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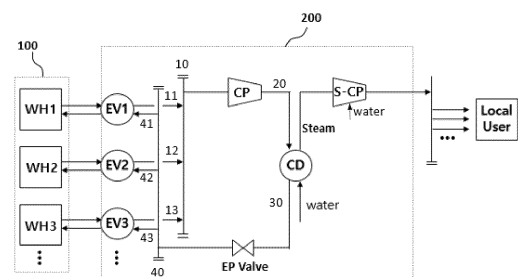
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(54) **METHOD FOR PREPARING STEAM USING WASTE HEAT**

(57) The present invention provides a method for preparing steam, comprising: (S1) making a process waste heat fluid supplied from a plurality of waste heat sources flow into each of refrigerant evaporators having numbers corresponding to the plurality of waste heat sources to vaporize a refrigerant through heat exchange to form a plurality of vaporized refrigerant streams; (S2) joining the plurality of vaporized refrigerant streams from each of the refrigerant evaporators to one integrated pipe to form a joined stream; (S3) compressing the joined stream in a refrigerant compressor to form a compressed refrigerant stream; (S4) heat exchanging the compressed refrigerant stream with water in a refrigerant condenser to prepare a condensed refrigerant stream and steam; and (S5) decompressing the condensed refrigerant stream by passing the condensed refrigerant stream through a refrigerant expansion valve, followed by branching and circulating the condensed refrigerant stream to each of the plurality of refrigerant evaporators, and further including transferring and compressing the steam flowing out of the refrigerant condenser to a steam compressor.

【FIG. 3】



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Description

CROSS REFERENCE TO PRIOR APPLICATIONS

[0001] This application claims priority to and the benefit Korean Patent Application Nos. 10-2023-0007494 and 10-2023-0183502 filed on January 18, 2023 and December 15, 2023, which are hereby incorporated by reference in their entirety.

[Technical Field]

[0002] The present invention relates to a method for preparing steam using waste heat, and more particularly, to a method for connecting a plurality of waste heat sources to one heat pump system to prepare high temperature/high pressure steam required in a process.

[Background Art]

[0003] A petrochemical process uses a lot of energy to produce products, and the used energy is discarded or reused.

[0004] In general, petrochemical products may be manufactured through processes that include reaction, separation, and purification. A lower portion of a column where these processes are performed is heated using steam, so a large amount of heat is discarded as a high-temperature fluid at an upper portion of the column is cooled through heat exchange with cooling water and the heated cooling water flows into a cooling tower and is cooled while dissipating heat. All heat dissipated during this cooling process may be referred to as waste heat within the process.

[0005] Meanwhile, the steam used as an energy source in the petrochemical processes is generally prepared by combustion heat generated by the combustion of hydrocarbons, and this process is expensive and causes global warming due to carbon dioxide generated while preparing the steam.

[0006] Therefore, in order to lower the manufacturing cost of the petrochemical products and reduce carbon emissions, there is a growing demand to reduce the amount of steam used in the process. As part of this, attempts to recover the waste heat in the petrochemical process and reuse the recovered waste heat to prepare the steam are increasing.

[0007] FIG. 1 illustrates a process of recovering waste heat (WH) from a petrochemical process through a heat pump device including an evaporator EV, a compressor CP, a condenser CD, and an expansion valve.

[0008] The heat pump is a device that performs a cycle of transferring a low-temperature heat source to a high temperature or transferring a high-temperature heat source to a low temperature using evaporation heat or condensation heat of the refrigerant. In the evaporator EV, a low-temperature and low-pressure liquid refrigerant is vaporized through heat exchange with the waste heat WH, the vaporized low-temperature and low-pressure refrigerant gas is compressed into high-temperature and high-pressure gas in the compressor CP, and the compressed refrigerant gas releases heat from the condenser CD to the outside, and is condensed and liquefied and becomes a low-temperature and high-pressure liquid state. The condensed high-pressure refrigerant is expanded due to a pressure drop in a narrowed portion while passing through the expansion valve (EP valve), and becomes a low-temperature and low-pressure liquid again. In the process of recovering the waste heat through this cycle, make-up water flowing into the condenser CD absorbs latent heat generated by the condensation of the refrigerant and is vaporized, thereby preparing steam.

[0009] However, in the existing method, waste heat energy was recovered by connecting only one waste heat source to a heat pump device. When a plurality of waste heat sources are to be applied, the number of heat pump devices should be increased, resulting in increasing a size of a steam preparation facility and increasing production costs accordingly.

[0010] Additionally, in the existing technology using the heat pump, a temperature lift is lowered when preparing the steam from the recovered waste heat, so it is difficult to meet an energy level required for the petrochemical process, for example, a temperature of 100 to 250°C.

[0011] Therefore, there is a need for technology that can increase economic and thermodynamic efficiency in steam preparation through waste heat recovery and prepare high temperature/high pressure steam required in a petrochemical process.

[Disclosure]

[Technical Problem]

[0012] The present invention is intended to solve the problems mentioned in the background technology of the invention, and provides a method for preparing high-temperature/high-pressure steam required in a process in large quantities through a simple and economical design that can connect a plurality of waste heat sources to one heat pump device.

