequently described purposes.

The downstream vessel 16 comprises a porous bed reactor, with the general function of reactor 16 being well known in the art. The fluffed pulp entering reactor 16 through inlet 58 drops onto a porous bed 64 of fluffed pulp, which moves continuously downward through the porous bed reactor 16. Inlet 58 may include a flow distributor or
deflector (not shown) for uniformly distributing the fluffed pulp onto the porous bed 64. The contacting gas flows through the porous bed, so as to further react the pulp with the ozone, at a substantially higher velocity than that of the porous bed. The oxygen carrier gas, and any remaining ozone which has not been consumed, then discharges into an annular gas separation chamber 66 of reactor 16 as indicated by flow arrows 68. At this point, the ozone/pulp reaction has been substantially completed and, as known in the art, the concentration of the ozone present in the contacting gas entering gas separation chamber 66 is typically very low. In certain applications, a portion of the contacting gas entering gas separation chamber 66 may be discharged from reactor 16 through a gas outlet 63 of reactor 16, a conduit 65 and a valve 67, as shown by flow arrow 69 so as to off-set the addition of fresh bleaching gas to system 10. In these applications valve 55 would be closed. The bleached pulp 70 at the bottom of the porous bed reactor 16 is diluted with recycled filtrate 72 through a dilution nozzle 74 and is then discharged through pulp outlet 76 as dilute, bleached pulp 78.

The present invention provides an independent control of the ozone concentration to each of the vessels 12, 14 and 16 while agitating the pulp within vessels 12 and 14 and controlling the pulp residence time within at least vessels 14 and 16. Fresh bleaching gas, comprising freshly generated ozone in an oxygen carrier gas, is supplied to a gas inlet 80 of the porous bed reactor 16 via conduit 82 and control valve 84. Valve 84 is in fluid
communication, via conduit 83, with a source 85 of the fresh bleaching gas. Source 85 may comprise an ozone generator and an oxygen dryer/cleaner. Alternatively, fresh bleaching gas may be supplied to conduit 83 from another location within the associated pulp processing plant. The concentration of ozone within the fresh bleaching gas may be in the range of 0.5% to 14% by weight, within the oxygen carrier gas with presently known technology, but is more typically in the range of about 6% to 10% by weight. Valve 84 may be used to control the quantity of fresh bleaching gas supplied to reactor 16, which mixes with the contacting gas entering reactor 16 through pulp inlet 58. Accordingly, a predetermined concentration of ozone within reactor 16 may be independently established, in contrast to those systems wherein the ozone concentration within reactor 16 is determined by the extent of the ozone/pulp reaction within one or more upstream vessels. At least a substantial portion (constituting an entire portion when valve 67 is closed) of the contacting gas entering gas separation chamber 66 of reactor 16 discharges reactor 16 through a gas outlet 86 and a conduit 87 having one end communicating with outlet 86. An opposite end of conduit 87 is attached to a conventional blower 88 which may optionally be used to provide the necessary transport velocity of the contacting gas discharging from outlet 86. The contacting gas then flows through a conduit 89 to a first inlet 90 of a proportioning valve indicated at 92. The concentration of the ozone within the contacting gas discharging from reactor 16 through outlet 86 is
determined by a conventional gas analyzer 94 which communicates with the gas outlet 86 of reactor 16 via a conduit 96 and conduit 87. Fresh bleaching gas is supplied to a second inlet 98 of the proportioning valve 92 from a source 100 of the fresh bleaching gas via a conduit 102. It is noted that source 100 may be separate from the source 85 of fresh bleaching gas discussed previously, or alternatively, may be manifolded together with source 85 so as to provide a common source of fresh bleaching gas. The fresh bleaching gas supplied from source 100 also typically has an ozone concentration of about 6%-10% ozone within an oxygen carrier gas. Valve 92 is used to proportion the amount of fresh bleaching gas from source 100 which is used to enrich the contacting gas discharging from reactor 16 through outlet 86, based on the concentration of the ozone discharging from reactor 16 through outlet 86 as determined by the gas analyzer 94. Accordingly, a desired ozone concentration may be established for the enriched contacting gas discharging from valve 92 through outlet 104 and supplied to the gas inlet 54 of the agitated mixer reactor 14, via conduit 106. In this manner, a predetermined concentration of ozone may be supplied to the agitated mixer reactor 14, independently of the ozone concentration supplied to the fluffer/blower 12 and porous bed reactor 16.

