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(54) PROCESS FOR SUPERHEATED STEAM

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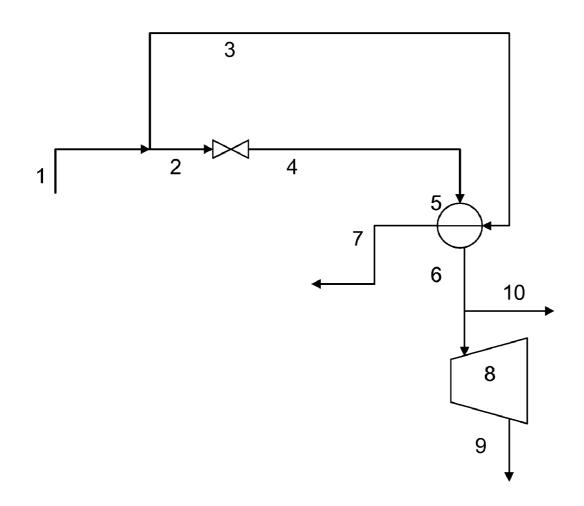
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(57)ABSTRACT

Disclosed is a process for the preparation of superheated of steam by transferring heat from at least a fraction of a high pressure steam to a lower pressure steam to produce a superheated, lower pressure steam. The high pressure steam can be generated by recovering heat from a heat producing chemical process such as, for example, the partial oxidation of carbonaceous materials. The lower pressure steam can be generated by reducing the pressure of a portion of the high pressure steam or by recovering heat from one or more chemical processes. The superheated, lower pressure steam may used to generate electricity in a steam turbine, operate a steam turbine drive, or as a heat source. Also disclosed is a process for driving a steam turbine using superheated steam produced by the process of the invention.



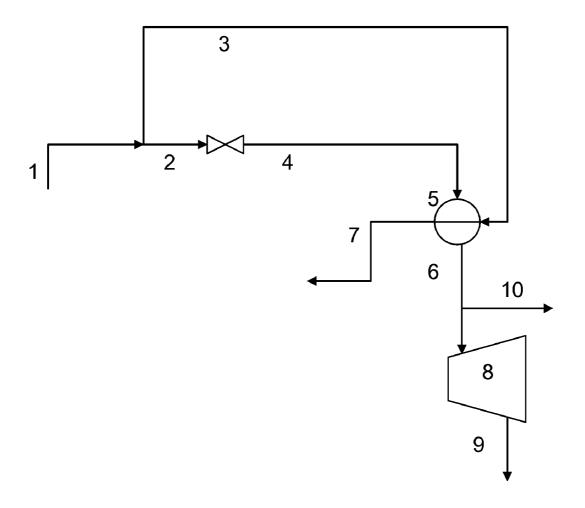


Figure 1

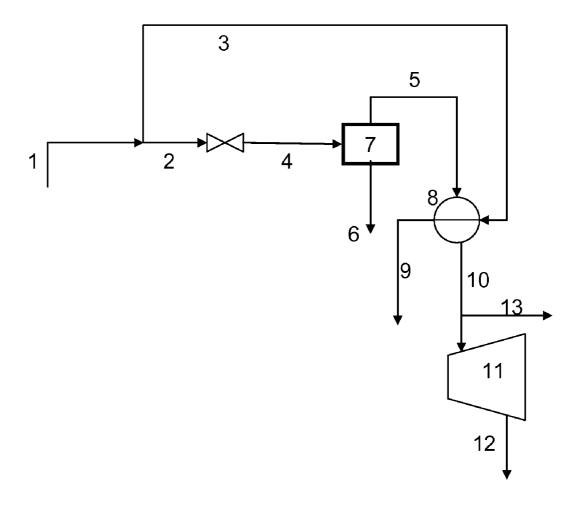


Figure 2

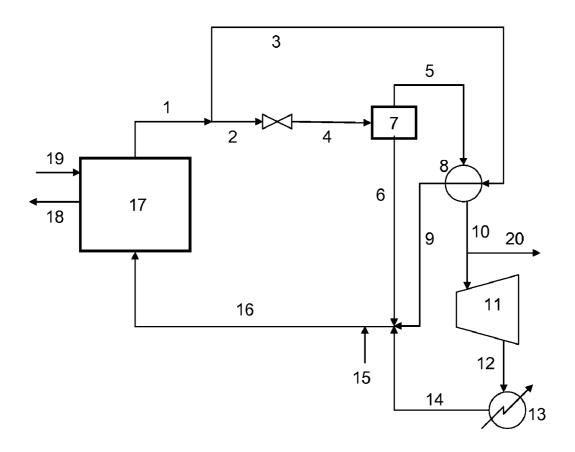


Figure 3

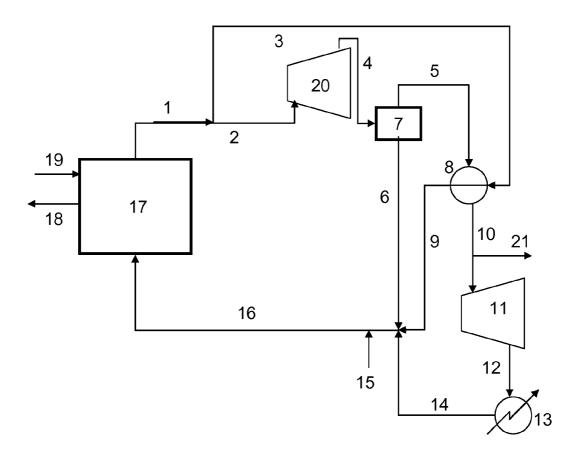


Figure 4

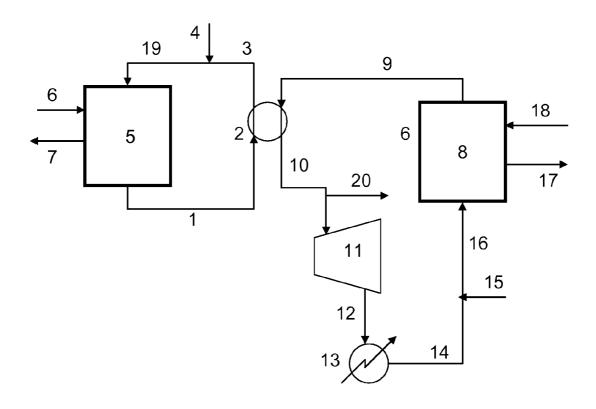


Figure 5

PROCESS FOR SUPERHEATED STEAM

FIELD OF THE INVENTION

[0001] This invention relates in general to a process for the preparation of superheated steam. More particularly, this invention relates to a process for the preparation of superheated steam by transferring heat from at least a fraction of a high pressure steam to a lower pressure steam to produce a superheated, lower pressure steam. The lower pressure steam can be generated by reducing the pressure of a portion of a high pressure steam or by recovering heat from one or more chemical processes. The superheated, lower pressure steam may used to generate electricity in a steam turbine, operate a steam turbine drive, or as a heat source.

BACKGROUND OF THE INVENTION

[0002] Many industrially significant chemical reactions are highly exothermic and the heat of reaction is used to generate steam. Examples of steam generating chemical processes include ethylene oxide production by partial oxidation of ethylene, methanol production from synthesis gas, gasification or partial oxidation of carbonaceous materials, formaldehyde production from methanol, production of Fischer-Tropsch hydrocarbons or alcohols from synthesis gas, ammonia production from hydrogen and nitrogen, and the water-gas shift reaction to produce hydrogen from carbon monoxide and water. In such processes, the saturated steam, that is steam at its dew point for the prevailing pressure and temperature conditions, typically is generated by cooling of reactors or as a post-reaction heat removal technique. The amount of steam generated, however, often can exceed the heating needs within the battery limits of the process itself.

[0003] In addition to its use as a heating medium, steam thus generated can be used as a source of work to generate electricity in a turbogenerator or as motive force to drive machinery such as a turbine-driven compressor or pump. During the expansion process in turbomachinery, a portion of the enthalpy of the inlet high pressure steam is converted to motive work, and is converted to a lower pressure, cooler steam that exits the turbine. Such processes are described for example in "Steam, Its Generation and Use", Babcock and Wilcox Co, New York, 37th Edition, 1960, Chapter 10, pp. 10-1 to 10-22.

[0004] Although either saturated or superheated steam can be used in turbomachinery, it is well-known in the art that the thermodynamic efficiency (useful work energy out divided by enthalpy input) is proportional to the amount of superheat. An example of this phenomenon is shown in FIG. 10, pg. 10-8, of the above reference, in which the thermodynamic efficiency is 39.7% for the expansion of 100 bara saturated steam across a steam turbine to 0.485 bara. By contrast, a 42.6% efficiency is achieved for the same pressure differential with the steam superheated by 167° C. prior to introduction to the turbine.