[Technical Solution]

[0013] To solve the above problem, the present invention provides a method for preparing steam, comprising: (S1) making a process waste heat fluid supplied from a plurality of waste heat sources flow into each of refrigerant evaporators having numbers corresponding to the plurality of waste heat sources to vaporize a refrigerant through heat exchange to form a plurality of vaporized refrigerant streams; (S2) joining the plurality of vaporized refrigerant streams from each of the refrigerant evaporators to one integrated pipe to form a joined stream; (S3) compressing the joined stream in a refrigerant compressor to form a compressed refrigerant stream; (S4) heat exchanging the compressed refrigerant stream with water in a refrigerant condenser to prepare a condensed refrigerant stream and steam; and (S5) decompressing the condensed refrigerant stream by passing the condensed refrigerant stream through a refrigerant expansion valve, followed by branching and circulating the condensed refrigerant stream to each of the plurality of refrigerant evaporators, and further including transferring and compressing the steam flowing out of the refrigerant condenser to a steam compressor.

[0014] In the present invention, the compressed refrigerant stream may have a temperature ranging from 100 to 200°C, and the refrigerant stream condensed through heat exchange with water in the refrigerant condenser may have a temperature ranging from 85 to 170°C.

[0015] In addition, the present invention provides a system for preparing steam for performing the method, including a plurality of waste heat sources and a heat pump device connected thereto, in which the heat pump device includes a refrigerant evaporator, a refrigerant compressor, a refrigerant condenser, and a refrigerant expansion valve connected through a pipe, the refrigerant evaporator is configured in plurality to communicate with each process waste heat fluid supplied from the plurality of waste heat sources, refrigerant streams flowing out of the pipe connected to the plurality of refrigerant evaporators are joined through an integrated pipe and transferred to the refrigerant compressor, the refrigerant stream passing through the refrigerant expansion valve is circulated to the plurality of refrigerant evaporators through a branched pipe, and the refrigerant condenser is connected to an additional steam compressor.

[Advantageous Effects]

[0016] According to the present invention, waste heat is recovered by connecting a plurality of waste heat sources to a heat pump device including the corresponding number of evaporators to perform heat exchange between the plurality of waste heat and a branched refrigerant flow, respectively, and then the vaporized refrigerant flows are integrated and compressed in the plurality of evaporators, it is possible to prepare steam required in the process in large quantities through the heat exchange with water.

[0017] In addition, when preparing the steam from the waste heat recovered in the heat pump device, the temperature of the compressed refrigerant and the condensed refrigerant is controlled to maximize a temperature lift, and also additional compression is performed on the prepared steam to be converted into final high-temperature and high-pressure steam which can be used as an energy source in various process stages, thereby reducing manufacturing costs of petrochemical products and reduce carbon emissions.

[0018] Moreover, by applying one heat pump device to the plurality of waste heat sources to implement simplification and operating efficiency of a steam preparation facility, it is possible to implement cost reduction, minimization of maintenance, and stabilization of operation, etc.

[Brief Description of the Drawings]

[0019]

FIG. 1 is a diagram illustrating a waste heat recovery process of a heat pump device according to the related art.

FIG. 2 is a diagram schematically illustrating a system for preparing steam in which a heat pump device including a plurality of waste heat sources and the corresponding number of evaporators is connected according to the present invention.

FIG. 3 is a diagram illustrating a configuration in which an additional steam compressor is connected to a refrigerant condenser of the heat pump device in the system for preparing steam according to the present invention.

[Best Mode]

[0020] Terms and words used in the present specification and claims are not to be construed as a general or dictionary meaning but are to be construed as meaning and concepts meeting the technical ideas of the present invention based on a principle that the inventors can appropriately define the concepts of terms in order to describe their own inventions in best mode.

[0021] The term "including" or "containing" used herein concretely indicates specific properties, regions, integer

numbers, steps, operations, elements, or components, and is not to exclude presence or addition of other specific properties, regions, integer numbers, steps, operations, elements, components, or a group thereof.

[0022] The term 'stream' used herein may mean a flow of a fluid in a process, and may also mean a fluid itself flowing in a pipe. Specifically, the stream may mean both the fluid itself and the flow of the fluid flowing within the pipe connecting each device. In addition, the fluid may include any at least one components of a gas, a liquid, and a solid.

[0023] One embodiment of the present invention relates to a method for recovering waste heat and preparing steam by connecting a plurality of waste heat sources to one heat pump device. Specifically, the method may include a step (S1) of vaporizing a refrigerant by heat exchange between a plurality of process waste heat fluids and the refrigerant, a step (S2) of integrating vaporized refrigerant streams, a step (S3) of compressing the integrated refrigerant stream, a step (S4) of preparing a condensed refrigerant stream and steam by heat exchange between the compressed refrigerant stream and water, and a step (S5) of depressurizing and branching the condensed refrigerant stream, and may further include compressing the steam.

[0024] Hereinafter, the method for preparing steam will be described step by step in detail with reference to the attached drawings.

[0025] Referring to FIG. 2, the method for preparing steam through waste heat recovery according to the present invention may be performed using a system for preparing steam including a plurality of waste heat sources 100 and a heat pump device 200 connected thereto.

[0026] The plurality of waste heat sources 100 is a member that supplies various process fluids including heat that are discarded using cooling water in a petrochemical process, that is, a plurality of process waste heat fluids WH1, WH2, WH3, ..., and in the present invention, in order to increase the economical and thermodynamic efficiency of the steam preparation using the waste heat, the waste heat source 100 is composed of at least one unit, for example, 2 to 10 units, and is connected through a pipe to fluid-communicate with one heat pump device 200.