The concentration of ozone provided to the fluffer/blower 12 is also independently controlled in the following manner. As set forth previously, a portion of the contacting gas flowing through the agitated mixer reactor 14 discharges through gas outlet 56 with the
suspended, fluffed pulp. The remaining portion of the contacting gas flowing through the agitated mixer reactor 14 discharges reactor 14 through outlet 62 and is supplied to a first inlet 110 of a proportioning valve indicated at 112, via a conduit 114. The concentration of the ozone discharging from outlet 62 of reactor 14 is determined by conventional means such as gas analyzer 116, which communicates with outlet 62 via conduits 118 and 114. Fresh bleaching gas is supplied from a source 120 to a second inlet 122 of valve 112 via a conduit 124. Source 120 may be separate from, or common with, the previously discussed sources 85 and 100 of fresh bleaching gas. Valve 112 proportions the quantities of fresh bleaching gas from source 120 and the contacting gas discharging from outlet 62 of reactor 14, based on the ozone concentration existing at outlet 62 as determined by gas analyzer 116. Accordingly, an enriched contacting gas, having a desired, predetermined ozone concentration, is supplied via an outlet 126 of valve 112 and conduit 128 to the gas inlet 38 of the fluffer/blower 12. Fluffer/blower 12 creates a slight vacuum within conduits 128 and 114 so as to assist in the flow of contacting gas through the gas outlet 62 of the agitated mixer reactor 14.

In operation, the high consistency wood pulp 18 is supplied to the fluffer/blower 12 via feed auger 20, where it is disintegrated and intensively mixed in the presence of the contacting gas having a selected, predetermined concentration of ozone, so as to suspend the fluffed pulp within the contacting gas and to react the pulp with a portion of the ozone. Some control of the pulp residence
time within fluffer/blower 12 may be provided, for instance by using a variable speed motor (not shown) to control the rotating speed of shaft 34. However, limited flexibility is available in this regard since, for a given type and consistency of pulp and a given pulp input rate, the speed required to disintegrate and fluff the pulp is somewhat fixed. The fluffed, gas-suspended pulp is then transported to the agitated mixer reactor 14 where it is further agitated so as to maintain the fluffed pulp in suspension in the contacting gas, and to further react the ozone with the pulp. The residence time of the pulp within reactor 14 may be controlled by varying the speed of motor 50, 80 as to vary the rotating, agitating action of paddles 52, and by varying the fill level of pulp within reactor 14. A predetermined concentration of ozone is established within reactor 14 due to the enriched, countercurrent flow of contacting gas supplied from the porous bed reactor 16. The gas-suspended pulp is then transported to the porous bed reactor 16 where it is further reacted with ozone, having a predetermined concentration. In a preferred embodiment, the ozone concentration supplied to each of the vessels 12, 14 and 16 is the same and is equal to that which is determined to be required to establish a sufficient driving force to maintain the ozone/pulp reaction, i.e. to sustain a movement of the ozone towards the center of the individual pulp particles. It is noted that this concentration may vary with the type of pulp being processed, for instance whether hardwood or softwood pulps are being bleached. In other instances, it may be determined that it is desirable
to provide ozone at different concentrations to vessels 12, 14 and 16. The inventor has observed that, once ozone is thoroughly introduced into a vessel such as fluffer/blower 12 or agitated mixer reactor 14, the intensity of pulp mixing is less critical to achieving uniformly bleached pulp, and may even be detrimental to the quality of the pulp by unnecessary fracturing of the pulp fiber. Additionally, high intensity mixing consumes considerable energy and results in an associated process cost. The control of the pulp residence time within at least the agitated mixer reactor 14 and the porous bed reactor 16, in combination with the ability to independently control the ozone concentration supplied to fluffer/blower 12, and reactors 14 and 16 permit increased process flexibility with the present invention and allow the percentage of the ozone/pulp reaction within each vessel to be independently controlled, with the percentage of reaction defined as the percentage of ozone consumed for a given quantity of ozone.