[0005] Often during the expansion process, a fraction of the vaporous steam feed condenses and forms liquid water. Generation of liquid water within the turbine results in formation of water droplets, these droplets strike the turbine blades with great force and cause erosive wear over time. The amount of liquid water generated in the turbine is a complex function of the degree of superheat of the inlet steam, the pressure differential across the turbine, and the

mechanical efficiency of the turbine. For example, if 100 bara saturated steam is expanded across a steam turbine to 0.485 bara at 85% efficiency, the quality (i.e., the fraction of a wet steam that is in the vapor state) of the outlet steam is 73.4%, whereas introduction into the same steam turbine of 100 bara saturated steam superheated by 200° C. results in an outlet quality of 87.5%. Alternatively if 50 bara saturated steam is expanded to 0.485 bara, the outlet steam quality is 74.8%. If the degree of superheat is high enough no liquid water will form. For a 100 bara to 0.485 bara expansion at 85% mechanical efficiency, the outlet quality is 100% if the inlet steam is superheated by at least 495° C.

[0006] It is well known that the use of saturated steam as the motive force in turbomachinery causes increased erosive wear and resulting higher maintenance costs as compared to the use of superheated steam. Typically, an outlet quality of at least 75% is preferred, an outlet quality of 85% or higher is more preferable. With many steam generating chemical processes, however, no high temperature heat source of sufficient quantity is available to superheat the steam thus generated. Although it is possible to burn a portion of either the raw material, product, by-product streams, or an externally supplied fuel to provide a high temperature heat source useful for superheating steam, this method is hampered by the wasteful consumption of raw materials, insufficient availability of by-products, or requires the purchase of expensive fuels and additional capital for the combustor and associated heat exchangers. Thus, there is a need to provide a means for superheating steam from steam generating chemical processes without undue capital or fuel costs.

SUMMARY OF THE INVENTION

[0007] In one embodiment of the invention, I have discovered that high pressure steam generated in a chemical process may be conveniently and economically used to produce a superheated steam by reducing the pressure of a portion of the high pressure steam to produce a lower pressure steam and using the remaining portion of the high pressure steam to superheat the lower pressure steam. Accordingly, a process for the preparation of superheated steam is set forth comprising:

[0008] (a) recovering heat from at least one chemical process to produce a high pressure steam;

[0009] (b) reducing the pressure of a portion of the high pressure steam of step (a) to produce a lower pressure steam and a remaining portion of the high pressure steam; and

[0010] (c) transferring heat from at least a fraction of the remaining portion of the higher pressure steam of step (b) to the lower pressure steam to produce a superheated steam from the lower pressure steam.

The process of the invention may be used in conjunction with a variety of chemical processes. For example, the high pressure steam may be generated from at least one chemical process selected from partial oxidation, carbonylation, hydrogenation, and homologation. Representative examples of chemical processes include, but are not limited to, gasification of carbonaceous materials to produce synthesis gas, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, partial oxidation of ethylene to produce ethylene oxide, steam reforming of

methane to produce synthesis gas, partial oxidation of methanol to produce formaldehyde, production of Fischer-Tropsch hydrocarbons or alcohols from synthesis gas, ammonia production from hydrogen and nitrogen, autothermal reforming of carbonaceous feedstocks to produce synthesis gas, hydrogenation of dimethyl terephthalate to cyclohexanedimethanol, carbonylation of methanol to acetic acid, the water-gas shift reaction to produce hydrogen and carbon dioxide from carbon monoxide and water, or a combination thereof. The superheated, lower pressure steam can be used to generate electricity in a steam turbine, operate a steam turbine drive, or as a heat source.

[0011] The process of the invention may be used advantageously with processes that produce syngas by the partial oxidation of carbonaceous materials. Such processes, either alone or in combination with other chemical processes, frequently produce abundant or excessive amounts of high pressure steam but are deficient in superheated steam. Hence, another aspect of the invention is a process for the preparation of superheated steam, comprising:

[0012] (a) reacting a carbonaceous material with oxygen, water, or carbon dioxide to produce heat and a syngas stream comprising hydrogen, carbon monoxide, and carbon dioxide;

[0013] (b) recovering the heat to produce a high pressure steam; and

[0014] (c) transferring heat from at least a fraction of the high pressure steam of step (b) to a lower pressure steam by indirect heat exchange to produce a superheated steam from the lower pressure steam.

The carbonaceous material may include, but is not limited to, methane, petroleum residuum, carbon monoxide, coal, coke, lignite, oil shale, oil sands, peat, biomass, petroleum refining residues, petroleum cokes, asphalts, vacuum resid, heavy oils, or combinations thereof, and can be reacted with oxygen in a gasifier, partial oxidizer, or reformer. The lower pressure steam may be obtained by reducing the pressure of a portion of the high pressure steam or by recovery of heat from at least one chemical process such as, for example a water-gas shift reaction, hydrogenation of carbon monoxide to produce methanol, hydrogenation of nitrogen to produce ammonia, carbonylation of methanol to produce acetic acid, Fischer-Tropsch processes, production of alkyl formates from carbon monoxide and alcohols, and combinations thereof.

[0015] In yet another aspect of the invention, the high pressure steam can be produced by recovering heat from a gasifier and can be used to generate a superheated steam which, in turn, can be used to drive a steam turbine. Thus, the invention also provides a process for driving a steam turbine, comprising:

[0016] (a) reacting a carbonaceous material with oxygen in a gasifier to produce heat and a syngas stream comprising hydrogen, carbon monoxide, and carbon dioxide;

[0017] (b) recovering the heat to produce a high pressure steam;

[0018] (c) transferring heat from at least a fraction of the high pressure steam of step (b) to a lower pressure steam

by indirect heat exchange to produce a superheated steam from the lower pressure steam; and

[0019] (d) passing the superheated steam to a steam turbine.

The steam turbine can be used to drive a generator to produce electricity or drive a gas compressor. For example, the gasifier and turbine may be part of an integrated gasification combined cycle (abbreviated herein as "IGCC") power plant, which may further comprise a chemical producing plant to convert excess syngas into fuel or salable chemicals.

BRIEF DESCRIPTION OF DRAWINGS

[0020] FIGS. 1-5 are schematic flow diagrams that illustrate several embodiments of the process of the invention.

DETAILED DESCRIPTION

[0021] In a general embodiment, the present invention provides a novel process for superheating steam in which high pressure steam generated in a chemical process can be used advantageously to produce a superheated steam without the use of an external heat source. It has been discovered that a portion of the high pressure steam may be reduced in pressure to produce a lower pressure steam and that the remaining portion of the high pressure steam can be used to superheat the lower pressure steam to produce a superheated steam. Accordingly, a process for the preparation of superheated steam is set forth comprising:

[0022] (a) recovering heat from at least one chemical process to produce a high pressure steam;

[0023] (b) reducing the pressure of a portion of the high pressure steam of step (a) to produce a lower pressure steam and a remaining portion of the high pressure steam; and

[0024] (c) transferring heat from at least a fraction of the remaining portion of the higher pressure steam of step (b) to the lower pressure steam to produce a superheated steam from the lower pressure steam.

The high pressure steam can be generated from a variety of chemical processes such as, for example, partial oxidation, carbonylation, hydrogenation, and homologation. Some representative examples of chemical processes include, but are not limited to, gasification of carbonaceous materials to produce synthesis gas, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, partial oxidation of ethylene to produce ethylene oxide, steam reforming of methane to produce synthesis gas, partial oxidation of methanol to produce formaldehyde, production of Fischer-Tropsch hydrocarbons or alcohols from synthesis gas, ammonia production from hydrogen and nitrogen, autothermal reforming of carbonaceous feedstocks to produce synthesis gas, hydrogenation of dimethyl terephthalate to cyclohexanedimethanol, carbonylation of methanol to acetic acid, water-gas shift reaction to produce hydrogen and carbon dioxide from carbon monoxide and water, or a combination thereof. The superheated, lower pressure steam may used to generate electricity with a steam turbine, operate a steam turbine drive, or as a heat source.

[0025] Unless otherwise indicated, all numbers expressing quantities of ingredients, properties such as molecular weight, reaction conditions, and so forth used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification and attached claims are approximations that may vary depending upon the desired properties sought to be obtained by the present invention. At the very least, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Further, the ranges stated in this disclosure and the claims are intended to include the entire range specifically and not just the endpoint(s). For example, a range stated to be 0 to 10 is intended to disclose all whole numbers between 0 and 10 such as, for example 1, 2, 3, 4, etc., all fractional numbers between 0 and 10, for example 1.5, 2.3, 4.57, 6.113, etc., and the endpoints 0 and 10. Also, a range associated with chemical substituent groups such as, for example, "C1 to C5 hydrocarbons", is intended to specifically include and disclose C₁ and C₅ hydrocarbons as well as C₂, C₃, and C₄ hydrocarbons.

