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Co-production of Bioethanol and Power

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1. Introduction

Recently, biomass usage for fuel has attracted increased interest in many countries to suppress global warming caused mainly by the consumption of fossil fuels. (Mousdale, 2010). In particular, many researchers expect that bioethanol may be a substitute for petroleum. In fact, bioethanol loses less energy and exergy potential during chemical reactions, saccharification and fermentation for ethanol production, because it is produced merely through energy conversion by chemical reactions (Cardona et al. 2010). However, after fermentation, the product contains a large amount of water, which prevents maximizing the heat value of the product. Therefore, separation of the ethanol-water mixture is required to obtain pure ethanol for fuel (Zamboni et al. 2009a, 2009b, Huang et al. 2008). In practice, distillation is widely used for the separation of this mixture (Fair 2008). However, conventional distillation is well-known to be an energy-consuming process, and also pure ethanol fuel cannot be produced directly from a distillation column, because ethanol and water form an azeotropic mixture. To separate pure ethanol from ethanol-water mixtures by distillation, it is necessary to use an entrainer (azeotrope breaking agent), because the azeotropic mixture is one that vaporizes without any change in composition. Benzene, cyclohexane, or isopropyl alcohol can be used as entrainers for the ethanol-water mixture. Therefore, at least two separation units are required to produce pure ethanol, leading to further increases in energy consumption (Doherty& Knapp 2008). In fact, it is believed that about half of the heat value of bioethanol is required to distill the ethanol from the mixture. To reduce energy consumption during bioethanol production, many researchers have proposed membrane separations (Baker 2008, Wynn 2008) or pressure swing adsorption (PSA) (Modla & Lang, 2008) as alternatives to azeotropic distillation, often successfully developing appropriate membranes or sorbents to achieve an efficient separation. However, in many cases, they have paid little attention to the overall process scheme or have developed heat integration processes based on conventional heat recovery technologies, such as the well known heat cascading utilization. As a result, the minimum energy requirement of the overall process has not been reduced, because changes to the condition of the process stream are constrained in conventional heat recovery technologies (Hallale 2008, Kemp 2007). Moreover, most cost minimization analyses for bioethanol plants have been conducted based on these conventional processes and technologies. Thus, the price of product bioethanol still remains high compared to fossil fuels.

Nowadays, by reconsidering the energy and production system from an improvement of energy conversion efficiency and energy saving point of view, the concept of co-production of energy and products has been developed. However, to realize co-production, it is

necessary to analyze and optimize the heat and power required for production in each process. Therefore, the authors have developed self-heat recuperation technology based on exergy recuperation (Kansha et al. 2009) and applied it to several chemical processes for co-production (Fushimi et al. 2011, Kansha et al. 2010a, 2010b, 2010c, 2011, Matsuda et al.2010). In this chapter, self-heat recuperation technology is introduced and applied to the separation processes in bioethanol production for co-production. Moreover, the feasibility and energy balance for co-production of bioethanol and power using biomass gasification based on self-heat recuperation is discussed.

2. Energy balance for conventional bioethanol production

It assumed that the amount of energy in feed stock wet biomass is 100 and that 50% of this energy consists of that from reactant sugars, such as starch, cellulose and others. Thus, the amount of energy of the original component of sugar (50) transfers to ethanol (46) and heat (4) through chemical reactions (saccharification and fermentation) with water. This energy is estimated from the following calculation; the caloric value of sugar is 685 kcal/mol, the caloric value of ethanol is 316 kcal/mol and 2 mol ethanol is produced from 1 mol sugar through the above reaction. The pure ethanol product is then separated by distillation and additional heat energy (23) is required for this distillation work when azeotropic distillation is used for the separation. Non-reactants contain a large amount of water, for which the higher heat value is almost equal to the evaporation heat, leading to a net heat value of 0. The above energy relation is shown in Fig. 1. Beyond this, some additional energy is required to produce heat energy from the wet biomass for distillation (23). This additional energy (15) is used to dry the wet biomass in a heater to produce dry biomass that is used as fuel for distillation. Figure 2 shows the total energy balance including this additional energy. It is noted that 50-80% moisture content in wet biomass is assumed in this energy analysis, because many types of wet biomass exist in this range, such as those that originate from ligneous, garbage and sludge. It can be seen from Fig. 2 that 138 units of energy in the wet biomass feed stock is required to produce 46 energy units of ethanol and that about 1/3 of the energy of the wet biomass can be utilized as bioethanol for fuel. Thus, 2/3 of the wet biomass feed stock energy is wasted. Even though this wasted heat energy could potentially be heat sources for other processes, the exergy ratio and temperature of the waste heats are quite low. Thus, it is difficult to achieve energy saving from this by heat integration technologies such as cascading utilization. In fact, the highest required temperature during bioethanol production is normally at the distillation column reboiler and this temperature is lower than 150 ˚C. This heat is exhausted from the condenser at below 100 ˚C. To utilize the biomass energy more effectively, it is clear that the energy consumption during distillation for separating water and product ethanol and for drying of the wet biomass must be reduced. When an integrated system of distillation and membrane separation processes are utilized to substitute for azeotropic distillation, the energy required can be decreased from 23 to 12 units (8: distillation, 4: membrane separation). However, the pressure difference for membrane separation requires electric power. If we assume that the power generation efficiency from dry biomass is 25% and 75% of the energy for the membrane separation process is provided by electricity, 35 energy units from wet biomass are required for distillation and dehydration by membrane separation.
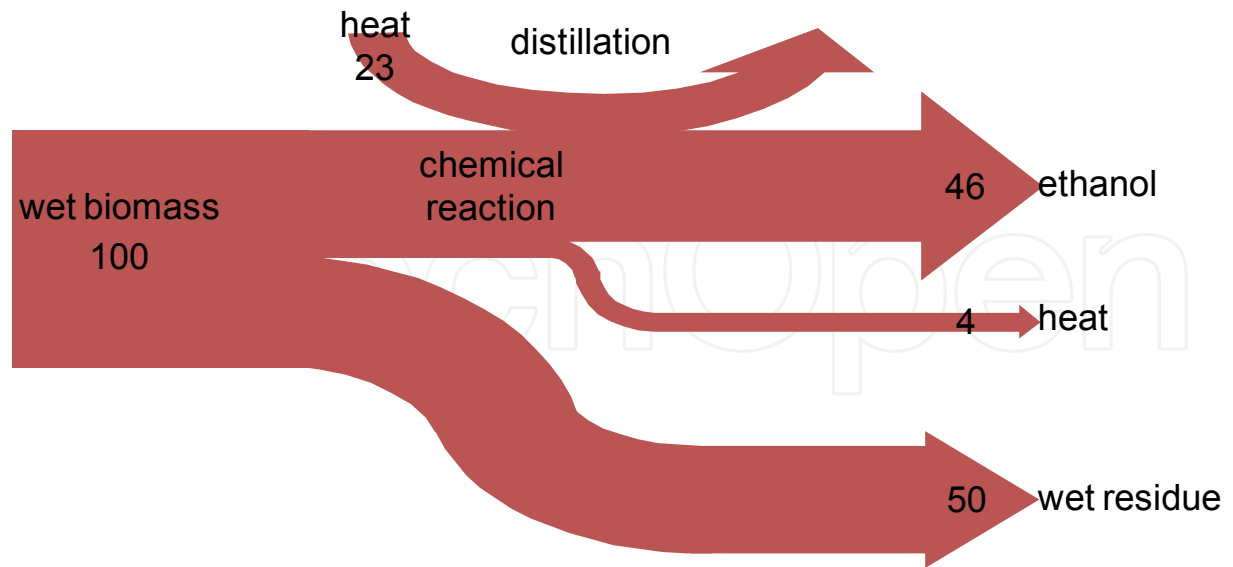
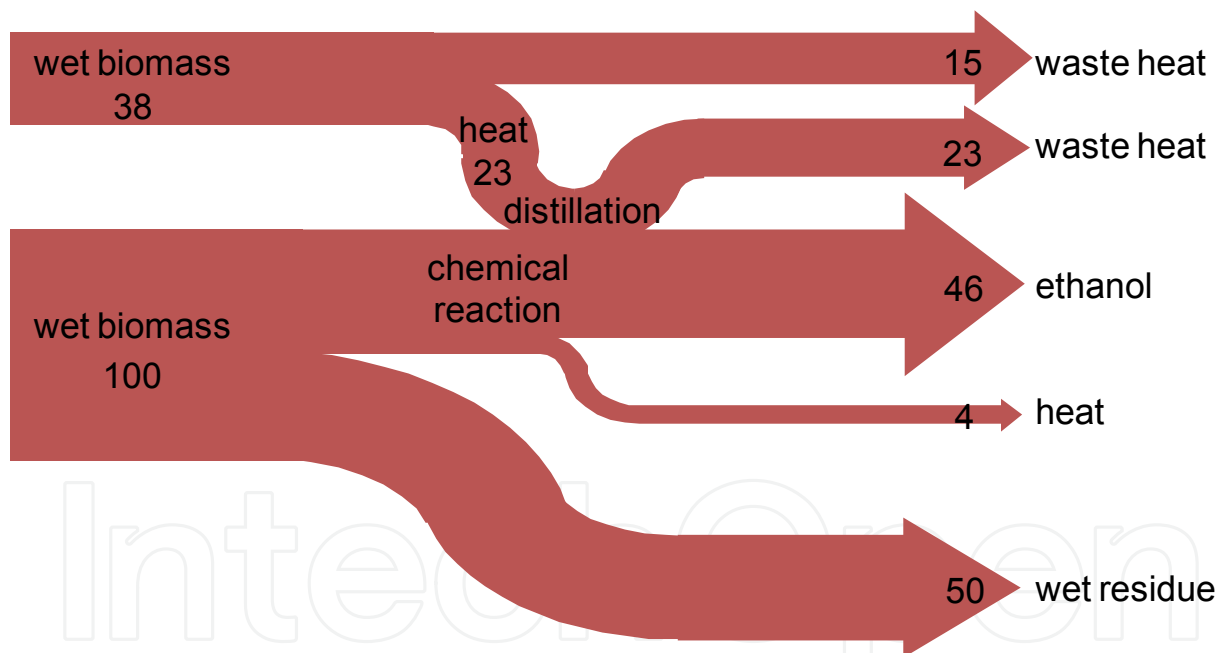Fig. 1. Energy balance for bioethanol production