The inventor has determined that in order to effect an economy of energy utilization, a minimization of pulp particle damage due to mechanical mixing, and a uniformity of pulp bleaching, that the range of reactions within the various vessels are as follows: about 10% to about 70% within fluffer/blower 12; about 10% to about 70% within agitated mixer reactor 14; and about 10% to about 70% within the porous bed reactor 16. More preferably, the inventor has determined that the range of reaction between the ozone and the pulp within each vessel is as follows: about 30% to about 40% within the fluffer/blower 12; about
30% to about 50% within the agitated mixer reactor 14; and
about 10% to about 25% within the porous bed reactor 16.

While the foregoing description has set forth the
preferred embodiment of the invention in particular
detail, it must be understood that numerous modifications,
substitutions and changes can be undertaken without
departing from the true spirit and scope of the present
invention as defined by the ensuing claims. The invention
is therefore not limited to specific preferred embodiments
as described, but is only limited as defined by the
following claims.
WHAT IS CLAIMED IS:

1. A method for bleaching pulp with a gaseous bleaching reagent, said method comprising the steps of:
   supplying high consistency pulp to a first, upstream vessel;
   intensively mixing the pulp within the upstream vessel in the presence of a contacting gas including the gaseous bleaching reagent, a carrier gas, and reaction by-product gases so as to suspend the pulp in the contacting gas and to initiate a reaction of the gaseous bleaching reagent with the pulp;
   discharging the gas-suspended pulp to a second, intermediate vessel;
   agitating the pulp within the intermediate vessel in the presence of the contacting gas so as to maintain the pulp in suspension in the contacting gas and to react further the gaseous bleaching reagent with the pulp;
   discharging the gas-suspended pulp to a third, downstream vessel so as to substantially complete the reaction of the gaseous bleaching reagent with the pulp;
   controlling pulp residence time within at least the intermediate and downstream vessels, and controlling separate supplies of the gaseous bleaching reagent to each of the vessels so that about 10% to about 70% of the reaction of the gaseous bleaching reagent with the pulp occurs in the upstream about 10% to about 70% of the
reaction occurs in the intermediate vessel, and about 10% to about 70% of the reaction occurs in the downstream vessel, wherein the step of controlling includes the steps of:

providing a first countercurrent flow of the contacting gas between the downstream vessel and the intermediate vessel, and a second countercurrent flow of the contacting gas between the intermediate vessel and the upstream vessel;

enriching the first and second countercurrent flows of the contacting gas with fresh bleaching gas so as to provide first, second and third predetermined concentrations of the gaseous bleaching reagent supplied to the upstream, intermediate and downstream vessels, respectively.

2. The method as recited in claim 1, further comprising the step

proportioning the fresh bleaching gas used to enrich the first and second countercurrent flows of the contacting gas based on measured concentrations of the gaseous bleaching reagent within each corresponding countercurrent flow of the contacting gas prior to enrichment.

3. The method as recited in claim 2, further comprising the step of:
providing a separate supply of the fresh bleaching
gas to the downstream vessel.

4. The method as recited in claim 1, further
comprising the step of:
flowing the contacting gas in co-current relationship
with the pulp through at least the intermediate and
downstream vessels.

5. The method as recited in claim 1, wherein about
30% to about 40% of the reaction of the gaseous bleaching
reagent with the pulp occurs in the upstream vessel, about
30% to about 50% of the reaction occurs in the
intermediate vessel, and about 10% to about 25% of the
reaction occurs in the downstream vessel.

6. The method as recited in claim 1, wherein the
first, second and third predetermined concentrations of
the gaseous bleaching reagent are substantially equal to
one another.