[0026] Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in their respective testing measurements and/or calculations.

[0027] As used in the specification and the appended claims, the singular forms "a,""an" and "the" include their plural referents unless the context clearly dictates otherwise. For example, references to a "heat exchanger," or a "steam flow," is intended to include the one or more heat exchangers, or steam flows. References to a composition or process containing or including "an" ingredient or "a" step is intended to include other ingredients or other steps, respectively, in addition to the one named.

[0028] The term "containing" or "including", as used herein, is intended to be synonymous with the term "comprising"; that is at least the named compound, element, particle, or process step, etc., is present in the composition or article or process, but does not exclude the presence of other compounds, catalysts, materials, particles, process steps, etc, even if the other such compounds, material, particles, process steps, etc., have the same function as what is named, unless expressly excluded in the claims.

[0029] It is also to be understood that the mention of one or more process steps does not preclude the presence of additional process steps before or after the combined recited steps or intervening process steps between those steps expressly identified. Moreover, the lettering of process steps or ingredients is a convenient means for identifying discrete activities or ingredients and the recited lettering can be arranged in any sequence, unless otherwise indicated.

[0030] The process of the invention comprises recovering heat from a least one chemical process to produce a high pressure steam. The high pressure steam used in the instant invention may be saturated or superheated. The recovery of heat may be from any chemical process which produces sufficient heat to produce steam having a pressure of about

4 bara. The term bara, as used herein means "bar absolute". Steam at about 4 bara or higher may be dropped in pressure and superheated to useful levels by means laid out in this invention. In such processes, typically saturated steam, i.e., steam at its dew point for the prevailing pressure and temperature conditions, is generated by cooling of reactors or as a post-reaction heat removal technique. Alternatively, the lower pressure steam derived from the steam generating chemical process may be superheated, but with a degree of superheat lower than desired. In this latter case, the lower pressure steam may be subjected to the steps of the instant invention to further increase its degree of superheat.

[0031] Representative examples of such heat producing chemical processes include, but are not limited to, partial oxidation, carbonylation, hydrogenation, water-gas shift reaction, steam reforming, and homologation. More specific, non-limiting examples of chemical processes which may be used in the process of the invention include gasification of carbonaceous materials to produce synthesis gas, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, partial oxidation of ethylene to produce ethylene oxide, steam reforming of methane to produce synthesis gas, partial oxidation of methanol to produce formaldehyde, production of Fischer-Tropsch hydrocarbons or alcohols from synthesis gas, ammonia production from hydrogen and nitrogen, autothermal reforming of carbonaceous feedstocks to produce synthesis gas, hydrogenation of dimethyl terephthalate to cyclohexanedimethanol, carbonylation of methanol to acetic acid, water-gas shift reaction to produce hydrogen and carbon dioxide from carbon monoxide and water, or a combination thereof.

[0032] The chemical process can, for example, include the partial oxidation of a carbonaceous material by reaction with oxygen, water, or carbon dioxide to produce heat and syngas stream comprising hydrogen, carbon monoxide, and carbon dioxide. The term "carbonaceous", as used herein, means the various, suitable feedstocks that contain carbon and is intended to include gaseous, liquid, and solid hydrocarbons, hydrocarbonaceous materials, and mixtures thereof. Substantially any combustible carbon-containing organic material, or slurries thereof, may be included within the definition of the term "carbonaceous". Solid, gaseous, and liquid feeds may be mixed and used simultaneously; and these may include paraffinic, olefinic, acetylenic, naphthenic, and aromatic compounds in any proportion. Also included within the definition of the term "carbonaceous" are oxygenated carbonaceous organic materials including carbohydrates, cellulosic materials, aldehydes, organic acids, alcohols, ketones, carbon monoxide, oxygenated fuel oil, waste liquids and by-products from chemical processes containing oxygenated carbonaceous organic materials, and mixtures thereof. The term "syngas", as used herein, is intended to be synonymous with the term "synthesis gas" and understood to mean a gaseous mixture of varying composition comprising primarily hydrogen, carbon monoxide, and various impurities depending on its method of generation. The partial oxidation process, for example, may comprise steam or carbon dioxide reforming of carbonaceous materials such as, for example, natural gas or petroleum derivatives. These processes are well known to persons skilled in the art and are practiced commercially. In another example, the partial oxidation process may comprise gasification of carbonaceous materials such as, for example, methane, coal, coke, lignite, oil shale, oil sands, peat, biomass, petroleum refining residues, petroleum cokes, asphalts, vacuum resid, heavy oils, or combinations thereof, by reaction with oxygen to produce syngas and heat. The term "oxygen", as used herein, is intented to include substantially pure gaseous, elemental oxygen, or any reactive O₂-containing gas, such as air, substantially pure oxygen having greater than about 90 mole percent oxygen, or oxygen-enriched air having greater than about 21 mole percent oxygen. Substantially pure oxygen is preferred in the industry. To obtain substantially pure oxygen, air is compressed and then separated into substantially pure oxygen and substantially pure nitrogen in an air separation plant. Such plants are known in the industry.

[0033] Any one of several known gasification processes can be incorporated into the process of the instant invention. These gasification processes generally fall into broad categories as laid out in Chapter 5 of "Gasification", (C. Higman and M. van der Burgt, Elsevier, 2003). Examples are moving bed gasifiers such as the Lurgi dry ash process, the British Gas/Lurgi slagging gasifier, the Ruhr 100 gasifier; fluid-bed gasifiers such as the Winkler and high temperature Winkler processes, the Kellogg Brown and Root (KBR) transport gasifier, the Lurgi circulating fluid bed gasifier, the U-Gas agglomerating fluid bed process, and the Kellogg Rust Westinghouse agglomerating fluid bed process; and entrained-flow gasifiers such as the Texaco, Shell, Prenflo, Noell, E-Gas (or Destec), CCP, Eagle, and Koppers-Totzek processes. The gasifiers contemplated for use in the process may be operated over a range of pressures and temperatures between about 1 to about 103 bar absolute and 400° C. to 2000° C., with preferred values within the range of about 21 to about 83 bara and temperatures between 500° C. to 1500° C. Depending on the carbonaceous or hydrocarbonaceous feedstock used therein and type of gasifier utilized to generate the gaseous carbon monoxide, carbon dioxide, and hydrogen, preparation of the feedstock may comprise grinding, and one or more unit operations of drying, slurrying the ground feedstock in a suitable fluid (e.g., water, organic liquids, supercritical or liquid carbon dioxide). Typical carbonaceous materials which can be oxidized to produce syngas include, but are not limited to, petroleum residuum, bituminous, subbituminous, and anthracitic coals and cokes, lignite, oil shale, oil sands, peat, biomass, petroleum refining residues, petroleum cokes, and

[0034] The heat produced in the chemical process may be recovered by any heat exchange means known in the art including, but not limited to, radiant heat exchange, convective heat exchange, or a combination thereof to produce a high pressure steam. For example, in gasification processes, the heat may be recovered using at least one of the following types of heat exchangers selected from steam generating heat exchangers (i.e., boilers), wherein heat is transferred from the syngas to boil water; shell and tube; plate and frame; spiral; or combinations of one or more of these heat exchangers. For example, the heat from the gasification process can be recovered by radiant heat exchange. Convective heating or cooling occurs by transfer of heat from one point within a fluid (gas or liquid) by mixing of one portion of the fluid with another portion. A typical indirect heat exchange process will involve transfer of heat to or from a solid surface (often a tube wall) to a fluid element adjacent to the wall, then by convection into the bulk fluid phase. Radiant heat transfer involves the emission of electromagnetic energy from matter excited by temperature and absorption of the emitted energy by other matter at a distance from the source of emission. For example, the raw syngas leaves the gasifier and can be cooled in a radiant syngas cooler. The recovered heat is used to generate high pressure steam. Radiant syngas coolers are known in the art and may comprise, for example, at least one ring of vertical water cooled tubes, such as shown and described in U.S. Pat. Nos. 4,310,333 and 4,377,132.

[0035] The use of multiple steam generating heat exchangers also is contemplated to be within the scope of the instant invention. Steam and condensate generated within gas cooling zones may embody one or more steam products of different pressures. The gas cooling zones optionally may comprise other absorption, adsorption, or condensation steps for removal of trace impurities, e.g., such as ammonia, hydrogen chloride, hydrogen cyanide, and trace metals such as mercury, arsenic, and the like.