Fig. 2. Total energy balance for bioethanol production

3. Self-heat recuperation technology and self-heat recuperative processes

Self-heat recuperation technology (Kansha et al. 2009) facilitates recirculation of not only latent heat but also sensible heat in a process, and helps to reduce the energy consumption of the process by using compressors and self-heat exchangers based on exergy recuperation. In this technology, i) a process unit is divided on the basis of functions to balance the heating and cooling loads by performing enthalpy and exergy analysis, ii) the cooling load is recuperated by compressors and exchanged with the heating load. As a result, the heat of

the process stream is perfectly circulated without heat addition, and thus, the energy consumption for the process can be greatly reduced. By applying this technology to each process (distillation and dehydration), the energy balance for the ethanol production can be changed significantly from that described above. In this section, the design methodology for self-heat recuperative processes is introduced by using a basic thermal process, and the self-heat recuperative processes applied to the separation processes are then introduced.

3.1 Self-heat recuperative thermal process

To reduce the energy consumption in a process through heat recovery, heating and cooling functions are generally integrated for heat exchange between feed and effluent to introduce heat circulation. A system in which such integration is adopted is called a self-heat exchange system. To maximize the self-heat exchange load, a heat circulation module for the heating and cooling functions of the process unit has been proposed, as shown in Figure 3 (Kansha et al. 2009).

Figure 3 (a) shows a thermal process for gas streams with heat circulation using self-heat recuperation technology. In this process, the feed stream is heated with a heat exchanger (1→2) from a standard temperature, T_0, to a set temperature, T_1. The effluent stream from the following process is pressurized with a compressor to recuperate the heat of the effluent stream (3→4) and the temperature of the stream exiting the compressor is raised to T_1' through adiabatic compression. Stream 4 is cooled with a heat exchanger for self-heat exchange (4→5). The effluent stream is then decompressed with an expander to recover part of the work of the compressor. This leads to perfect internal heat circulation through self-heat recuperation. The effluent stream is finally cooled to T_0 with a cooler (6→7). Note that the total heating duty is equal to the internal self-heat exchange load, Q_{HX}, without any external heating load, as shown in Fig. 3 (b).

In the case of ideal adiabatic compression and expansion, the input work provided to the compressor performs a heat pumping role in which the effluent temperature can achieve perfect internal heat circulation without any exergy dissipation. Therefore, self-heat recuperation can dramatically reduce energy consumption.

