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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

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— *with international search report (Art. 21(3))*

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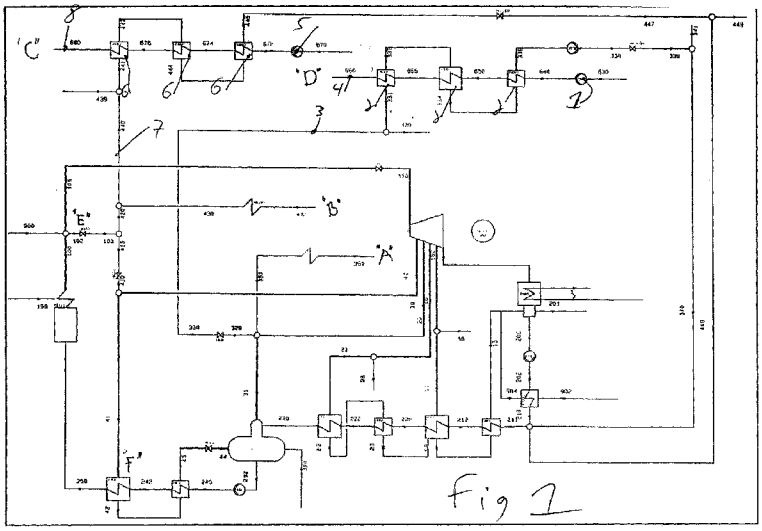
(54) **Title**: STEAM DELIVERY SYSTEM FOR BIOMASS PROCESSING



(57) **Abstract**: The present invention relates to delivery of steam produced by an electrical power generation plant to a lignocellulosic biomass refinery.

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— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Steam delivery system for biomass processing.

Inventors: Henning Andersen and Henrik Boye Jørgensen

Field

The field of the invention relates to delivery of steam produced by an electrical power generation plant to a lignocellulosic biomass refinery.

Background

The annual growth of plant lignocellulosic biomass on earth is of such great magnitude that biomass conversion is considered a fundamental feature of any sustainable future economy.

Accordingly, great interest has arisen in so-called "second generation" bioethanol, produced from lignocellulosic biomass such as crop wastes (stalks, cobs, pits, stems, shells, husks, etc...), grasses, straws, wood chips, waste paper and the like. In "second generation" technology, fermentable 6-carbon sugars, and potentially fermentable 5-carbon sugars, are liberated from biomass polysaccharide polymer chains by enzymatic hydrolysis or, in some cases, by pure chemical hydrolysis. The fermentable sugars obtained from biomass conversion can be used to produce fuel ethanol or, alternatively, other fuels such as butanol, or lactic acid monomers for use in synthesis of bioplastics, or many other products.

Because of limitations of its physical structure, lignocellulosic biomass cannot be effectively converted to fermentable sugars by enzymatic hydrolysis without some pretreatment process. A wide variety of different pretreatment schemes have been reported. Most rely on industrial chemicals such as ammonia, lime, or hydrosulfuric acid, or even on exotic "ionic liquids." However, from an environmental and "renewability" perspective, hydrothermal pretreatments are especially attractive. These utilize pressurized steam/liquid hot water at temperatures on the order of 160 – 230 o C to gently melt hydrophobic lignin that is intricately associated with cellulose strands, to solubilize a major component of hemicellulose, rich in 5 carbon

sugars, and to disrupt cellulose strands so as to improve accessibility to productive enzyme binding. Hydrothermal pretreatment does not require any added industrial chemicals and can be conveniently integrated with existing coal- and biomass-fired electrical power generation plants to efficiently utilize turbine steam and "excess" power production capacity.

The general principle has been previously reported that efficiency advantage can be obtained by integrating biomass processing facilities or "biorefineries" with electrical power or combined heat/power generation facilities. See J. Larsen et al. (2008), Chem. Eng. Technol. 31(5):765; WO2007/0094631; WO2007/138534. The power plant supplies steam for hydrothermal pretreatment and for other biorefinery processes such as distillation, evaporation and drying, with overall savings relative to direct consumption of electrical power.

We have discovered a variety of specific methods and systems that provide further improved efficiency of steam delivery from an associated power plant to a biomass refinery. These improvements are described herein.

Detailed description of preferred embodiments

Considerable advantage can be obtained where the power plant supplies steam for biomass refinery processes indirectly through a pressurized water pre-heating train.

In preferred embodiments, steam supply for the biomass refinery is produced first by pressurizing comparatively low temperature water (< 100 o C) to a desired final pressure then heating the pressurized water to a final steam temperature by means of a series of heat exchangers fed by turbine steam.