[0036] The high pressure steam can be saturated or superheated and typically will have a pressure of about 4 to about 140 bara. In another example, the high pressure steam can have a pressure of about 20 to about 120 bara. A portion of the high pressure steam can be reduced in pressure to produce a lower pressure steam and a remaining portion of the high pressure steam. If the high pressure steam is superheated, the lower pressure steam also may be superheated but to an insufficient degree. The terms "high pressure steam" and "lower pressure steam", as used herein, are intended to indicate the relative and not absolute pressures of the various steam flows of the present invention. As used herein in the context of the claims and description, "high pressure steam" is intended to mean steam from which heat is transferred, wherein the term "lower pressure steam" means steam to which heat is transferred. Representative examples of portions or fractions of the high pressure steam that can be let down or expanded to produce the lower pressure steam are about 40 to about 95 mass %, about 50 to about 80 mass %, about 60 to about 95 mass %, about 70 to about 95 mass %, and about 75 to about 95 mass %, based on the total mass of the high pressure steam. Any means known in art may be used to reduce the pressure of the high pressure steam; however, it will be evident to persons skilled in the art that generation of a lower pressure steam will involve expanding a portion of the high pressure steam. For example, the process of the invention may comprise expanding a portion of the high pressure steam through a valve, a turbine, or a combination thereof. Typically, the ratio of the pressures of the high to lower pressure steams will be 140:1 to 1.5:1, 100:1 to 2:1, 25:1 to 2:1, or 10:1 to 2:1. In addition, the higher pressure steam and the lower pressure steam typically will have a difference in water saturation temperature of about 40° C. to about 250° C.

[0037] According to the invention, heat can be transferred from at least a fraction of the remaining portion of the higher pressure steam to the lower pressure steam to produce a superheated steam from the lower pressure steam or increase the degree of superheat if the lower pressure steam is already superheated. The term "superheated", as used herein, is understood to mean that the lower pressure steam is heated above its dew point at a given pressure or, if it is already superheated, its degree of superheat increased. The amount of superheat typically is at least 40° C. Other examples of superheat are from about 20° C. to about 250° C., from about 50° C. to, at least 150° C., and at least 50° C. to about 125°

C. The heat exchange between the low and high pressure steam can occur by indirect methods using any device known in the art, including shell and tube heat exchangers, plate and frame exchangers, spiral exchangers, and compact plate-fin exchangers. "Indirect heat exchange", as used herein, is understood to mean the exchange of heat across a surface without mixing as opposed to "direct heat exchange" in which the high and lower pressure steam are mixed together. Typically, the heat exchanger is of shell and tube design, with the condensing high pressure steam on the shell side. The heat exchange process may be implemented as multiple heat exchangers in series.

[0038] The approach temperature, i.e., the temperature difference between the superheated lower pressure steam and the temperature of the high pressure steam, is typically from about 1 to about 20° C. Other examples of approach temperatures are from about 1 to about 10° C. and from about 1 to about 5° C. Although, desired to be as low as possible, the practical limit to the approach temperature is strongly dictated by economics. The area required for heat transfer increases logarithmically with a decrease in approach temperature.

[0039] The lower pressure steam subjected to heat exchange against the remaining portion of high pressure steam may have a quality less than or equal to unity depending on the temperature and pressure conditions of the inlet high pressure steam as well as the outlet pressure. The term "quality", as used herein with respect to steam, means the mass fraction of vapor in the vapor phase with respect to the total mass of water and vapor in the steam. If desired, liquid water may be removed from the lower pressure steam by any means known in the art such as described in "Phase Segregation", Chapter 3, pp. 129-148, L. J. Jacobs and W. R. Penney, in Handbook of Separation Process Technology, R. W. Rousseau, ed., Wiley & Sons, 1987, including knockout pots, pipe separators, mesh pads, centrifugal vanes, tangential entry separators, demister or coalescer pads, wavy plates, packing, cyclone or venturi scrubbers, electrostatic precipitators, and the like.

[0040] The superheated, lower pressure steam generated in the instant invention may used to generate electricity in a steam turbine, operate a steam turbine drive, or as a heat source. Typically, the superheated, lower pressure steam can be passed to a steam turbine where is used to supply motive force to operate a compressor or a generator. When passed to a steam turbine, the degree of superheating of the lower pressure steam produced in the process of the invention generally will produce outlet quality of about 75% to about 100%. Other examples of outlet quality for the steam exiting the steam turbine are about 80% to about 100% and about 85% to about 100%.

[0041] The superheated steam process of the present invention, in particular, may be used in conjunction with processes that produce syngas by the partial oxidation of carbonaceous materials such as, for example, gasification or steam reforming of methane. Such processes, either alone or in combination with other chemical processes frequently produce abundant or excessive amounts of high pressure steam but are deficient in superheated steam. Therefore, another aspect of the invention is a process for the preparation of superheated steam, comprising:

[0042] (a) reacting a carbonaceous material with oxygen, water, or carbon dioxide to produce heat and a syngas stream comprising hydrogen, carbon monoxide, and carbon dioxide;

[0043] (b) recovering the heat to produce a high pressure steam; and

[0044] (c) transferring heat from at least a fraction of the high pressure steam of step (b) to a lower pressure steam by indirect heat exchange to produce a superheated steam from the lower pressure steam.

The above process is understood to include the various embodiments of heat recovery, heat exchange, steam pressure, steam turbines, steam pressure reduction, steam quality, etc., as set forth hereinabove in any combination. For example, the carbonaceous material can be reacted with oxygen, water, or carbon dioxide to produce heat and syngas stream comprising hydrogen, carbon monoxide, and carbon dioxide. As described above, carbonaceous materials can include, but are not limited to, methane, petroleum residuum, coal, coke, lignite, carbon monoxide, oil shale, oil sands, peat, biomass, petroleum refining residues, petroleum cokes, asphalts, vacuum resid, heavy oils, or combinations thereof. The carbonaceous material may be reacted in any type partial oxidation reactor known in the art such as, for example, a gasifier, partial oxidizer, or reformer. In one embodiment, for example, the carbonaceous material can comprise methane and is reacted with water in a reformer. In another example, the carbonaceous material may comprise coal or petroleum coke and is reacted with oxygen in a gasifier. In yet another example, the carbonaceous material comprises carbon monoxide and is reacted with water in a water-gas shift reaction.

[0045] The heat produced by the syngas process can be recovered by radiant heat exchange, convective heat exchange, or a combination thereof to produce a high pressure steam as described previously. The high pressure steam can be saturated or superheated and, typically, will have a pressure of about 4 to 140 bara or, in another example, about 20 to 120 bara. A portion of the high pressure steam can be reduced in pressure to produce a lower pressure steam and a remaining portion of the high pressure steam. Any means known in art may be used to reduce the pressure of the high pressure steam such as, for example, expanding a portion of the high pressure steam through a valve, a turbine, or combination thereof.

[0046] The lower pressure steam also may be produced by recovering heat from one or more chemical processes in addition to and distinct from the process used to generate the high pressure steam. Representative examples of chemical processes which can be used include the water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, hydrogenation of nitrogen to produce ammonia, carbonylation of methanol to produce acetic acid, Fischer-Tropsch processes, production of alkyl formates from carbon monoxide and alcohols, and combinations thereof. Heat recovery can be accomplish by heat exchange techniques well known in the art and described hereinabove. In another embodiment, the chemical process may include the water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, hydrogenation of nitrogen to produce ammonia, or a combination thereof.

[0047] Typically the water-gas shift reaction is accomplished in a catalyzed fashion by methods known in the art. The water gas shift catalyst is advantageously sulfur-tolerant. For example, such sulfur tolerant catalysts can include, but are not limited to, cobalt-molybdenum catalysts. Operating temperatures are typically 250° C. to 500° C. Alternatively, the water-gas shift reaction may be accomplished, after sulfur removal from the carbon monoxide-containing reactant gas, using high or low temperature shift catalysts. High temperature shift catalysts, for example iron-oxide promoted with chromium or copper, operate in the range of 300° C. to 500° C. Low temperature shift catalysts, for example, copper-zinc-aluminum catalysts, operate in the range of 200° C. to 300° C. Alternatively, the water-gas shift reaction may be accomplished without the aid of a catalyst when the temperature of the gas is greater than about 900° C. Because of the highly exothermic nature of the water-gas shift reaction, steam may be generated by recovering heat from the exit gases of the water-gas shift reactor. The water-gas shift reaction may be accomplished in any reactor format known in the art for controlling the heat release of exothermic reactions. Examples of suitable reactor formats are single stage adiabatic fixed bed reactors; multiple-stage adiabatic fixed bed reactors with interstage cooling, steam generation, or cold-shotting; tubular fixed bed reactors with steam generation or cooling; or fluidized beds.