Figure 3 (c) shows a thermal process for vapor/liquid streams with heat circulation using the self-heat recuperation technology. In this process, the feed stream is heated with a heat exchanger (1→2) from a standard temperature, T_0, to a set temperature, T_1. The effluent stream from the subsequent process is pressurized with a compressor (3→4). The latent heat can then be exchanged between feed and effluent streams because the boiling temperature of the effluent stream is raised to T_b' by compression. Thus, the effluent stream is cooled through the heat exchanger for self-heat exchange (4→5) while recuperating its heat. The effluent stream is then depressurized by a valve (5→6) and finally cooled to T_0 with a cooler (6→7). This leads to perfect internal heat circulation by self-heat recuperation, similar to the above gas stream case. Note that the total heating duty is equal to the internal self-heat exchange load, Q_{HX}, without any external heating load, as shown in Fig. 3 (d). It can be understood that the vapor and liquid sensible heat of the feed stream can be exchanged with the sensible heat of the corresponding effluent stream and the vaporization heat of the feed stream is exchanged with the condensation heat of the effluent stream. As a result, the energy required by the heat circulation module is reduced to 1/22–1/2 of the original by the self-heat exchange system in gas streams and/or vapor/liquid streams.
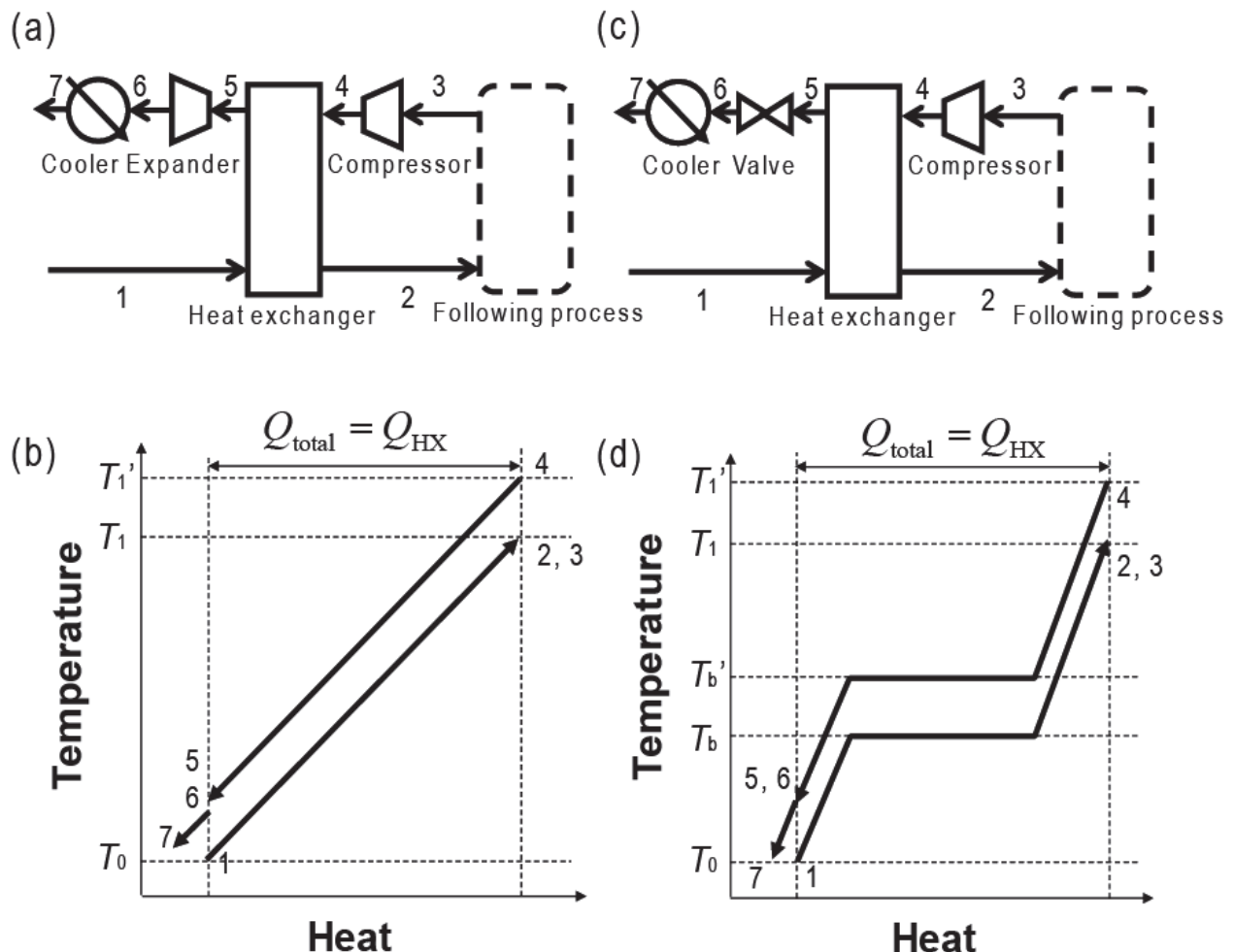
Fig. 3. Self-heat recuperative thermal process a) process flow of gas streams, b) temperature-heat diagram of gas streams, c) process flow of vapor/liquid streams, d) temperature-heat diagram of vapor/liquid streams