This arrangement has several advantages compared with direct use of turbine steam as previously reported. First, because turbine steam is used only indirectly, to feed a pressurized water pre-heating train, steam delivery is not associated with any significant loss of high quality "boiler water." Boilers become quickly fouled unless high quality water is used having low content of salts and dissolved substances. The requirement for "boiler quality" water is, itself, an energy consuming process that is avoided by the steam delivery systems and methods of the invention.

Second, the indirect steam delivery system is highly flexible in its steam pressure requirements. A biomass refinery powered primarily by steam typically requires steam of definite pressure. For example, hydrothermal pretreatment may requires 15 or 20 bar steam pressure, while distillation, dryers and evaporation units may require 8 or 10 bar steam pressure. For a power generation plant to be able to provide steam directly to a biomass refinery, it must be able to provide steam at an appropriate pressure. Power generation plants are typically configured so as to provide discrete extraction points where turbine steam may be extracted for other purposes. However these extraction points typically extract steam having a definite pressure. It can occur that a power generation plant is configured to provide extraction steam at pressures that do not correspond to the steam pressure requirements of the biomass refinery. Accordingly, where steam is provided directly by the power generation plant to the biomass refinery, there can often be requirement for adjustment of steam pressure from the extraction pressure to the level required by the biomass refinery. This adjustment in steam pressure level is inevitably associated with energy costs.

Surprisingly, relative to direct use of turbine steam, the overall energy cost associated with indirect use of steam to pre-heat pressurized water is offset by the savings of process energy provided by avoiding the requirement for replenishment of high quality boiler water.

Accordingly in some embodiments the invention provides a steam delivery system for biomass processing comprising

- at least one compressor for pressurizing low temperature water to pressures of at least 5 bar

- a series of heat exchangers supplied by turbine steam from an electrical power generation plant for pre-heating pressurized low temperature water to temperatures of at least 150o C, and

- means for delivering the pre-heated, pressurized water as steam having pressure of at least 5 bar to any one or more of a hydrothermal pretreatment reactor, a distillation unit, an evaporator, or a dryer.

Figure 1 shows a schematic illustration of one preferred embodiment of a system according to the invention. Two separate pre-heating trains are used to provide steam at two different final pressures of 10 and 20 bar. In one train, a compressor (1) compresses low temperature water to a final pressure of 10 bar. The compressed low temperature water is then heated by series of three counter-current heat exchangers (2) supplied with heat by extracted turbine steam (3) from an associated power generation plant. The pre-heated, pressurized water is then conveyed as steam to biomass processing devices such as distillation units, dryers and evaporators by means of steam pipeline (4). In a second train, a compressor (5) compresses low temperature water to a final pressure of 20 bar. The compressed low temperature water is then heated by series of three counter-current heat exchangers (6) supplied with heat by extracted turbine steam (7) from an associated power generation plant. The pre-heated, pressurized water is then conveyed as steam to biomass processing devices such as hydrothermal pretreatment reactors by means of steam pipeline (8).

It will be readily apparent to one skilled in the art that the pre-heating trains may be configured in a variety of different ways, depending on the level of turbine steam pressure that is available for extraction from the power generation plant. In some embodiments, it may be advantageous to include a final "super-heating" step of heat exchange fed by pre-turbine boiler steam.

In some embodiments, a steam delivery system according to the invention may be used in combination with an additional heat source. For example, 10 bar steam from a pre-heating train fed by turbine steam can be further super-heated to 20 bar steam using a gas-fired boiler. In preferred embodiments, methane gas for such a boiler can be provided by anaerobic digestion of waste water produced by the biomass refinery.

Claims

1. A steam delivery system for biomass processing comprising

- at least one compressor for pressurizing low temperature water to pressures of at least 5 bar

- a series of heat exchangers supplied by turbine steam from an electrical power generation plant for pre-heating pressurized low temperature water to temperatures of at least 150o C, and

- means for delivering the pre-heated, pressurized water as steam having pressure of at least 5 bar to any one or more of a hydrothermal pretreatment reactor, a distillation unit, an evaporator, or a dryer.

2. A method for providing steam to a biomass processing facility comprising

- compressing low temperature water < 100oC to a pressure of at least 5 bar

- heating the pressurized water through a series of heat-exchangers supplied by turbine steam from an electrical power generation plant, and

- delivering the pre-heated, pressurized water as steam having pressure of at least 5 bar to any one or more of a hydrothermal pretreatment reactor, a distillation unit, an evaporator, or a dryer.

3. The method of claim 2 further comprising super-heating by heat exchange with pre-turbine boiler steam.

4. The method of claim 2 further comprising super-heating by a gas boiler.

5. The method of claim 4 wherein gas for the boiler is methane provided by anaerobic digestion of biomass refinery waste water.