[0048] The process of hydrogenation of carbon monoxide or carbon dioxide to produce methanol can comprise any type of methanol synthesis plant that is well known to persons skilled in the art, many of which are widely practiced on a commercial basis. Most commercial methanol synthesis plants operate in the gas phase at a pressure range of about 25 to about 140 bara using various copper based catalyst systems depending on the technology used. A number of different state-of-the-art technologies are known for synthesizing methanol such as, for example, the ICI (Imperial Chemical Industries) process, the Lurgi process, and the Mitsubishi process. Liquid phase processes are also well known in the art. Thus, the methanol process according to the present invention may comprise a fixed bed methanol reactor, containing a solid or supported catalyst, or liquid slurry phase methanol reactor, which utilizes a slurried catalyst in which metal or supported catalyst particles are slurried in an unreactive liquid medium such as, for example, mineral oil.

[0049] Typically, a syngas stream is supplied to a methanol reactor at the pressure of about 25 to about 140 bara, depending upon the process employed. The syngas then reacts over a catalyst to form methanol. The syngas stream may or may not contain carbon dioxide in addition to hydrogen and carbon monoxide. The reaction is exothermic; therefore, heat removal is ordinarily required. The raw or impure methanol is then condensed and may be purified to remove impurities such as higher alcohols including ethanol, propanol, and the like or, burned without purification as fuel. The uncondensed vapor phase comprising unreacted syngas feedstock typically is recycled to the methanol process feed.

[0050] The chemical process also can include the hydrogenation of nitrogen to produce ammonia. This process can be carried by the Haber-Bosch process by means known in the art as exemplified by LeBlance et al in "Ammonia", Kirk-Othmer Encyclopedia of Chemical Technology, Volume 2, 3rd Edition, 1978, pp. 494-500.

[0051] In another embodiment of the invention, the chemical process can comprise a Fischer-Tropsch process for the production of hydrocarbons and alcohols from syngas as exemplified in U.S. Pat. Nos. 5,621,155 and 6,682,711. Typically, the Fischer-Tropsch reaction may be effected in a fixed bed, in a slurry bed, or in a fluidized bed reactor. The Fischer-Tropsch reaction conditions may include using a reaction temperature of between 190° C. and 340° C., with the actual reaction temperature being largely determined by the reactor configuration. For example, when a fluidized bed reactor is used, the reaction temperature is preferably between 300° C. and 340° C.; when a fixed bed reactor is used, the reaction temperature is preferably between 200° C. and 250° C.; and when a slurry bed reactor is used, the reaction temperature is preferably between 190° C. and 270° C.

[0052] In one embodiment, the process of the invention can be used in an integrated combined cycle power plant in which coal or petroleum coke is reacted with oxygen to produce syngas and that syngas is used to fuel a combustion turbine for the generation of electricity and for the coproduction of chemicals such as, for example, methanol, Fischer-Tropsch hydrocarbons, or ammonia. Recovery of heat from the gasification process can be used to generate a high pressure steam which, in turn, can be used to superheat a lower pressure steam that is generated by heat recovery from the chemical process or by reducing a portion of the pressure of the high pressure steam.

[0053] As described above, heat can be transferred from at least a fraction of the higher pressure steam to the lower pressure steam to produce a superheated, lower pressure steam. The superheated lower pressure steam may used to generate electricity in a steam turbine, operate a steam turbine drive, or as a heat source. When passed to a steam turbine, the degree of superheating of the lower pressure steam produced in the process of the invention generally will produce outlet quality of about 75% to about 100%. Other examples of outlet quality for the steam exiting the steam turbine are about 80% to about 100% and about 85% to about 100%.

[0054] The present invention also provides a process for driving a steam turbine using superheated, lower pressure steam produced by exchanging heat between a high pressure steam and a lower pressure steam as described hereinabove. Thus, another aspect of the invention is a process for driving a steam turbine, comprising:

[0055] (a) reacting a carbonaceous material with oxygen in a gasifier to produce heat and a syngas stream comprising hydrogen, carbon monoxide, and carbon dioxide;

[0056] (b) recovering the heat to produce a high pressure steam:

[0057] (c) transferring heat from at least a fraction of the high pressure steam of step (b) to a lower pressure steam by indirect heat exchange to produce a superheated steam from the lower pressure steam; and

[0058] (d) passing the superheated steam to a steam turbine.

The above process is understood to include the various embodiments of heat recovery, heat exchange, steam pressure, steam turbines, steam pressure reduction, steam quality, etc., as set forth hereinabove in any combination. Our process comprises reacting a carbonaceous material such as, for example, petroleum residuum, coal, coke, lignite, oil shale, oil sands, peat, biomass, petroleum refining residues, petroleum cokes, asphalts, vacuum resid, heavy oils, or combinations thereof, in a gasifier to produce a syngas stream. Typically, the carbonaceous material will comprise coal or petroleum coke and is reacted with oxygen or oxygen-containing gas in a gasifier

[0059] The heat produced by the gasification process can be recovered by radiant heat exchange, convective heat exchange, or a combination thereof to produce a high pressure steam as described previously. Typically, the heat from the gasification process is recovered by radiant heat exchange. The high pressure steam can be saturated or superheated and, typically, will have a pressure of about 4 to 140 bara or, in another example, about 20 to 120 bara.

[0060] The lower pressure steam may be produced, as described above, by reducing the pressure of a portion of the high pressure steam or by recovering heat from one or more chemical processes in addition to and distinct from the process used to generate the high pressure steam. Representative examples of chemical processes which can be used have been described previously and include the water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, hydrogenation of nitrogen to produce ammonia, carbonylation of methanol to produce acetic acid, Fischer-Tropsch processes, production of alkyl formates from carbon monoxide and alcohols, and combinations thereof. In another embodiment, the chemical process comprises a water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, hydrogenation of nitrogen to produce ammonia, or a combination thereof. In yet another embodiment, the chemical process comprises hydrogenation of carbon monoxide or carbon dioxide to produce methanol. In yet another embodiment, the chemical process may include the water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, hydrogenation of nitrogen to produce ammonia, or a combination thereof. Heat recovery can be accomplish by heat exchange techniques well known in the art and described hereinabove.

[0061] Heat can be transferred from at least a fraction of the higher pressure steam of to the lower pressure steam to produce a superheated, lower pressure steam as described previously. The superheated, lower pressure steam may be passed to steam turbine, which may be used to drive a generator to produce electricity or to drive a gas compressor. The degree of superheating of the lower pressure steam produced in the process of the invention generally will produce outlet quality of about 75% to about 100%. Other examples of outlet quality for the steam exiting the steam turbine are about 80% to about 100% and about 85% to about 100%.

[0062] Several embodiments of the process of the invention are are illustrated herein with particular reference to FIGS. 1-5. In the embodiment set forth in FIG. 1, a portion of the high pressure steam flowing in conduit 1 is directed to conduit 2 and passed through a control valve to produce lower pressure steam 4. Conduit 4 may comprise lower pressure steam with a quality less than or equal to unity,

depending on the temperature and pressure conditions of steam 2. Steam 4 is passed through one side of a heat exchange device 5 wherein, steam 4 is superheated by indirect contact with the remaining portion of the high pressure steam flowing via conduit 3 to the other side of heat exchange device 5. Superheated lower pressure steam emerges from heat exchange device 5 via conduit 6. Condensate and any remaining vapor fraction of the high pressure steam exits via conduit 7. A fraction of superheated steam 6 may be removed from the process via conduit 10 and the remainder of steam 6 is passed on to a steam driven turbine 8 to provide motive force to produce electrical or mechanical energy. The exhaust from turbine 8 exits via conduit 9.

[0063] In the embodiment set forth in FIG. 2, a portion of the high pressure steam flowing in conduit 1 is directed to conduit 2 and passed through a control valve to produce lower pressure steam 4. Conduit 4 may comprise lower pressure steam with a quality less than or equal to unity, depending on the temperarture and pressure conditions of steam 2.

[0064] Liquid water is separated from the lower pressure vaporous steam in gas-liquid segregation zone 7. Lower pressure steam, essentially free from liquid water, exits gas-liquid segregation zone 7 via conduit 5, while liquid water is removed via conduit 6. Removal of liquid water may be accomplished by any means known in the art, for example as described in "phase Segregation", Chapter 3, pp. 129-148, L. J. Jacobs and W. R. Penney, in *Handbook of Separation Process Technology*, R. W. Rousseau, ed., Wiley & Sons, 1987, including knockout pots, pipe separators, mesh pads, centrifugal vanes, tangential entry separators, demister or coalescer pads, wavy plates, packing, cyclone or venturi scrubbers, electrostatic precipitators, and the like.

[0065] Steam 5 is passed through one side of a heat exchange device 8 wherein, steam 5 is superheated by indirect contact with the remaining portion of the high pressure steam flowing via conduit 3 to the other side of heat exchange device 8. Superheated, lower pressure steam emerges from heat exchange device 8 via conduit 10. Condensate and any remaining vapor fraction of the high pressure steam exits via conduit 9. A fraction of Superheated steam 10 may be removed from the process via conduit 13 and the remainder of steam 10 is passed on to steam driven turbine 11 to provide motive force to produce electrical or mechanical energy. The exhaust from turbine 11 exits via conduit 12.