3.2 Self-heat recuperative distillation

Expanding the self-heat recuperative thermal process to distillation processes in particular (Kansha et al. 2010a, 2010b), a system including not only the distillation column but also the preheating section, is developed in order to minimize the required energy, as shown in Fig. 4. A distillation process can be divided into two sections, namely the preheating and distillation sections, on the basis of functions that balance the heating and cooling load by performing enthalpy and exergy analysis, and the self-heat recuperation technology is applied in these two sections. In the preheating section, one of the streams from the distillation section is a vapor stream and the stream to the distillation section has a vapor–liquid phase that balance the enthalpy of the feed streams and that of the effluent streams in the section. In balancing the enthalpy of the feed and effluent streams in the preheating section, the enthalpy of the streams in the distillation section is automatically balanced. Thus, the reboiler duty is equal to the condenser duty of the distillation column. Therefore, the vapor and liquid sensible heat of the feed streams can be exchanged with the sensible heat of the corresponding effluent streams and the vaporization heat can be exchanged with the condensation heat in each section.
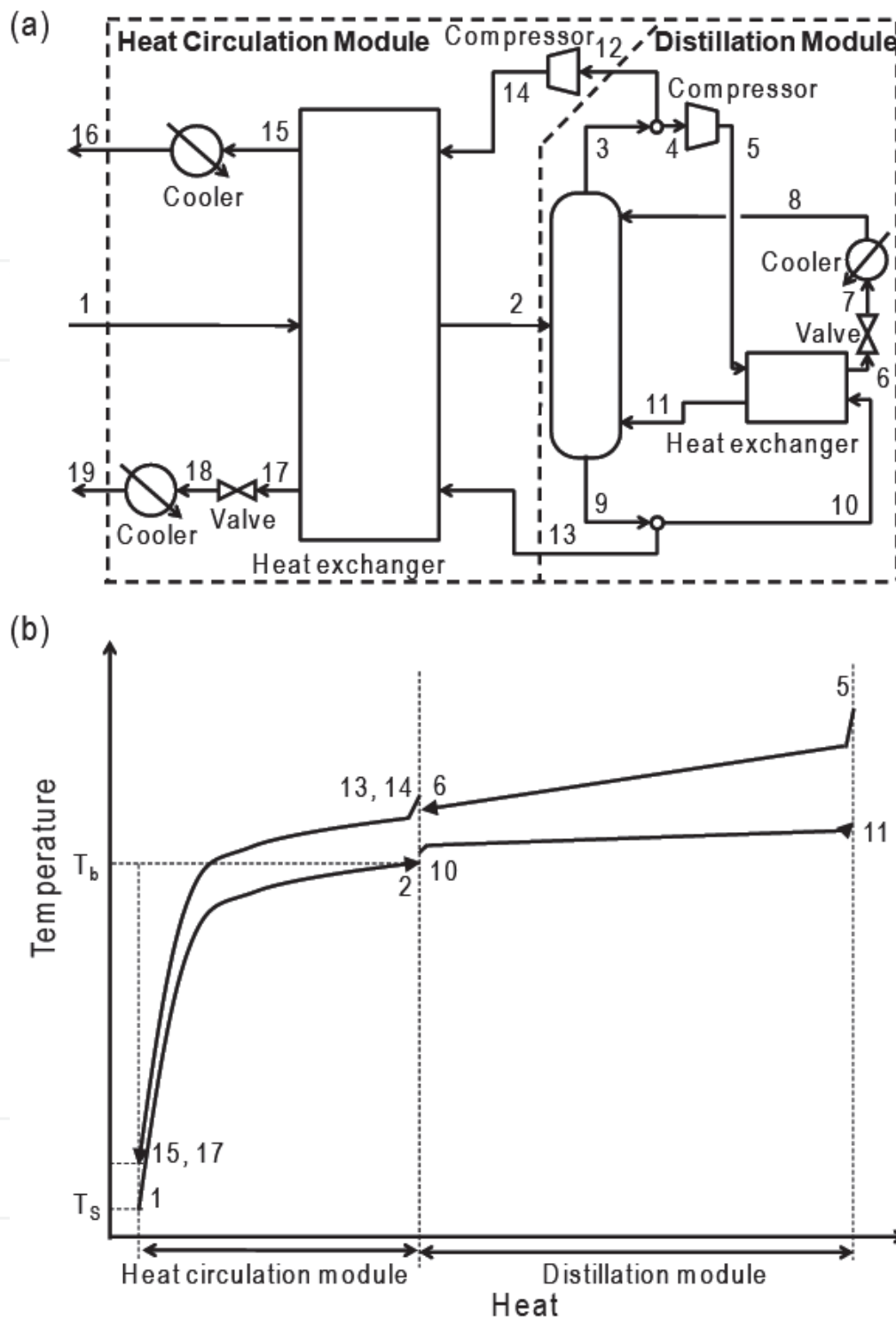
Fig. 4. Self-heat recuperative distillation process a) process flow diagram, b) temperature-heat diagram

Figure 4 (a) shows the structure of a self-heat recuperative distillation process consisting of two standardized modules, namely, the heat circulation module and the distillation module. Note that in each module, the summation of the enthalpy of the feed streams and that of the effluent streams are equal. The feed stream in this integrated process module is represented as stream 1. This stream is heated to its boiling point by the two streams independently

recuperating heat of the distillate (12) and bottoms (13) by the heat exchanger (1→2). A distillation column separates the distillate (3) and bottoms (9) from stream 2. The distillate (3) is divided into two streams (4, 12). Stream 4 is compressed adiabatically by a compressor and cooled down by the heat exchanger (2). The pressure and temperature of stream 6 are adjusted by a valve and a cooler (6→7→8), and stream 8 is then fed into the distillation column as a reflux stream. Simultaneously, the bottoms (9) is divided into two streams (10, 13). Stream 10 is heated by the heat exchanger and fed to the distillation column (10→11). Streams 12 and 13 are the effluent streams from the distillation module and return to the heat circulation module. In addition, the cooling duty of the cooler in the distillation module is equal to the compression work of the compressor in the distillation module because of the enthalpy balance in the distillation module.

The effluent stream (12) from the distillation module is compressed adiabatically by a compressor (12→14). Streams 13 and 14 are successively cooled by a heat exchanger. The pressure of stream 17 is adjusted to standard pressure by a valve (17→18), and the effluents are finally cooled to standard temperature by coolers (15→16, 18→19). The sum of the cooling duties of the coolers is equal to the compression work of the compressor in the heat circulation module. Streams 16 and 19 are the products.

Figure 4 (b) shows the temperature and heat diagram for the self-heat recuperative distillation process. In this figure, each number corresponds to the stream numbers in Figure 4 (a), and T_s and T_b are the standard temperature and the boiling temperature of the feed stream, respectively. Both the sensible heat and the latent heat of the feed stream are subsequently exchanged with the sensible and latent heat of effluents in heat exchanger 1. The vaporization heat of the bottoms from the distillation column is exchanged with the condensation heat of the distillate from the distillation column in the distillation module. The heat of streams 4 and 12 are recuperated by the compressors and exchanged with the heat in the module. It can be seen that all the self-heat is exchanged. As a result, the exergy loss of the heat exchangers can be minimized and the energy required by the distillation process is reduced to 1/6–1/8 of that required by the conventional heat exchanged distillation process.

3.1.2 Self-heat recuperative azeotropic distillation for dehydration

Conventional azeotropic distillation processes, which have one distillation column for dehydration to separate ethanol and another to separate water from their mixture, are divided into three modules. The sum of the feed enthalpy is made equal to that of the effluent stream enthalpy in each module to analyze the heating and cooling loads of all process streams by following self-heat recuperation technology. According to this analysis, the recovery streams are selected and the internal heat of the process stream in each module can be recovered and recirculated using a compressor and heat exchanger through self-heat recuperation technology.