[0027] In an embodiment of the present invention, the temperature of the process waste heat fluids WH1, WH2, WH3, ..., supplied from the plurality of waste heat sources 100 may range from 30 to 140°C, specifically 60 to 100°C. When the temperature of the process waste heat fluid is less than 30°C, energy consumption increases as a compression ratio of a refrigerant increases during waste heat recovery in the heat pump device 200, and when the temperature of the process waste heat fluid exceeds 140°C, due to an excessive increase in refrigerant vapor pressure, it may not be easy to manufacture facilities or latent heat per unit mass may decrease, making it difficult to select the capacity of the refrigerant condenser.

[0028] The heat pump device 200 performs a cycle of transferring a low-temperature heat source to a high temperature or transferring a high-temperature heat source to a low temperature using the evaporation or condensation heat of the refrigerant, and includes a refrigerant evaporator EV, a refrigerant compressor CP, a refrigerant condenser CD, and a refrigerant expansion valve (EP valve), and each of these members is connected through a pipe so that the refrigerant may circulate.

[0029] In the heat pump device 200, the refrigerant evaporator EV is a member that is connected to the plurality of waste heat sources 100 through the pipe to perform heat exchange between the process waste heat fluids WH1, WH2, WH3, ..., and the refrigerant, and may be composed of a plurality of refrigerant evaporators EV1, EV2, EV3, ..., and the refrigerant streams flowing out of each pipe 11, 12, 13, ..., connected to the plurality of evaporators are joined through an integrated pipe 10, and then the mixed refrigerant stream may sequentially pass through the refrigerant compressor CP, the refrigerant condenser CD, and the refrigerant expansion valve (EP valve). Thereafter, the refrigerant stream passing through the refrigerant expansion valve may be circulated to the plurality of evaporators through pipes 41, 42, 43, etc., branched from an integrated pipe 40.

[0030] More specifically, the refrigerant evaporator EV included in the heat pump device 200 may be composed of numbers EV1, EV2, EV3, ..., corresponding to the plurality of waste heat sources 100 to communicate with each of the process waste heat fluids WH1, WH2, WH3, ..., supplied from the plurality of waste heat sources 100. For example, when the plurality of waste heat sources 100 are composed of 2 to 10 units, the refrigerant evaporator EV may also be composed of 2 to 10 units.

[0031] Each of the refrigerant evaporators applicable to the present invention may be a general shell and tube type, and may also be a plate type or falling film evaporator type to increase heat exchange efficiency, but is not limited thereto.

[0032] A low-temperature and low-pressure liquid refrigerant, for example, a refrigerant indicating a pressure of 1 to 30 bar or 3 to 20 bar and a temperature of 10 to 120°C or 40 to 80°C, respectively, may flow into each of the refrigerant evaporators EV1, EV2, EV3, ..., through a pipe, and the high-temperature process waste heat fluids WH1, WH2, WH3, ..., supplied from the plurality of waste heat sources 100 flow into each of the refrigerant evaporators through which the low-temperature and low-pressure refrigerant flows, thereby vaporizing the refrigerant through the heat exchange.

[0033] That is, when the process waste heat fluid of 30 to 140°C flows into each of the refrigerant evaporators, the refrigerant may absorb heat from the process waste heat fluid through mutual heat exchange and may be converted into a gaseous stream with a relatively high temperature.

[0034] In one embodiment of the present invention, the total flow rate of the refrigerant flowing into each of the refrigerant

evaporators EV1, EV2, EV3, ..., through the pipe is 10 to 1,000 Tons/hr, for example, 20 to 500 Tons/hr, or 30 to 400 Tons/hr, and the flow rates of each of the process waste heat fluids flowing into each of the refrigerant evaporators EV1, EV2, EV3, ..., may be 5 to 10,000 Tons/hr, for example, 10 to 5,000 Tons/hr or 15 to 4,000 Tons/hr, but are not limited thereto.

[0035] Among the total components of the refrigerant stream vaporized in the refrigerant evaporator, the gaseous component is in a rich state. For example, a mole fraction of the gaseous component among all the components of the refrigerant stream may be 1.0.

[0036] In one embodiment of the present invention, the temperature of the refrigerant stream vaporized in each of the refrigerant evaporators may satisfy Equation 1 below, and thus, the high-temperature steam may be prepared using waste heat of 30 to 140°C.

[Equation 1]

$$1^{\circ}\text{C} \leq T_{\text{WH}} - T_{\text{G}} \leq 20^{\circ}\text{C}$$

wherein,

T_{WH} is a terminal temperature of the process waste heat fluid flowing into each of the refrigerant evaporators, and T_{G} is a temperature of the vaporized refrigerant stream in each of the refrigerant evaporators.

[0037] Meanwhile, the process waste heat fluid that exchanges heat with the refrigerant in each of the refrigerant evaporators EV1, EV2, EV3, ..., may flow out from each of the refrigerant evaporators at a temperature lower than an initial temperature, for example, from 25 to 135°C or from 55 to 95°C.

[0038] Subsequently, the refrigerant streams vaporized in each of the refrigerant evaporators EV1, EV2, EV3, ..., may flow out through the pipes 11, 12, 13, ..., connected to each of the refrigerant evaporators and may be joined into one integrated pipe 10.