[0066] In the embodiment set forth in FIG. 3, a portion of the high pressure steam flowing in conduit 1 is directed to conduit 2 and passed through a control valve to produce lower pressure steam 4. Conduit 4 may comprise lower pressure steam with a quality less than or equal to unity, depending on the temperarture and pressure conditions of steam 2.

[0067] Liquid water is separated from the lower pressure vaporous steam in gas-liquid segregation zone 7. Lower pressure steam, essentially free from liquid water, exits gas-liquid segregation zone 7 via conduit 5, while liquid water is removed via conduit 6. Steam 5 is passed through one side of a heat exchange device 8 wherein, steam 5 is superheated by indirect contact with the remaining portion of the high pressure steam flowing via conduit 3 to the other

side of heat exchange device 8. Superheated lower pressure steam emerges from heat exchange device 8 via conduit 10. Condensate and any remaining vapor fraction of the high pressure steam exits via conduit 9. A fraction of superheated steam 10 may be removed from the process via conduit 20 and the remainder of steam 10 is passed on to steam driven turbine 11 to provide motive force to produce electrical or mechanical energy. The exhaust from turbine 11 exits via conduit 12 and is condensed in condenser 13 to produce condensate 14. Condensate 14, stream 9, and condensate 6, may be combined with make-up water 15 to produce a boiler feed water stream 16.

[0068] Steam generating zone 17 may comprise steam generating heat exchangers (i.e., boilers) wherein heat is transferred from a heating medium to boil water and boiler feed water exchangers. Heat transfer within steam generating zone 17 may occur by radiant and/or convective heat transfer mechanisms. Heat is transferred into zone 17 via stream 19. Stream 19 may represent heat flow such as, for example, from a chemical reaction, as described hereinabove, or a flow of matter. The use of multiple heat exchangers is contemplated to be within the scope of the instant invention. High pressure steam generated within zone 17 exits via conduit 1. A fraction of the steam generated in zone 17 may be directed to conduit 18 to exit the process.

[0069] In the embodiment set forth in FIG. 4, a portion of the high pressure steam flowing in conduit 1 is directed to conduit 2 and passed through steam turbine 20 to produce lower pressure steam 4 and electricity. Conduit 4 may comprise a lower pressure steam with a quality less than or equal to unity, depending on the temperature and pressure conditions of steam 2.

[0070] Liquid water is separated from the lower pressure vaporous steam in gas-liquid segregation zone 7. Lower pressure steam, essentially free from liquid water, exits gas-liquid segregation zone 7 via conduit 5, while liquid water is removed via conduit 6. Steam 5 is passed through one side of a heat exchange device 8 wherein, steam 5 is superheated by indirect contact with the remaining portion of the high pressure steam flowing via conduit 3 to the other side of heat exchange device 8. Superheated lower pressure steam emerges from heat exchange device 8 via conduit 10. Condensate and any remaining vapor fraction of the high pressure steam exits via conduit 9. A fraction of lower pressure superheated steam 10 may be removed from the process via conduit 21 and the remainder of steam 10 is passed on to steam driven turbine 11 to provide motive force to produce electrical or mechanical energy. The exhaust from turbine 11 exits via conduit 12 and is condensed in condenser 13 to produce condensate 14. Condensate 14, stream 9, and condensate 6, may be combined with make-up water 15 to produce a boiler feed water stream 16.

[0071] Steam generating zone 17 may comprise steam generating heat exchangers (i.e., boilers) wherein heat is transferred from a heating medium to boil water, and boiler feed water exchangers. Heat transfer within steam generating zone 17 may occur by radiant and/or convective heat transfer mechanisms. Heat is transferred into zone 17 via stream 19. Stream 19 may represent heat flow such as, for example, from a chemical reaction, as described hereinabove, or a flow of matter. The use of multiple heat exchangers is contemplated to be within the scope of the instant

invention. High pressure steam generated within zone 17 exits via conduit 1. A fraction of the high pressure steam generated in zone 17 may be directed to conduit 18 to exit the process.

[0072] In the embodiment set forth in FIG. 5, a high pressure steam flowing in conduit 1 is directed to one side of heat exchange device 2, such that heat is transferred to lower pressure steam 9 on the other side of device 2 to produce superheated steam 10. Condensate and any remaining vapor fraction of the high pressure steam exits device 2 via conduit 3. Condensate 3, may be combined with makeup water 4 to produce a boiler feed water stream 19 to steam generating zone 5.

[0073] High pressure steam generating zone 5 may comprise steam generating heat exchangers (i.e., boilers) wherein heat is transferred from a heating medium to boil water, and boiler feed water exchangers. Heat transfer within steam generating zone 5 may occur by radiant and/or convective heat transfer mechanisms. Heat is transferred into zone 5 via stream 6. Stream 6 may represent heat flow, for example from a chemical reaction, or a flow of matter. The use of multiple heat exchangers is contemplated to be within the scope of the instant invention. High pressure steam generated within zone 5 exits via conduit 1. A fraction of high pressure steam generated in zone 5 may be directed to conduit 7 to exit the process.

[0074] A fraction of superheated steam 10 may be removed from the process via conduit 20 and the remainder of steam 10 is passed on to steam driven turbine 11 to provide motive force to produce electrical or mechanical energy. The exhaust from turbine 11 exits via conduit 12 and is condensed in condenser 13 to produce condensate 14. Condensate 14 may be combined with make-up water 15 to produce a boiler feed water stream 16 for lower pressure steam generating zone 8.

[0075] Steam generating zone 8 may comprise steam generating heat exchangers (i.e., boilers) wherein heat is transferred from a heating medium to boil water, and boiler feed water exchangers. Heat transfer within steam generating zone 8 may occur by radiant and/or convective heat transfer mechanisms. Heat is transferred into zone 8 via stream 18. Stream 18 may represent heat flow such as, for example, from a chemical reaction, as described hereinabove, or a flow of matter. The use of multiple heat exchangers is contemplated to be within the scope of the instant invention. High pressure steam generated within zone 8 exits via conduit 1. A fraction of the steam generated in zone 8 may be directed to conduit 17 to exit the process.

EXAMPLES

[0076] General—A better understanding of the invention is provided with particular reference to the examples given below. For Examples 1-9 and Comparative Examples 1-3, heat and material balance calculations were carried out to illustrate the aspects of the instant invention by process simulation software using methods described in "Program Computes Steam Rates and Properties", by V. Ganaphthy in *Hydrocarbon Processing, November* 1988, pp. 105-108, and in standard engineering texts such as, for example, *Perry's Handbook of Chemical Engineering*, 6th ed., New York, McGraw Hill, 1984. Also, unless expressly stated otherwise, it should be understood that the high pressure steam or heat

used to generate the high pressure steam, as set forth in the Examples and Comparative Examples, may be obtained by recovering heat from any heat-producing chemical process as described hereinabove such as, for example, the production of syngas by gasification of carbonaceous materials or by steam reforming of methane, the water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, production of ammonia by hydrogenation of nitrogen, or a combination of one or more of these processes.

Comparative Example 1

[0077] 100,000 kg/hr of saturated high pressure steam at 131 bara and 331.45° C. is fed to a steam turbine with an outlet pressure of 0.12 bara and a mechanical efficiency of 86.5% to produce electricity. The turbine generates 22.3 MW, with a steam quality of 69.3% at the outlet of the turbine.

Examples 1-5

[0078] Examples 1-5 illustrate the effect on turbine outlet steam quality by changing the pressure to which the high pressure inlet steam is reduced as per FIG. 1 of the instant invention. 100,000 kg/hr of saturated high pressure steam at 131 bara and 331.45° C. is divided and a portion is reduced in pressure. The resulting lower pressure steam is subjected to heat exchange with the remaining portion of high pressure steam. The approach temperature in the heat exchanger is 5° C., i.e., the superheated lower pressure steam temperature is 326.45° C. in all cases. The superheated lower pressure steam is fed to a steam turbine with an outlet pressure of 0.12 bara and a mechanical efficiency of 86.5% to produce electricity. Table 1 shows results per the instant invention for various lower pressure values.