7. The method as recited in claim 1, wherein the
gaseous bleaching reagent comprises ozone.

8. The method as recited in claim 1, wherein:
the upstream vessel comprises a fluffer/blower;
the intermediate vessel comprises an agitated mixer
reactor; and
the downstream vessel comprises a porous bed reactor.
9. A system for bleaching pulp with a gaseous bleaching reagent, said system comprising:

means for intensively mixing the pulp within the presence of a contacting gas including the gaseous bleaching reagent, a carrier gas, and reaction by-product gases, wherein said means for intensively mixing comprises a first, upstream vessel having a pulp inlet, a pulp outlet and a gas inlet;

means for agitating the pulp in the presence of the contacting gas, wherein said means for agitating comprises a second, intermediate vessel having a pulp inlet, a pulp outlet, a gas inlet and a pair of gas outlets, wherein said pulp outlet of said upstream vessel is in fluid communication with said pulp inlet of said intermediate vessel;

a third, downstream vessel having a pulp inlet, a pulp outlet, a gas inlet and a gas outlet, wherein said pulp outlet of said intermediate vessel is in fluid communication with said pulp inlet of said downstream vessel; and

means for supplying a first, countercurrent flow of enriched contacting gas between said downstream vessel and said intermediate vessel and for supplying a second countercurrent flow of enriched contacting gas between said intermediate vessel and said upstream vessel, wherein said means for supplying includes:

a first proportioning valve having a first inlet in fluid communication with said gas outlet of said downstream vessel, a second inlet in fluid communication with a first source of fresh
bleaching gas, and an outlet in fluid
communication with said gas inlet of said
intermediate vessel; and

a second proportioning valve having a first inlet in
fluid communication with one of said pair of
said gas outlets of said intermediate vessel, a
second inlet in fluid communication with a
second source of fresh bleaching gas, and an,
outlet in fluid communication with said gas
inlet of said upstream vessel.

10. The system as recited in claim 9, further
comprising:

a first gas analyzing means disposed in fluid
communication with said gas outlet of said downstream
vessel; and

a second gas analyzing means disposed in fluid
communication with said gas outlet of said intermediate
vessel.

11. The system as recited in claim 9, further
comprising:

means for providing fresh bleaching gas to said
downstream vessel, wherein said means for providing
includes a control valve, a first conduit interconnecting
said control valve and a third source of fresh bleaching
gas, and a second conduit interconnecting said valve and
said gas inlet of said downstream vessel.

12. The system as recited in claim 9, wherein:
said upstream vessel comprises a fluffer/blower;  
said intermediate vessel comprises an agitated mixer  
reactor; and  
said downstream vessel comprises a porous bed  
reactor.
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 D21C9/15D D21C9/153

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

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 D21C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
<td>A</td>
<td>WO 94 15018 A (INGERSOLL RAND CO) 7 July 1994 see page 6, line 30 - page 8, line 15; figures 2,3 see page 10, line 15 - line 27; figure 6</td>
<td>1,2,4,5, 7-10,12</td>
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<tr>
<td>A</td>
<td>EP 0 492 039 A (KAMYR INC) 1 July 1992 see column 5, line 2 - line 16; figure 1</td>
<td>1,3,4,7, 9,11</td>
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<tr>
<td>A</td>
<td>FR 2 672 314 A (INGERSOLL RAND CO) 7 August 1992 see page 4, line 30 - page 6, line 16; figure 1</td>
<td>1,4,5, 7-9,12</td>
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* Spinal categories of cited documents:

A' document defining the general state of the art which is not considered to be of particular relevance
B' earlier document but published on or after the international filing date
L' document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another invention or other special reason (as specified)
O' document referring to an oral disclosure, use, exhibition or other means
P' document published prior to the international filing date but later than the priority date claimed

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

X

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Date of mailing of the international search report: 7.01.97

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Txs. 31 651 epo ml, Fax (+31-70) 340-3016

Authorized officer

Bernardo Noriega, F
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<th>Category</th>
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<td>A</td>
<td>EP 0 492 040 A (KAMyr INC) 1 July 1992 see column 4, line 46 - column 5, line 30 see column 11, line 10 - line 51; figures 1-3</td>
<td>1,4,7,9</td>
</tr>
<tr>
<td>A</td>
<td>EP 0 515 303 A (UNION CAMP PATENT HOLDING INC) 25 November 1992 see page 4, line 49 - page 6, line 46; figures 1-3</td>
<td>1,4,7-9, 12</td>
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