[0039] In the present invention, the refrigerant streams vaporized by the heat exchange in the plurality of refrigerant evaporators EV1, EV2, EV3, ..., in which the plurality of process waste heat fluids WH1, WH2, WH3, ..., flow are joined in the integrated pipe 10, and then, the mixed refrigerant stream sequentially passes through the refrigerant compressor CP, the refrigerant condenser CD, and the refrigerant expansion valve (EP valve). When the refrigerant streams flowing out of the plurality of refrigerant evaporators directly flow into the refrigerant compressor CP without passing through the integrated pipe 10, as the physical properties such as the flow rate, temperature, and pressure of the refrigerant stream become non-uniform, the normal operation of the refrigerant compressor CP becomes difficult. That is, when the plurality of waste heat sources are applied, the refrigerant streams vaporized in each of the plurality of refrigerant evaporators flow into the refrigerant compressor through the integrated pipe, so it is possible to normally operate the compressor.

[0040] In one embodiment of the present invention, a linear length of the integrated pipe 10 may be from 5 to 5,000 m, specifically from 10 to 1,000 m. When the length of the integrated pipe is less than 5 m, as the heat mixing of the heated coolant becomes non-uniform, a refrigerant evaporation rate changes in the refrigerant evaporator EV of the heat pump device 300 due to the heat exchange, and the surging or cavitation phenomenon may occur in the refrigerant compressor CP at a rear stage, resulting in making the driving itself impossible. When the length of the integrated pipe exceeds 5,000 m, heat loss may occur to reduce the amount of waste heat or increase a pipe differential pressure, resulting in the increase in power.

[0041] In addition, the flow velocity of the integrated pipe 10 may range from more than 5 m/s to 50 m/s, specifically 10 to 40 m/s. When the flow velocity of the integrated pipe is less than or equal to 5 m/s, the heat mixing efficiency of the evaporated refrigerant may decrease, and when the flow velocity of the integrated pipe exceeds 50 m/s, the erosion and vibration may occur within the pipe.

[0042] By applying the integrated pipe 10 as described above, it is possible to implement the cost reduction, the minimization of maintenance, and the stabilization of operation through the simplification and operation efficiency of the steam generation facility.

[0043] To be more specific, the related art is the method for recovering waste heat energy by connecting only one waste heat source to the heat pump device, and thus, has the limitation of requiring the plurality of heat pumps for the plurality of waste heat sources, resulting in the inconvenience of managing the plurality of facilities and the accompanying increase in personnel and costs. On the other hand, in the present invention, by joining the plurality of waste heat sources and the heat-exchanged refrigerant streams in the integrated pipe and then flowing the joined waste heat sources and heat-exchanged refrigerant into the compressor, it is possible to simplify the control and operation, reduce the number of abnormal operations, and increase the replacement cycle.

[0044] In addition, when connecting a single waste heat source to a single heat pump, there is a waste heat source that cannot be recovered due to the limitations of a small-capacity facility, but as in the present invention, the introduction of the

heat pump that uses the compressor after passing through the integrated pipe can recover even a trace amount of waste heat.

[0045] Additionally, when preparing the steam individually using the plurality of heat pumps, there is difficulty in controlling a material balance of the entire facility. However, as in the present invention, the introduction of the heat pump that uses the compressor after passing through the integrated pipe can help stabilize the operation through the reduced number of times of maintenance and more efficient material balance control.

[0046] The gaseous refrigerant stream joined in the integrated pipe 10 may flow into one refrigerant compressor CP, the pressure of the gaseous refrigerant stream may increase by the compression using electrical energy, and the temperature of the gaseous refrigerant stream may also increase in proportion to the amount of electrical energy supplied.

[0047] If the refrigerant compressor CP is a device capable of compressing a gaseous flow, various devices known in the art can be used without limitation. For example, a turbo-type compressor capable of compressing a large capacity may be used. In addition, the refrigerant compressor CP may be applied as one or as a plurality of refrigerant compressors connected in series depending on the capacity of the flowing refrigerant stream.

[0048] This refrigerant compressor CP may increase the pressure of the gaseous refrigerant stream flowing through the refrigerant evaporator EV by 1.2 to 5 times. For example, the pressure of the refrigerant stream passing through the compressor CP may be from 3 to 50 bar or from 6 to 40 bar, and when the compression of the gaseous refrigerant stream is performed in the above range, it is easy to implement the type selection, design and manufacture of the compressor.

[0049] In addition, the temperature of the refrigerant stream compressed through the compressor CP may be adjusted to a range of 90 to 200°C or 105 to 180°C. When the temperature of the compressed refrigerant stream is less than 100°C, a problem may occur in which the heat exchange efficiency with water in the refrigerant condenser at the rear stage rapidly decreases, and when the temperature of the compressed refrigerant stream exceeds 200°C, the carbonization of the refrigerant or compressor lubricating oil may be caused, or the excessive increase in the refrigerant vapor pressure may make the manufacture of the facility impossible or cause the incomplete operation.

[0050] Thereafter, the high-temperature/high-pressure refrigerant stream flowing out of the compressor flows into the refrigerant condenser CD, and the heat exchange may be performed between the high-temperature/high-pressure refrigerant stream compressed in the refrigerant condenser CD and externally replenished water, so the condensed refrigerant stream and steam may be prepared.

[0051] The refrigerant condenser CD applicable to the present invention may be a general shell and tube type, and may also be a plate type or falling film evaporator type to increase the heat exchange efficiency, but is not limited thereto. In addition, the refrigerant condenser CD may be applied as one or as a plurality of refrigerant compressors connected in series depending on the capacity of the flowing refrigerant stream.

[0052] In the refrigerant condenser CD, the refrigerant is condensed as it releases heat through the heat exchange with water, and the externally replenished water absorbs the heat generated as the refrigerant condenses and becomes steam.