Figure 5 a) shows the structure of the self-heat recuperative azeotropic distillation module (Kansha et al. 2010c), consisting of three modules, namely, the first distillation module, the heat circulation module, and the second distillation module. In this self-heat recuperative distillation module, stream 1 represents a feed stream of the ethanol-water azeotropic mixture and stream 2 represents an entrainer (benzene and cyclohexane) feed stream. These streams are fed into the distillation column of the first distillation module. The vapor stream from the first distillation process is compressed adiabatically by a compressor (4→5). Subsequently, stream 5 is cooled in a heat exchanger (5→6), and the pressure and
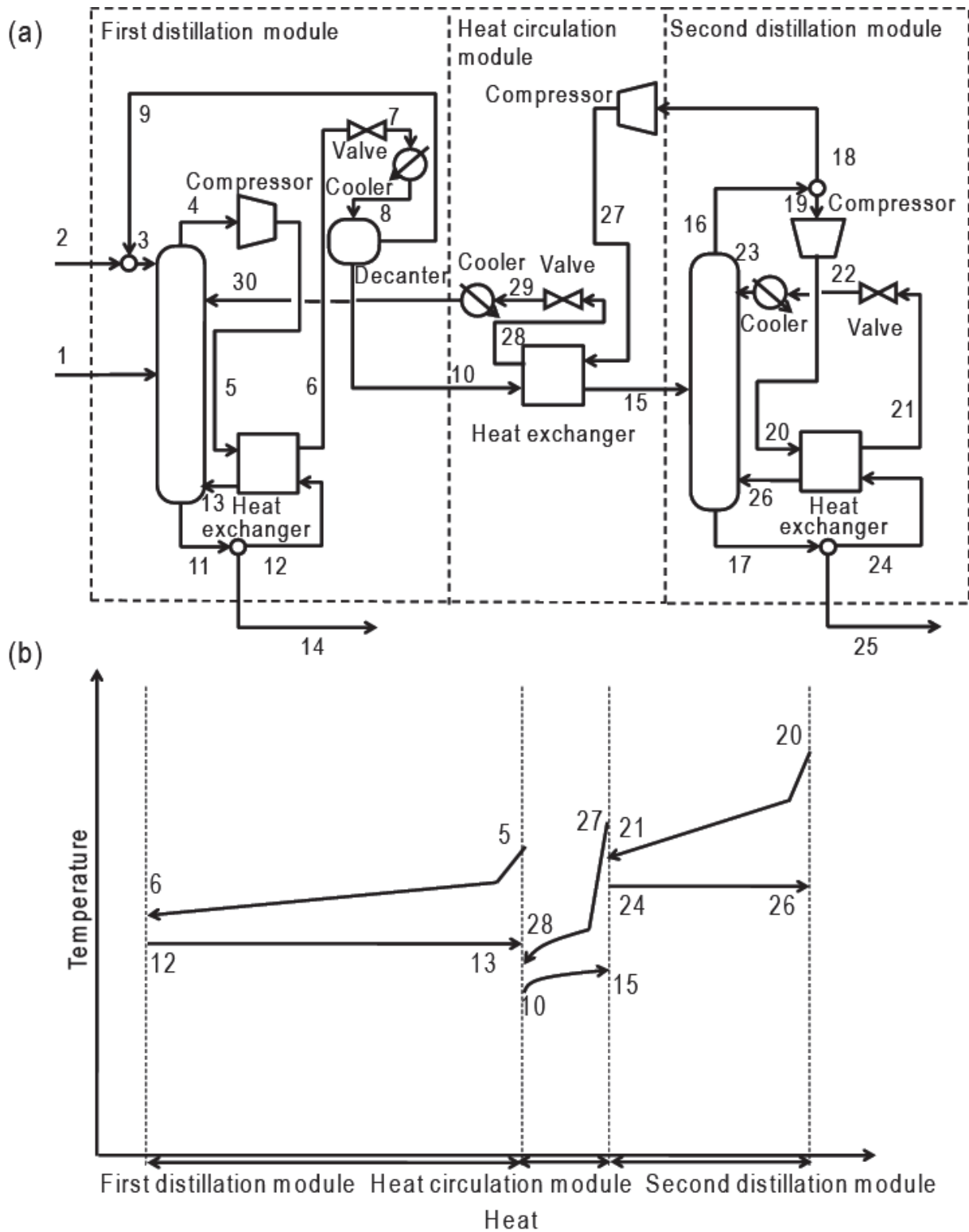
Fig. 5. Self-heat recuperative azeotropic distillation process for dehydration a) process flow diagram, b) temperature-heat diagram

temperature of stream 6 are adjusted by a valve and a cooler (6→7→8). The liquid stream (8) is divided into two streams (9 and 10) in a decanter. Stream 9 consists mainly of the entrainer, which is recycled to the feed benzene (3). The bottom (11) of the distillation

column is divided into two streams (12 and 14). Stream 14 becomes a product stream (pure ethanol). Stream 12 is heated in the heat exchanger and fed into the distillation column. In the heat circulation module, the effluent stream (10) from the first distillation module is heated in a heat exchanger and fed to the distillation column in the second distillation module. At the same time, the recycled stream, which is the distillate stream from the second distillation module, is adiabatically compressed by a compressor (18→27) and cooled by exchanging heat in the heat exchanger (27→28). The pressure and temperature of stream 28 are adjusted by a valve and cooler (28→29→30) and stream 30 is fed into the distillation column of the first distillation module as the recycled stream. Next, in the second distillation module, the feed stream (15) is separated into the distillate (16) and the bottoms (17) by the distillation column. The vapor distillate (16) is divided into two streams (18 and 19) by a separator. Stream 18 is recycled to the heat circulation module, while stream 19 is adiabatically compressed (19→20) and exchanged with the heat in a heat exchanger (20→21). The temperature and pressure of stream 21 are adjusted by a valve and a cooler (21→22→23), and then the effluent stream is fed into the distillation column. Subsequently, the bottom stream (17) from the distillation column is divided into two streams (24 and 25). Stream 25 is the product water. The other stream (24) is vaporized in the heat exchanger and fed into the distillation column (26).

Figure 5 b) shows a temperature–heat diagram for the self-heat recuperative distillation module for azeotropic distillation. Note that numbers beside the composite curve correspond to the stream numbers in Figure 5 a). It can be seen that the latent heats of the effluent streams are exchanged with those of the feed streams, as well as the sensible heats in each module, leading to minimization of the exergy loss in the heat exchangers. From this figure, it can be understood that all of process heat is recirculated without any heat addition and the total heating duty was covered by internal heat recovery. All of the compression work in each module was discarded into coolers in each module, because the sum of enthalpy in the feed streams was equal to that of the effluent streams in each module when using internal heat recovery. As this relationship indicates, the compression work was used for inducing heat recovery and circulation in each module and exhausted as low exergy heat. As a consequence, the energy required of the self-heat recuperative distillation module for azeotropic distillation is 1/8 of that of the conventional azeotropic distillation process.

3.1.3 Self-heat recuperative drying

Biomass resources usually contain a large amount of moisture, leading to higher transportation costs, debasement during storage, and reduction of thermal efficiency during conversion. Drying is a key technology for utilizing the biomass (McCormick & Mujumdar 2008). In addition to the use of biomass for fuel, the energy required for drying occupies a large amount of energy in the production due to the large latent heat of water during evaporation. Moreover, this characteristic of the drying process is the same as for the thermal and distillation processes. Therefore, a drying process based on self-heat recuperation technology was recently proposed (Fushimi et al., 2011).