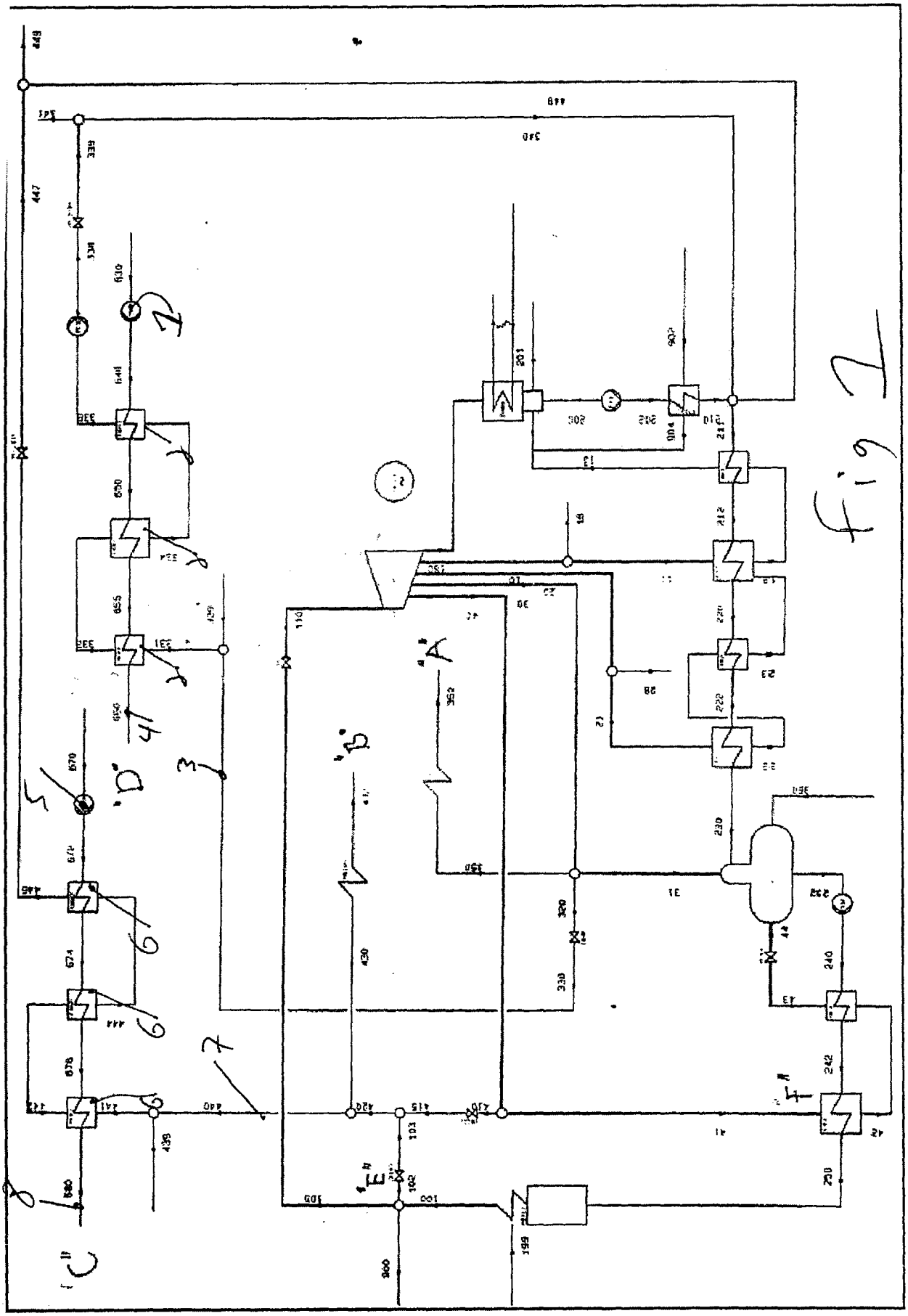

Fig 1

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
INV. C10J3/72 C10J3/20 C10J3/00 F01K17/02 F01K17/06
F01K17/04 C02F3/28 C10L9/00
ADD.
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)
C10J F01K C02F C10L

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)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 212 652 A (DUPONT ANTHONY A [US]) 15 July 1980 (1980-07-15) column 2, line 40 - column 3, line 60; figure 1	1-5
Y	EP 0 005 825 A1 (EGOSI DAN) 12 December 1979 (1979-12-12) page 34, line 26 - page 35, line 12	2-5
Y	GB 2 351 323 A (NEWTONVILLE LTD [GB]) 27 December 2000 (2000-12-27) page 5, line 11 - page 6, line 5	2-5
A	WO 97/30011 A1 (MARATHON OIL CO [US]) 21 August 1997 (1997-08-21) the whole document	1-5

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

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier 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 citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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