[0053] The refrigerant stream condensed through the heat exchange with water in the refrigerant condenser CD is preferably maintained at a temperature of 85 to 170°C, specifically 100 to 170°C, at a high pressure of 3 to 50 bar or 6 to 40 bar. When the temperature of the condensed refrigerant stream is less than 85°C, the pressure of water in the refrigerant condenser CD may become lower than atmospheric pressure, which may cause air leakage and contaminate the steam prepared by the heat exchange, making it difficult to use in the process or resulting in the corrosion or erosion of the pipe. When the temperature of the condensed refrigerant stream exceeds 170°C, the carbonization of the refrigerant or the compressor lubricating oil may occur, or the excessive increase in the refrigerant vapor pressure may make the manufacture of the facility impossible or cause the incomplete operation.

[0054] In this way, in order to ensure the temperature of the condensed refrigerant stream at 85°C or higher, it is advantageous to adjust a critical temperature of the refrigerant to 100°C or higher. The critical temperature of the refrigerant is a unique physical property value given to each material thermodynamically, and physically refers to the maximum temperature at which the gas phase and liquid phase may be distinguished. The heat exchange potential of the refrigerant may be maintained when this critical temperature differs from the temperature of the condensed refrigerant stream by 15°C or higher. When the heat exchange potential in the refrigerant condenser decreases, it becomes difficult to prepare the steam required in the process and malfunction problems such as the compressor surge may occur.

[0055] When the critical temperature conditions of the refrigerant as described above are satisfied, the refrigerant may be selected from various types known in the art and used without any particular restrictions. For example, one or more refrigerants selected from hydrofluorocarbon (HFC) series R245fa, R134a, R1234ze and R1234yf, and hydrofluoroolefin (HFO) series R1234ze(E), R1234ze(Z), and R1233zd(E) may be used.

[0056] In addition, the pressure of the condensed refrigerant stream may be maintained at a high pressure of 3 to 50 bar or 6 to 40 bar, but is not limited thereto.

[0057] Meanwhile, the water replenished in the refrigerant condenser CD should be pure with ions and oxygen removed, and may flow at a temperature of 10 to 100°C or 20 to 95°C and a pressure of 1 to 20 bar or 1.5 to 10 bar. In addition, the flow rate of water replenished in the refrigerant condenser CD may be from 1 to 100 Tons/hr, for example, from 2 to 80 Tons/hr or from 3 to 50 Tons/hr, but is not limited thereto.

[0058] The steam prepared by the heat exchange with the high-temperature/high-pressure gaseous refrigerant stream in the refrigerant condenser CD may indicate a temperature of 100 to 200°C or 101 to 180°C and a pressure of 1 to 16 bar or 1 to 10 bar.

[0059] Thereafter, the liquid refrigerant stream flowing out of the refrigerant condenser CD is decompressed by passing through the refrigerant expansion valve (EP valve) and the refrigerant stream passing through the refrigerant expansion valve may be circulated to the plurality of evaporators, respectively, through the pipes 41, 42, and 43 branched from the integrated pipe 40.

[0060] The refrigerant expansion valve (EP valve) is a device that lowers the pressure and temperature of the refrigerant stream liquefied in the condenser so that the refrigerant stream may easily evaporate in the evaporator and controls the flow rate of the refrigerant stream. That is, the liquid refrigerant stream that has passed through the expansion valve may be evaporated even at a relatively low temperature when it flows into the refrigerant evaporator again as both the pressure and boiling point are lowered.

[0061] For example, the refrigerant stream passing through the expansion valve may be in the form of a low-temperature/low-pressure liquid phase indicating a pressure of 0.5 to 30 bar or 3 to 20 bar and a temperature of 10 to 120°C or 40 to 80°C, respectively.

[0062] The expansion valve (EP valve) applicable to the present invention may be formed in various structures, such as an electric expansion valve, a thermostatic expansion valve, and an automatic expansion valve. In addition, the expansion valve may be applied as one or as a plurality of refrigerant compressors connected in series depending on the capacity of the flowing refrigerant stream.

[0063] The refrigerant stream passing through the expansion valve may be circulated to each of the plurality of evaporators EV1, EV2, EV3, ..., through the pipes 41, 42, 43, ..., branched from the integrated pipe 40.

[0064] Meanwhile, the steam prepared in the refrigerant condenser CD has a low pressure of 1 to 16 bar, and thus, is difficult to utilize directly in the process. Considering the lower limit of the effective pressure that may be used in the petrochemical process, the steam utilized in the process is required to have a pressure of 4 to 60 bar or 5 to 30 bar.

[0065] Accordingly, in the present invention, as illustrated in FIG. 3, a steam compressor S-CP is connected to the refrigerant condenser CD of the heat pump device 200, and the steam flowing out of the refrigerant condenser CD flows into the steam compressor S-CP to increase the pressure of final steam to a range of 4 to 60 bar or 5 to 30 bar.

[0066] Similar to the refrigerant compressor CP described above, the steam compressor S-CP may use a turbo-type compressor capable of handling large capacities, may be supplied with electrical energy for compression of water molecules, and may increase the temperature of the steam in proportion to the amount of electrical energy supplied.

[0067] In this case, since the heat exchange efficiency of superheated steam decreases when input into the heat exchanger in the process, water is supplied to prepare saturated steam. The water supplied to the steam compressor S-CP should be pure with ions and oxygen removed, and may be input to the process by joining the saturated steam while lowering the superheat of the steam. The flow rate of the supplied water may be from 0.1 to 30 Tons/hr or from 1 to 20 Tons/hr, but is not limited thereto.