Figure 6 a) shows a schematic image of a self-heat recuperative drying process. The wet sample is heated in a heat exchanger (1→2). The heated wet sample and vapor are then fed into an evaporator (dryer) with dry gas to assist evaporation (16). The heat for evaporation is supplied by superheated steam and gas (7). The hot dry sample (3) is separated and cooled by the dry gas (15) (3→5). After eliminating the unseparated sample to prevent it from entering the compressor, the evaporated steam and gas (4) are compressed (7) by a
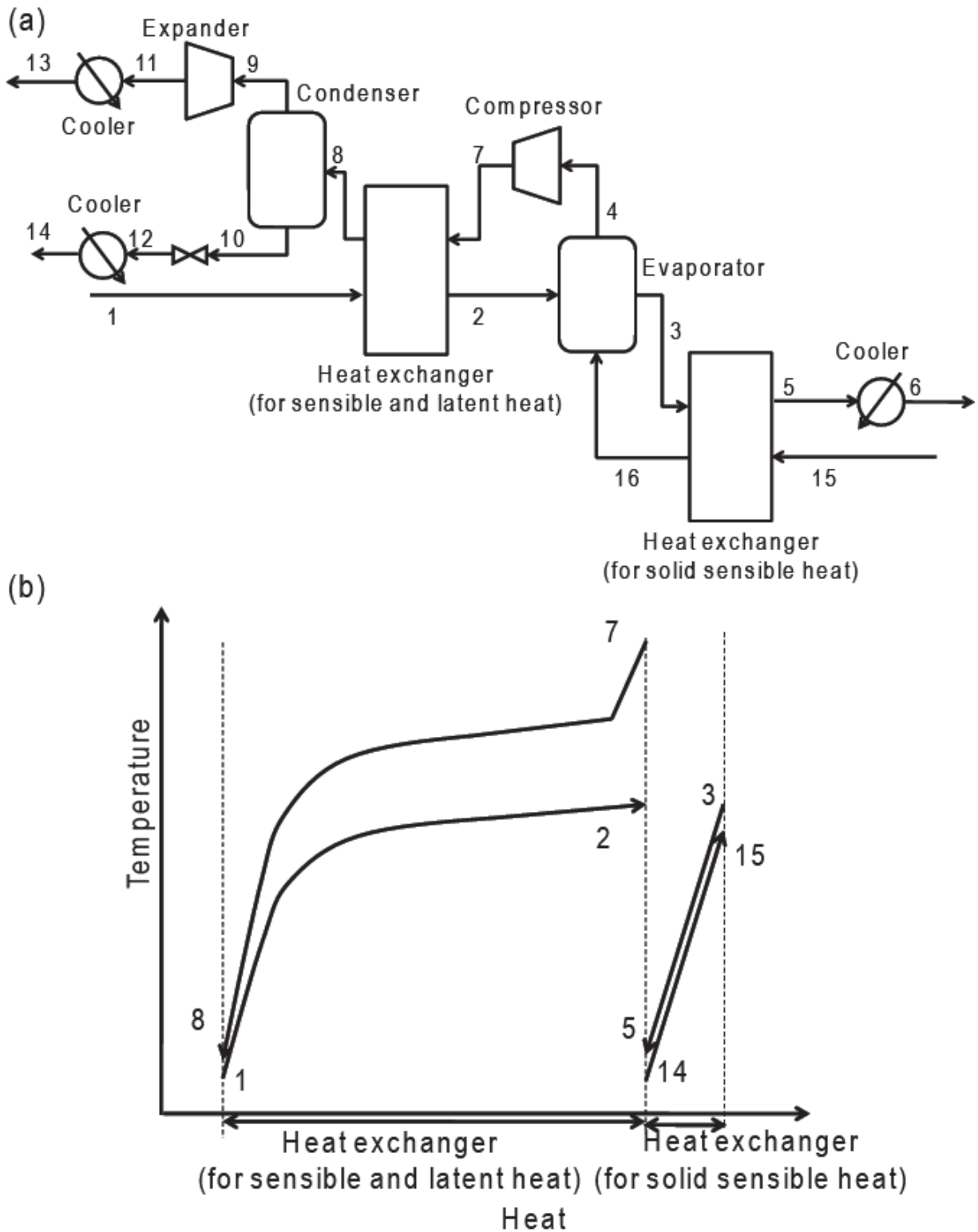
Fig. 6. Self-heat recuperative drying process for dehydration a) process flow diagram, b) temperature-heat diagram

compressor. The sensible and latent heats of the compressed steam and gas are exchanged in the heat exchanger (7→8) and fed into a condenser to separate the water and gas; the water is then drained (10). The pressure and temperature of drain water are adjusted by a valve

and cooler (10→12→14). Simultaneously, the pressure energy of the gas (9) is partially recovered in an expander. The temperature of the gas is then cooled by a cooler (13). This exhausted gas can be recycled as the gas feed (15). To use this gas as the dry gas feed, makeup gas is necessary to compensate for the loss, because a small amount of gas dissolves in water in the condenser. Considering a real application for a drying process, the dried sample is separated immediately after the evaporation and reversed back to the heat exchanger for heat utilization. However, with the aim of reducing drying time (higher drying rate) and providing the driving force required in the drying process, gas that has been preheated by the sample enters the evaporator. It should be noted that an increase in gas flow rate causes an increase in the energy required for compression for the following reasons: (1) an excess amount of gas must be compressed and (2) a smaller partial pressure of steam requires larger compression pressure for condensation. Consequently, the gas flow rate should be optimized.

Figure 6 b) shows a temperature-heat diagram of the self-heat recuperative drying process. Note that the numbers beside the composite curve in this temperature-heat diagram correspond to the stream numbers in Figure 6 a). It can be seen that the condensation heat of the steam in the effluent stream (7→8) is exchanged with the evaporation heat of the feed stream (1→2), as well as the sensible heats in a heat exchanger. At the same time, the heat of solid sample after evaporation is exchanged with the heat of the gas stream in the other heat exchanger and this heat is supplied to the feed solid sample. These lead to minimization of the exergy loss in the heat exchangers. From this figure, it can be understood that all process heat is recirculated without heat addition, and that the total heating duty is covered by internal heat recovery. All of the compression work in each module was discarded into coolers, because the base conditions of the stream are fixed at standard conditions. As a consequence, to circulate the process stream heat in the process using heat exchangers and a compressor, the energy required for the self-heat recuperative drying process is 1/7 of that of the conventional heat recovered drying process.

4. Integration with biomass gasification

To adopt self-heat recuperative processes, it is necessary to generate power in substitution for heat energy. According to the energy balance shown in Figs. 1 and 2, much residue with insufficient heat value for utilization due to its high moisture content is produced during bioethanol production. By integrating the self-heat recuperative drying process with power generation, this wet biomass can be utilized for energy. In this section, an integrated system for self-heat recuperative bioethanol production with biomass gasification is introduced.