TABLE 1

Effect of Pressure					
	Lower Pressure Steam, bara	Amount of Lower P Steam (thousands Kg/hr)	Degrees Superheat, ° C.	Electricity, MW	Turbine Outlet Steam Quality
Example 1	65.5	79.2	45.1	18.8	79.5%
Example 2	56.2	77.6	55.1	18.3	81.0%
Example 3	42.4	75.4	72.6	17.5	83.3%
Example 4	28.6	73.6	95.2	16.4	86.2%
Example 5	14.6	72.2	128.7	14.7	90.5%

Comparative Example 2

[0079] 100,000 kg/hr of saturated high pressure steam at 131 bara and 331.45° C. is fed to a steam turbine with an outlet pressure of 0.12 bara and a mechanical efficiency of 86.5% to produce electricity. The turbine generates 22.3 MW, with a steam quality of 69.3% at the outlet of the turbine. The wet steam from the outlet of the turbine is condensed at the saturation temperature of 0.12 bara steam (49.6° C.), giving up 165.1 GJ/hr during the condensation process. The condensed steam is pumped back up to 131 bara and subjected to heat transfer where 245.3 GJ/hr are transferred to produce 100,000 kg/hr of saturated high pressure steam at 131 bara and 331.45° C., completing the

steam cycle. The overall efficiency, E, of the steam cycle is 32.7%, where:

E=(heat in-condensing duty)/heat in=(245.3 GJ/hr-165.1 GJ/hr)/245.3 GJ/hr

Example 6

[0080] Example 6, following the nomenclature of FIG. 3, illustrates the overall efficiency of a steam cycle. Heat input into steam generating zone 17 via conduit 19 is 245.3 GJ/hr as in Comparative Example 2. 112,350 kg/hr of liquid water at 49.5° C., is boiled in heat transfer zone 17 to produce 112,350 kg/hr of saturated high pressure steam at 131 bara and 331.45° C. in conduit 1. 17,550 Kg/hr is diverted via conduit 3, the remainder of 94,800 kg/hr passes via conduit 2 and is flashed across a valve to produce saturated steam at 42.4 bara, 253.8° C., 91.8% quality. The resulting lower pressure steam is divided into 7800 kg/hr of saturated liquid in conduit 6 and 87,000 kg/hr of saturated vapor in conduit 5. Conduit 5 subjected to heat exchange with conduit 3 in exchanger 8. The approach temperature in the heat exchanger is 5° C., producing superheated lower pressure steam temperature at 326.45° C., 42.4 bara in conduit 10 and condensed high pressure steam at 331.45° C. in conduit 9. The superheated lower pressure steam in conduit 10 is fed to steam turbine 11 with an outlet pressure of 0.12 bara and a mechanical efficiency of 86.5% to produce 20.2 MW of electricity. The steam at the outlet of the turbine, conduit 12, has a quality of 83.3%. Conduit 12 is fully condensed in exchanger 13 by removal of 172.8 GJ/hr of energy, and exits as saturated liquid stream 14 at 49.5° C. Streams 14, 9, and 6 are combined and pumped back up to 131 bara, subjected to steam generating zone in zone 17 where 245.3 GJ/hr are transferred via conduit 19 to produce 112,350 kg/hr of saturated high pressure steam at 131 bara and 331.45° C., completing the steam cycle. The overall efficiency, E, of the steam cycle is 29.6%. This efficiency is 90.5% of the efficiency reported in Comparative Example 2, but with a much higher steam turbine outlet quality, as per the objective of the instant invention.

Example 7

[0081] Example 7, following the nomenclature of FIG. 4, illustrates the overall efficiency of a steam cycle. Heat input into steam generating zone 17 via conduit 19 is 245.3 GJ/hr as in Comparative Example 2. 115,290 kg/hr of liquid water via conduit 16 is boiled in heat transfer zone 17 to produce 115,290 kg/hr of saturated high pressure steam at 131 bara and 331.45° C., exiting via conduit 1. 16,410 Kg/hr is diverted via conduit 3, the remainder of 98,880 kg/hr passes via conduit 2 and is expanded in steam turbine 20 with a mechanical efficiency of 86.5% to produce 4.4 MW of electricity, and saturated steam at 42.4 bara, 253.8° C., 82.3% quality. The resulting lower pressure steam is divided into 17510 kg/hr of saturated liquid in conduit 6 and 81,370 kg/hr of saturated vapor in conduit 5. Conduit 5 subjected to heat exchange with conduit 3 in exchanger 8. The approach temperature in the heat exchanger is 5° C., producing superheated lower pressure steam temperature at 326.45° C., 42.4 bara in conduit 10 and condensed high pressure steam at 331.45° C. in conduit 9. The superheated lower pressure steam in conduit 10 is fed to steam turbine 11 with an outlet pressure of 0.12 bara and a mechanical efficiency of 86.5% to produce 18.8 MW of electricity. The steam at the outlet of the turbine, conduit 12, has a quality of 83.3%. Conduit 12 is fully condensed in exchanger 13 by removal of 161.6 GJ/hr of energy, and exits as saturated liquid stream 14 at 49.5° C. Streams 14, 9, and 6 are combined and pumped back up to 131 bara, subjected to steam generating zone in zone 17 where 245.3 GJ/hr are transferred via conduit 19 to produce 115,290 kg/hr of saturated high pressure steam at 131 bara and 331.45° C., completing the steam cycle. The overall efficiency, E, of the steam cycle is 34.1%. This efficiency is 104.2% of the efficiency reported in Comparative Example 2, and with a much higher steam turbine outlet quality, as per the objective of the instant invention. Furthermore, the total electricity production of 23.2 MW exceeds that of Comparative Example 2 (22.3 MW) by 4.1%.

Comparative Example 3

[0082] 100,000 kg/hr of saturated high pressure steam at 41.4 bara and 252.36° C. is fed to a steam turbine with an outlet pressure of 0.12 bara and a mechanical efficiency of 86.5% to produce electricity. The turbine generates 20.75 MW, with a steam quality of 77.4% at the outlet of the turbine. The wet steam from the outlet of the turbine is condensed at the saturation temperature of 0.12 bara steam (49.6° C.), giving up 184.5 GJ/hr during the condensation process. The condensed steam is pumped back up to 41.4 bara and subjected to heat transfer where 259.3 GJ/hr are transferred to produce 100,000 kg/hr of saturated high pressure steam at 41.4 bara and 252.36° C., completing the steam cycle. The overall efficiency, E, of the steam cycle is 28.9%, where:

E=(heat in-condensing duty)/heat in=(259.3 GJ/hr-784.5 GJ/hr)/259.3 GJ/hr

Example 8

[0083] Example 8, following the nomenclature of FIG. 4, illustrates the overall efficiency of a steam cycle. Heat input into steam generating zone 17 via conduit 19 is 259.3 GJ/hr as in Comparative Example 3. 104,860 kg/hr of liquid water via conduit 16 is boiled in heat transfer zone 17 to produce 104,860 kg/hr of saturated high pressure steam at 41.4 bara and 252.36° C., exiting via conduit 1. 8,070 Kg/hr is diverted via conduit 3, the remainder of 96,790 kg/hr passes via conduit 2 and is expanded in steam turbine 20 with a mechanical efficiency of 86.5% to produce 6.00 MW of electricity, and saturated steam at 10.34 bara, 181.35° C., 90% quality. The resulting lower pressure steam is divided into 9,660 kg/hr of saturated liquid in conduit 6 and 87,130 kg/hr of saturated vapor in conduit 5. Conduit 5 subjected to heat exchange with conduit 3 in exchanger 8. The approach temperature in the heat exchanger is 5° C., producing superheated lower pressure steam at 247.36° C., 10.34 bara in conduit 10 and condensed high pressure steam at 252.36° C. in conduit 9. The superheated lower pressure steam in conduit 10 is fed to steam turbine 11 with an outlet pressure of 0.12 bara and a mechanical efficiency of 86.5% to produce 15.2 MW of electricity. The steam at the outlet of the turbine, conduit 12, has a quality of 88.1%. Conduit 12 is fully condensed in exchanger 13 by removal of 173.34 GJ/hr of energy, and exits as saturated liquid stream 14 at 49.5° C. Streams 14, 9, and 6 are combined and pumped back up to 41.4 bara, subjected to steam generating zone in zone 17 where 259.3 GJ/hr are transferred via conduit 19 to produce 104,860 kg/hr of saturated high pressure steam at 41.4 bara and 252.36° C., completing the steam cycle. The overall efficiency, E, of the steam cycle is 29.5%. This efficiency is 102.2% of the efficiency reported in Comparative Example 2, and with a much higher steam turbine outlet quality, as per the objective of the instant invention. Furthermore, the total electricity production of 21.21 MW exceeds that of Comparative Example 2 (20.75 MW) by 2.2%

Example 9

[0084] Example 9 illustrates the embodiment of the invention as set forth in FIG. 5. A syngas stream from an oxygen blown gasifier comprising 57,242 lbmole/hr of carbon monoxide, hydrogen, water, and carbon dioxide is subjected to a water gas shift reaction to produce a hot shifted syngas. A portion of the heat of reaction is removed in heat transfer zone 5 by generating 115,693 kg/hr of 37.6 bara steam at 246.7° C. The syngas is further cooled in heat transfer zone **8** to produce 455,475 kg/hr of 4.5 bara steam at 147.6° C. The lower pressure steam exits zone 8 via conduit 9 and is superheated in exchanger 2 by heat exchange with 62,600 kg/hr of high pressure steam in conduit 1. The approach temperature in exchanger 2 is 5° C. 455,475 kg/hr of superheated steam at 241.65° C. is passed via conduit 10 through turbine 11 (86.5% efficiency) to generate 66.7 MW of power. The outlet quality of the steam in conduit 12 is 92.8%. This compares to a power generation of 59.9 MW, with an outlet quality of 86% if steam 9 had not been superheated.