[0068] The saturated steam flowing into the steam compressor S-CP may ultimately have a temperature of 140 to 280°C or 150 to 240°C, thereby satisfying the energy level required for petrochemicals.

[0069] According to the present invention, after the waste heat is recovered by connecting the plurality of waste heat sources to the heat pump device including the corresponding number of evaporators to perform heat exchange between the plurality of waste heat and the branched refrigerant flow, respectively, and the vaporized refrigerant flows are integrated and compressed in the plurality of evaporators, it is possible to prepare the steam required in the process in large quantities through the heat exchange with water. For example, the final amount of steam prepared according to the present invention may be from 1 to 120 Tons/hr or from 2 to 100 Tons/hr.

[0070] The steam preparation heat according to the present invention may be defined by Equation 2 below, and the coefficient of performance COP of the system applied to the method for preparing steam of the present invention may be expressed by Equation 3 below.

Steam preparation heat = Waste heat + Supplied power (power used for refrigerant compression and steam compression) [Equation 2]

[Equation 3]

$$\text{COP} = \text{Steam preparation heat} / \text{supplied power}$$

[0071] The coefficient of performance (COP) according to Equation 3 above is defined as the steam preparation heat (the amount of heat absorbed by water) compared to the electric energy input to the refrigerant compressor and the steam

compressor. For example, when the COP value is 2, this means that the amount of heat that is twice that of the input electrical energy is obtained.

[0072] The steam prepared by the method according to the present invention satisfies the value of COP calculated through Equation 3 that is 2 or more, ensuring economic efficiency compared to the input electric energy.

[0073] According to the present invention, steam prepared in large quantities through waste heat recovery by connecting the plurality of waste heat sources to one heat pump device may be stored and distributed and supplied to local user throughout the process.

[Mode for Invention]

[0074] Hereinafter, the present invention will be described in more detail with through Examples. However, the following examples are for illustrating the present invention, and it is clear to those skilled in the art that various changes and modifications are possible within the scope and spirit of the present invention, and the scope of the present invention is not limited only thereto.

Example 1:

[0075] As illustrated in FIG. 3, by using a system in which three waste heat sources 100 were connected to one heat pump device 200, waste heat was recovered and steam was prepared.

[0076] Specifically, the heat pump device 200 includes three refrigerant evaporators EV1, EV2, and EV3, a refrigerant compressor CP, a refrigerant condenser CD, and a refrigerant expansion valve (EP valve) that are connected through a pipe for refrigerant circulation, and a refrigerant (trans-1-chloro-3,3,3-trifluoropropene, R1233zd(E)) in a liquid state (60°C and 3.9 bar) flowed into each of the three refrigerant evaporators EV1, EV2, and EV3 at a flow rate of 310 Tons/hr and circulated.

[0077] Process waste heat fluids WH1, WH2, and WH3 in a gaseous state (75°C and 5 bar) were supplied to each of the three waste heat sources 100 at a flow rate of 52 Tons/hr, and flowed into the three refrigerant evaporators EV1, EV2, and EV3 to perform the heat exchange. After the heat exchange, the process waste heat fluids WH1, WH2, and WH3 in each of the three refrigerant evaporators EV1, EV2, and EV3 were radiated and flow out in a liquid state of 65°C and 4 bar, and the refrigerant was vaporized by heat absorption to flow out in a gaseous state of 60°C and 3.9 bar.

[0078] The refrigerant stream flowing out after being vaporized in each of the refrigerant evaporators EV1, EV2, and EV3 was mixed by being joined to one integrated pipe 10 (straight length 50 m, flow velocity 10 m/s).

[0079] After the mixed refrigerant stream flowed into the refrigerant compressor CP through the integrated pipe, compression was performed under a power of 4.4 Gcal/h to obtain a refrigerant stream in a gaseous state of 128°C and 16 bar.

[0080] The compressed refrigerant stream (128°C and 16 bar) flowing into the refrigerant condenser CD and water (20°C and 1 bar) was supplied to the refrigerant condenser CD at a flow rate of 27 Tons/hr, thereby performing the heat exchange. After the heat exchange, the water was produced as steam of 124°C and 2 bar, and the refrigerant stream was condensed and flows out in a liquid state at 120°C and 16 bar.

[0081] The condensed refrigerant stream (120°C and 16 bar) passed through an expansion valve (EP valve) to obtain the refrigerant stream in a liquid state at 60°C and 3.9 bar, and then was circulated to each of the plurality of evaporators EV1, EV2, EV3, ..., respectively, through pipes 41, 42, 43, ... branched from the integrated pipe 40.

[0082] In addition, compression was performed by transferring the steam prepared in the refrigerant condenser CD to a steam compressor S-CP and supplying water (20°C and 1 bar) at a flow rate of 27 Tons/hr under a power of 3.5 Gcal/h, so steam of 200°C and 13 bar was finally prepared in an amount of 34 Tons/hr.

[0083] For the finally prepared steam, steam preparation heat was calculated according to Equation 2 below, and a coefficient of performance (COP) was calculated according to Equation 3 below.