4.1 Biomass gasification and its impact on the system

One of the easiest ways to generate power from biomass is direct combustion of biomass in a boiler, wherein thermal energy is produced and power is generated from this thermal energy by using a steam turbine (boiler and turbine generator). However, energy conversion efficiency under this procedure is not good enough. To increase the conversion efficiency of energy from biomass to power, biomass gasification reaction is used. Gasification reactions can be divided into two mechanisms; pyrolysis and gasification by chemical reaction (partial oxidation, etc.) Biomass gasification normally passes through both of these. After passing through a series of gasification procedures, the gases are fed into a gas turbine, and then the

power is generated. Gasification reactions are normally endothermic reactions, and must be provided with heat during reactions. However, the overall energy conversion efficiency will be increased compared with the boiler and turbine generator. In addition, a further increase in energy conversion efficiency, through a biomass-based integrated gasification combined cycle (IGCC) technology has been investigated (Bridgwater 1995).

It is currently assumed that the energy conversion efficiency of biomass through power generation and biomass gasification is 25%. The energy amount of the wet residue is 50 in Figs. 1 and 2. It assumed that half of the energy amount of this wet residue can be utilized for drying the biomass. According to the analysis of self-heat recuperative drying above, 1/8 of the amount of energy for water evaporation is required for power to dry this wet residue using self-heat recuperative drying. This means that power (8) can be generated and a part of this power (3) is used for drying, leading to 4% of the initial wet biomass being converted to power as net energy (5) from the wet residue as shown in Fig. 7.
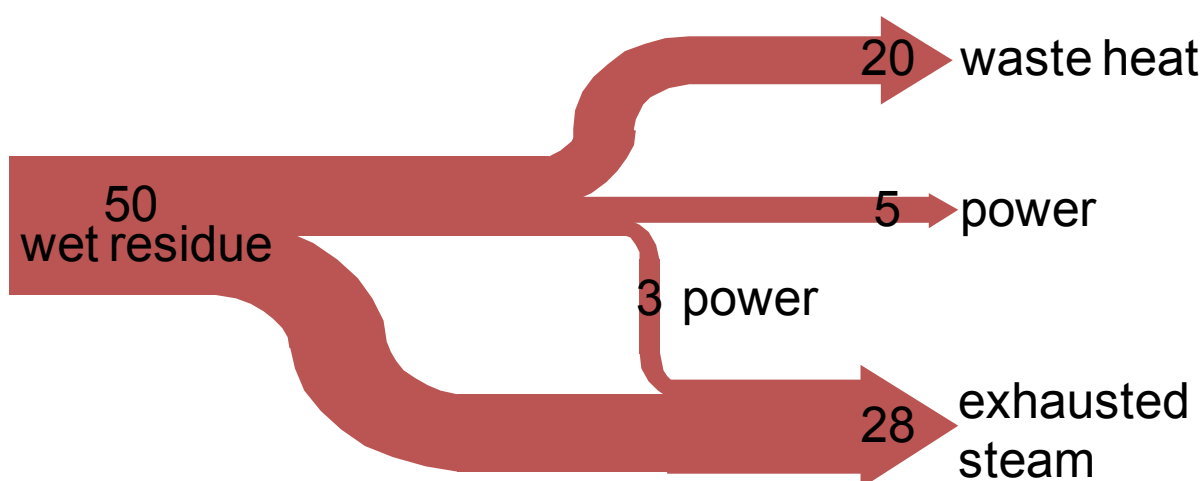

Fig. 7. Power generation from wet residue during bioethanol production

5. Energy balance for self-heat recuperative bioethanol production

The same assumption as for section 2 is assumed; the amount of energy in the wet biomass feed stock is 100, 50% of the energy value of the wet biomass consists of the energy value of reactant sugars such as starch, cellulose and others, and the amount of energy of the original sugar component (50) transfers to ethanol (46) and heat (4) through chemical reactions (saccharification and fermentation) with water.

By applying the self-heat recuperative distillation and azeotropic distillation process to the distillation and dehydration process, the additional heat energy for distillation is converted to power. At the same time, the energy (23) in Figure 1 is reduced to 4. This value was estimated from the energy reduction results from the self-heat recuperative processes in section 3.

By integrating the aforementioned biomass gasification in section 4 with the self-heat recuperative processes introduced in section 3, bioethanol (46) and power (1) can be produced as co-products from wet biomass (100) during bioethanol production, as shown in Fig. 8. Wet residue (non-reactants contain a large amount of water, for which the higher heat value is almost equal to the required evaporation heat, leading to net heat value of 0) in Figs.

1 and 2 can be utilized as the energy supply. Thus, it can be understood that 46% of the energy of the wet biomass is transferred to the bioethanol and 1% of the energy to power. Furthermore, the additional wet biomass (38) required to provide the distillation heat (23) is no longer necessary for this bioethanol production. Thus, power (4) can be generated from the additional wet biomass by using a self-heat recuperative drying process and biomass gasification, as shown in Fig. 9. As a result, 33% (= 46/138×100) of the energy of the wet biomass is transferred to bioethanol and 4% (= 5/138×100) is transferred to power for co-production. It can be said that this bioethanol production procedure achieves not only energy savings but also reduction of exergy dissipation for the whole process, leading to achievement of optimal co-production. In addition, substituting the azeotropic distillation process by dehydration uses a membrane separation. All of the self-heat recuperative processes and biomass gasification are applied to produce this energy. The energy required can be decreased to 4 as power, where the same assumptions as used for the results described above are used in the calculation, such that power generation efficiency from dry biomass is 25% and 75% of the energy required for the membrane separation process is provided by electricity. This value of power is the same as the energy required by applying self-heat recuperative processes to the distillation and dehydration processes. Although the energy required by membrane separation process is smaller than that of azeotropic distillation in the conventional processes, it becomes equal after applying the self-heat recuperative processes.
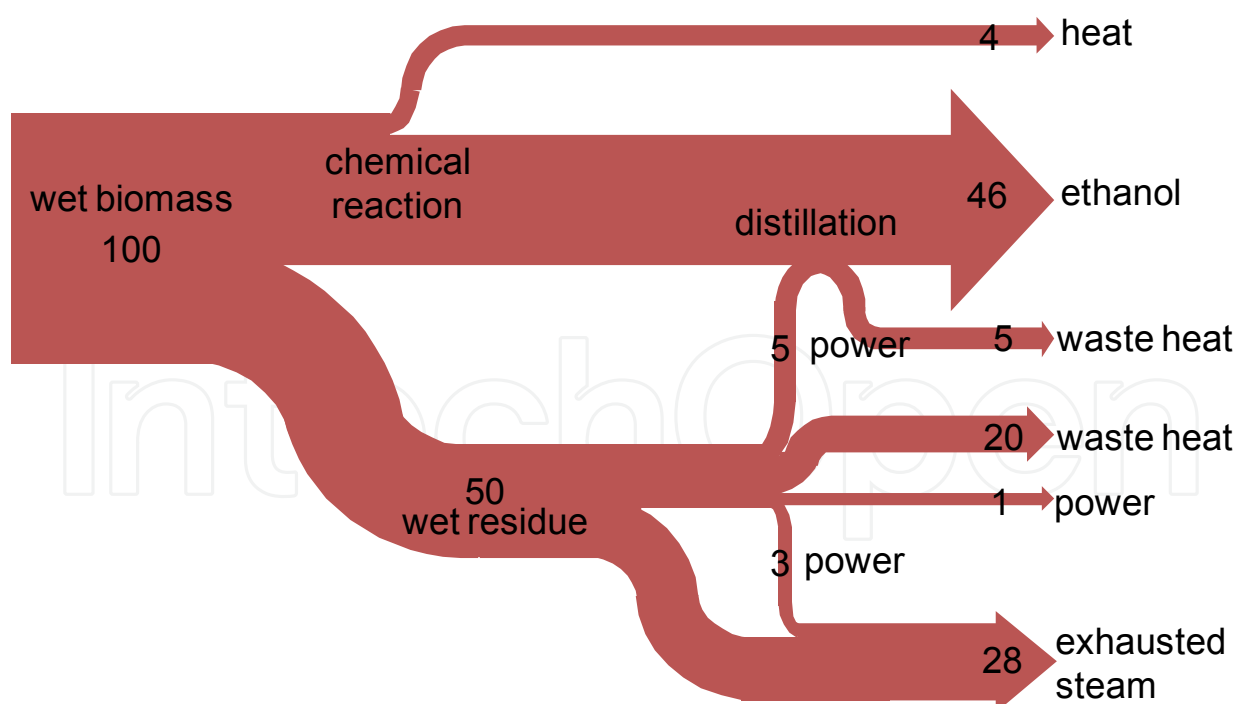