I claim:

- 1. A process for the preparation of superheated steam, comprising:
 - (a) recovering heat from at least one chemical process to produce a high pressure steam;
 - (b) reducing the pressure of a portion of said high pressure steam of step (a) to produce a lower pressure steam and a remaining portion of said high pressure steam; and
 - (c) transferring heat from at least a fraction of said remaining portion of said higher pressure steam of step(b) to said lower pressure steam to produce a superheated steam from said lower pressure steam.
- 2. The process according to claim 1 wherein said remaining portion of said high pressure steam and said lower pressure steam have a difference in water saturation temperature of about 40° C. to about 250° C.
- 3. The process according to claim 1 wherein said high pressure steam is generated by recovering heat from at least one chemical process selected from partial oxidation, carbonylation, hydrogenation, water-gas shift reaction, steam reforming, and homologation.
- 4. The process according to claim 3 wherein said at least one chemical process comprises gasification of carbonaceous materials to produce synthesis gas, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, partial oxidation of ethylene to produce ethylene oxide, steam reforming of methane to produce synthesis gas, partial oxidation of methanol to produce formaldehyde, production of Fischer-Tropsch hydrocarbons or alcohols from synthesis gas, ammonia production from hydrogen and nitrogen, autothermal reforming of carbonaceous feedstocks to produce synthesis gas, hydrogenation of dimethyl terephthalate to

- cyclohexanedimethanol, carbonylation of methanol to acetic acid, a water-gas shift reaction to produce hydrogen and carbon dioxide from carbon monoxide and water, or a combination thereof.
- **5**. The process according to claim 4 wherein said chemical process comprising gasification of carbonaceous materials to produce synthesis gas.
- **6**. The process according to claim 1 wherein said recovering heat of step (a) is by radiant heat exchange, convective heat exchange, or a combination thereof.
- 7. The process according to claim 6 wherein said recovering heat is by radiant heat exchange.
- **8**. The process according to claim 1 wherein said high pressure steam of step (a) is saturated or superheated and has a pressure of about 4 to about 140 bara.
- **9**. The process according to claim 8 wherein said high pressure steam of step (a) has a pressure of about 20 to about 120 bara.
- 10. The process according to claim 1 wherein said pressure reducing of step (b) comprises expanding said said portion of said high pressure steam through a valve, a turbine, or a combination thereof.
- 11. The process according to claim 1 wherein said superheated steam is passed to a steam turbine.
- 12. The process according to claim 11 wherein said steam turbine produces an outlet steam having a quality of about 80 percent to about 100 percent.
- 13. The process according to claim 1 wherein said transferring of heat of step (c) is performed with a shell and tube heat exchanger, plate and frame exchanger, spiral exchanger, plate-fin exchanger, or a combination thereof.
- 14. The process according to claim 1 wherein said superheated steam and said remaining portion of said higher pressure steam have an approach temperature of about 1 to about 20° C.
- 15. The process according to claim 14 wherein said superheated steam and said remaining portion of said higher pressure steam have an approach temperature of about 1 to about 10° C.
- **16**. A process for the preparation of superheated steam, comprising:
 - (a) reacting a carbonaceous material with oxygen, water, or carbon dioxide to produce heat and a syngas stream comprising hydrogen, carbon monoxide, and carbon dioxide;
 - (b) recovering said heat to produce a high pressure steam; and
 - (c) transferring heat from at least a fraction of said high pressure steam of step (b) to a lower pressure steam by indirect heat exchange to produce a superheated steam from said lower pressure steam.
- 17. The process according to claim 16 wherein said carbonaceous material comprises methane, petroleum residuum, carbon monoxide, coal, coke, lignite, oil shale, oil sands, peat, biomass, petroleum refining residues, petroleum cokes, asphalts, vacuum resid, heavy oils, or combinations thereof.
- **18**. The process according to claim 17 wherein said carbonaceous material of step (a) is reacted in a gasifier, partial oxidizer, or reformer.
- 19. The process according to claim 18 wherein said carbonaceous material comprises methane and is reacted with water in a reformer.

- 20. The process according to claim 18 wherein said carbonaceous material comprises carbon monoxide and is reacted with water in a water-gas shift reaction.
- 21. The process according to claim 18 wherein said carbonaceous material comprises coal or petroleum coke and is reacted with oxygen in a gasifier.
- 22. The process according to claim 21 wherein said lower pressure steam is generated by reducing the pressure of a portion of said high pressure steam.
- 23. The process according to claim 22 wherein said pressure reducing comprises expanding said portion of said high pressure steam through a valve, a turbine, or a combination thereof.
- 24. The process according to claim 21 wherein said lower pressure steam is generated by recovery of heat from at least one chemical process selected from a water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, hydrogenation of nitrogen to produce ammonia, carbonylation of methanol to produce acetic acid, a Fischer-Tropsch process, production of alkyl formates from carbon monoxide and alcohols, and combinations thereof.
- 25. The process according to claim 24 wherein said chemical process is said water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, hydrogenation of nitrogen to produce ammonia, or a combination thereof.
- **26**. The process according to claim 16 wherein said recovering heat of step (a) is by radiant heat exchange, convective heat exchange, or a combination thereof.
- 27. The process according to claim 26 wherein said recovering heat is by radiant heat exchange.
- **28**. The process according to claim 16 wherein said high pressure steam of step (a) is saturated or superheated and has a pressure of about 4 to about 140 bara.
- 29. The process according to claim 28 wherein said high pressure steam of step (a) has a pressure of about 20 to about 120 bara.
- **30**. The process according to claim 16 wherein said superheated steam is passed to a steam turbine.
- **31**. The process according to claim 30 wherein said steam turbine produces an outlet steam having a quality of about 80 to 100 percent.
- **32**. The process according to claim 16 wherein said transferring of heat of step (c) is performed with a heat shell and tube heat exchanger, plate and frame exchanger, spiral exchanger, compact plate-fin exchangers, or a combination thereof.
- **33**. The process according to claim 16 wherein said superheated steam and said remaining portion of said higher pressure steam have an approach temperature of about 1 to about 20° C.
- **34**. The process according to claim 33 wherein said superheated steam and said remaining portion of said higher pressure steam have an approach temperature of about 1 to about 10° C.
 - 35. A process for driving a steam turbine, comprising:
 - (a) reacting a carbonaceous material with oxygen in a gasifier to produce heat and a syngas stream comprising hydrogen, carbon monoxide, and carbon dioxide;
 - (b) recovering said heat to produce a high pressure steam;
 - (c) transferring heat from at least a fraction of said high pressure steam of step (b) to a lower pressure steam by

- indirect heat exchange to produce a superheated steam from said lower pressure steam; and
- (d) passing said superheated steam to a steam turbine.
- 36. The process according to claim 35 wherein said lower pressure steam is generated by reducing the pressure of a portion of said high pressure steam, by recovery of heat from at least one chemical process selected from a water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to produce methanol, hydrogenation of nitrogen to produce ammonia, carbonylation of methanol to produce acetic acid, a Fischer-Tropsch process, production of alkyl formates from carbon monoxide and alcohols, and combinations thereof, or by a combination thereof.
- 37. The process according to claim 36 wherein said reducing pressure comprises expanding said portion of said high pressure steam through a valve, a turbine, or combination thereof.
- **38**. The process according to claim 36 wherein said chemical process comprises said water-gas shift reaction, hydrogenation of carbon monoxide or carbon dioxide to

- produce methanol, hydrogenation of nitrogen to produce ammonia, or a combination thereof.
- **39**. The process of claim 38 wherein said chemical process comprises hydrogenation of carbon monoxide or carbon dioxide to produce methanol.
- **40**. The process according to claim 35 wherein said recovering heat of step (b) is by radiant heat exchange, convective heat exchange, or a combination thereof.
- **41**. The process according to claim 40 wherein said recovering heat is by radiant heat exchange.
- **42**. The process according to claim 35 wherein said high pressure steam of step (a) has a pressure of about 20 to about 120 bara.
- **43**. The process according to claim 35 wherein said steam turbine drives a generator to produce electricity or drives a gas compressor.
- **44**. The process according to claim 43 wherein said steam turbine produces an outlet steam having a quality of about 80 percent to about 100 percent.

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