Steam preparation heat = Waste heat + Supplied power (power used for refrigerant compression and steam compression) [Equation 2]

[Equation 3]

$$\text{COP} = \text{Steam preparation heat} / \text{supplied power}$$

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Example 2:

[0084] Refrigerant evaporation by heat exchange between a process waste heat fluid (75°C and 5bar) and a refrigerant (60°C and 3.9bar) in three refrigerant evaporators EV1, EV2, and EV3, and mixing of the vaporized refrigerant in the integrated pipe 10 were performed under the same conditions as Example 1.

[0085] After the mixed refrigerant stream was compressed in the refrigerant compressor CP under a power of 1.5 Gcal/h to obtain a refrigerant stream in a gaseous state at 88°C and 7.8 bar, the obtained refrigerant stream in the gaseous state flowed into the refrigerant condenser CD and water (20°C and 1 bar) was supplied at a flow rate of 27 Tons/hr to perform the heat exchange. The steam of 78°C and 0.4 bar was prepared by the heat exchange, while the condensed refrigerant stream at 75°C and 7.8 bar flows out and is transferred to the expansion valve (EP valve).

[0086] In addition, the compression was performed by transferring the steam prepared in the refrigerant condenser CD to a steam compressor S-CP, and supplying water (20°C and 1 bar) at a flow rate of 27 Tons/hr under a power of 3.5 Gcal/h, so steam of 149°C and 3.9 bar was finally prepared in an amount of 32 Tons/hr.

[0087] The subsequent process was performed in the same manner as Example 1.

Example 3:

[0088] The same process as Example 1 was performed except that the flow velocity of the integrated pipe was changed to 40 m/s.

Example 4:

[0089] The same process as Example 1 was performed except that the flow velocity of the integrated pipe was changed to 5m/s.

Example 5:

[0090] The same process as Example 1 was performed except that the flow velocity of the integrated pipe was changed to 60m/s.

Comparative Example 1

[0091] Without an integrated pipe 10 in a heat pump device 200, that is, without integrating refrigerant streams flowing out after being vaporized in a plurality of refrigerant evaporators EV1, EV2, and EV3, the refrigerant stream flowed into the refrigerant compressor CP as it is, and the same process as Example 1 was performed except that no additional steam compression process was performed on the steam prepared in a refrigerant condenser CD.

[0092] The steam preparation results according to the examples and comparative examples are shown in Table 1 below.

[Table 1]

	Waste heat source (temperature/pressure)	Integrated pipe (flow velocity)	Compressed refrigerant (temperature/pressure)	Condensed refrigerant (temperature/pressure)	Steam compression	Finally prepared steam (temperature/pressure/COP)
Ex. 1	75°C/5bar	10m/s	128°C/ 16bar	120°C/ 16bar	○	200°C/13bar/ 2.2
Ex. 2	75°C/5bar	10m/s	88°C/ 7.8bar	75°C/ 7.8bar	○	149°C/3.9bar/ 2.8
Ex. 3	75°C/5bar	40m/s	128°C/ 16bar	120°C/ 16bar	○	200°C/13bar/ 2.2
Ex. 4	75°C/5bar	5m/s	115°C/ 9.3bar	95°C/ 9.3bar	○	167°C/6.2bar/ 2.0
Ex. 5	75°C/5bar	60m/s	118 °C/ 9.1bar	94°C/ 9.1bar	○	157°C/6.0bar/ 1.9
Com. Ex. 1	75°C/5bar	-	108°C/ 8.1bar	85°C/ 8.1bar	X	95°C/0.8bar/ 3.3

[0093] As can be seen in Table 1, in Examples 1 to 5, waste heat was recovered by the heat exchange between the process waste heat fluid and the refrigerant in each of the plurality of refrigerant evaporators to vaporize the refrigerant, the vaporized refrigerant was mixed and compressed through the integrated pipe, and the steam was prepared by the heat

exchange with water in the condenser, and was additionally compressed, thereby finally preparing the high-temperature and high-pressure steam.

[0094] In particular, in Examples 1 and 3, the flow velocity of the integrated pipe satisfied the range of more than 5 m/s to 50 m/s, and the temperature of the condensed refrigerant after the compression was controlled to 85°C or higher, thereby maintaining the temperature of the prepared steam into 85°C or higher. Thereafter, through the steam compression, it could be confirmed that a difference between an initial waste heat temperature and a finally prepared steam temperature, that is, a temperature lift is high.

[0095] In the case of Example 2, as the flow velocity of the integrated pipe satisfied the range of more than 5 m/s to 50 m/s, but the temperature of the condensed refrigerant after the compression was lowered to 75°C, the prepared steam exhibited a low temperature of 78°C, so the temperature lift was insufficient even after the steam compression. In addition, since air leakage occurred due to the low pressure of the steam, the steam was contaminated, resulting in corrosion and erosion of the pipe, and as a result, it was impossible to prepare the high temperature/high pressure steam required in the petrochemical process.

[0096] In the case of Example 4, as the flow velocity of the integrated pipe was lowered to 5 m/s, the heat mixing efficiency of the refrigerant vaporized at a front stage of the refrigerant compressor decreased, resulting in the large change range in the temperature and pressure of the refrigerant. As a result, a surging and cavitation phenomenon occurred in the refrigerant compressor and steam compressor, and the amount of steam changed at a rear end of the steam compressor, resulting in a pressure change. As a result, the temperature, pressure, and coefficient of performance (COP) of the final prepared steam decreased compared to Example 1.