Fig. 8. Energy balance for bioethanol production with self-heat recuperation
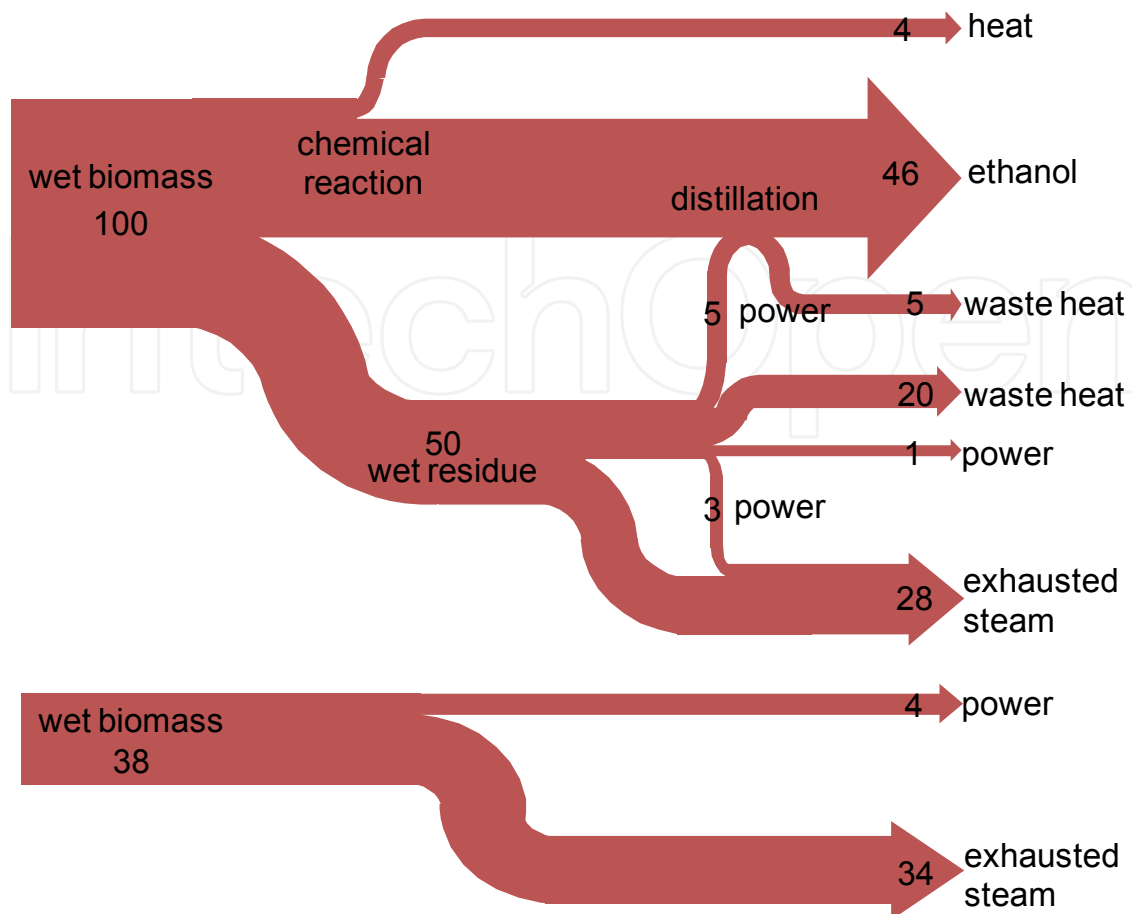
Fig. 9. Total energy balance for bioethanol production with self-heat recuperation

6. Conclusion

In this chapter, a newly developed self-heat recuperation technology is introduced and the feasibility of co-production of bioethanol and power by integration of self-heat recuperative processes and biomass gasification for power generation is examined based on energy balances. From analysis of the energy balance for the conventional bioethanol production processes, a large amount of energy is consumed for separation of water (distillation and drying) so that the operational costs for bioethanol production are high, limiting the potential contribution of bioethanol to society. However, by incorporating self-heat recuperative processes for distillation, azeotropic distillation and drying, not only are the energy requirements reduced dramatically due to heat circulation in the processes, but also wasted residue can be utilized as a power source through biomass gasification. Thus, it is shown that co-production of bioethanol and power is feasible, enabling the economic impact of the bioethanol product. Finally, this system is expected to help the uptake of bioethanol and decrease global CO_2 emissions.

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Biofuel's Engineering Process Technology

Edited by Dr. Marco Aurelio Dos Santos Bernardes

This book aspires to be a comprehensive summary of current biofuels issues and thereby contribute to the understanding of this important topic. Readers will find themes including biofuels development efforts, their implications for the food industry, current and future biofuels crops, the successful Brazilian ethanol program, insights of the first, second, third and fourth biofuel generations, advanced biofuel production techniques, related waste treatment, emissions and environmental impacts, water consumption, produced allergens and toxins. Additionally, the biofuel policy discussion is expected to be continuing in the foreseeable future and the reading of the biofuels features dealt with in this book, are recommended for anyone interested in understanding this diverse and developing theme.

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