[0097] In the case of Example 5, as the flow velocity of the integrated pipe was raised to 60 m/s, the erosion and vibration occurred within the refrigerant pipe at the front end of the refrigerant compressor. As a result, since it was difficult to operate the refrigerant pipe for a long time, maintenance or pipe replacement was required, and eroded foreign matter caused damage to rotating members in the compressor and noise due to vibration. As a result, the temperature, pressure, and coefficient of performance (COP) of the final prepared steam decreased compared to Example 1.

[0098] Meanwhile, in the case of Comparative Example 1 that the integrated pipe was not applied, physical properties of a fluid on an inlet side such as the flow rate, temperature, and pressure of the refrigerant stream at an inlet of the refrigerant compressor CP became non-uniform to change the performance of the refrigerant compressor CP, so the refrigerant compressor CP was operating abnormally. As a result, difficulties arose in terms of uneven steam preparation or failure in steam preparation. In addition, the surging and cavitation phenomenon, etc., of the compressor continued to occur, resulting in facility damage, which made long-term operation difficult and caused problems with maintenance and facility replacement. Additionally, as the steam compression was not performed, it was impossible to prepare the high temperature/high pressure steam required in the petrochemical process.

[Description of reference numerals]

[0099]

100: Plurality of waste heat sources including process waste heat fluid WH1, WH2, WH3, ...

200: Heat pump device

EV1, EV2, EV3: Refrigerant evaporator

CP: Refrigerant compressor

CD: Refrigerant condenser

EP valve: Refrigerant expansion valve

10, 40: Integrated pipe

11, 12, 13, 41, 42, 43: Branched pipe

S-CP: Steam compressor

Claims

1. A method for preparing steam, comprising:

(S1) making a process waste heat fluid supplied from a plurality of waste heat sources flow into each of refrigerant evaporators having numbers corresponding to the plurality of waste heat sources to vaporize a refrigerant through heat exchange to form a plurality of vaporized refrigerant streams;

(S2) joining the plurality of vaporized refrigerant streams from each of the refrigerant evaporators to one integrated pipe to form a joined stream;

(S3) compressing the joined stream in a refrigerant compressor to form a compressed refrigerant stream;

(S4) heat exchanging the compressed refrigerant stream with water in a refrigerant condenser to prepare a condensed refrigerant stream and steam; and

(S5) decompressing the condensed refrigerant stream by passing the condensed refrigerant stream through a refrigerant expansion valve, followed by branching and circulating the condensed refrigerant stream to each of the plurality of refrigerant evaporators, and

further including transferring and compressing the steam flowing out of the refrigerant condenser to a steam compressor.

2. The method of claim 1, wherein the plurality of waste heat sources and refrigerant evaporators include of 2 to 10 units, respectively.

3. The method of claim 1, wherein the process waste heat fluid flowing into each of the refrigerant evaporators has an initial temperature of 30 to 140°C.

4. The method of claim 1, wherein the refrigerant flowing through each of the refrigerant evaporators has a pressure ranging from 1 to 30 bar and a temperature ranging from 10 to 120 °C.

5. The method of claim 1, wherein the refrigerant stream vaporized in each of the refrigerant evaporators has a temperature satisfying Equation 1:

[Equation 1]

$$1^{\circ}\text{C} \leq T_{\text{WH}} - T_{\text{G}} \leq 20^{\circ}\text{C}$$

wherein,

T_{WH} is a terminal temperature of the process waste heat fluid flowing into each of the refrigerant evaporator, and T_{G} is a temperature of the vaporized refrigerant stream in each of the refrigerant evaporators.

6. The method of claim 1, wherein the integrated pipe has a straight length of 5 to 5,000 m and is controlled to maintain a flow rate of more than 5 m/s to 50 m/s.

7. The method of claim 1, wherein the refrigerant compressor uses electrical energy to increase a pressure of the refrigerant stream by 1.2 to 5 times.

8. The method of claim 1, wherein the compressed refrigerant stream has a temperature ranging from 90 to 200°C.

9. The method of claim 1, wherein the refrigerant stream condensed by the heat exchange with the water in the refrigerant condenser has a temperature ranging from 85 to 170°C.

10. The method of claim 1, wherein the refrigerant stream passing through the refrigerant expansion valve has a pressure ranging from 0.5 to 30 bar.

11. The method of claim 1, wherein the steam prepared by the heat exchange between the refrigerant stream and the water in the refrigerant condenser has a pressure ranging from 1 to 16 bar.

12. The method of claim 1, wherein the steam flowing out of the refrigerant condenser is compressed to 4 to 60 bar by supplying electrical energy from the steam compressor, converted into saturated steam by supplying water to the compressed steam, and is then used as a process heat source.

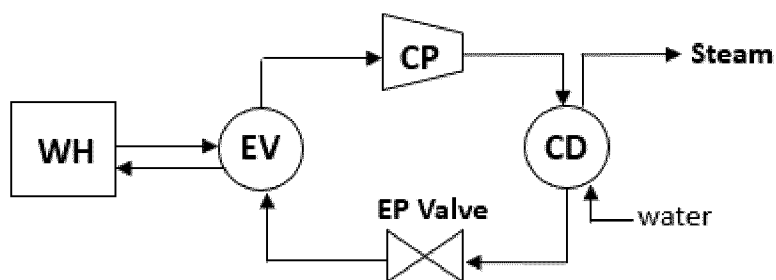
13. A system for preparing steam, comprising:

a plurality of waste heat sources and a heat pump device connected thereto, wherein the heat pump device includes a refrigerant evaporator, a refrigerant compressor, a refrigerant condenser, and a refrigerant expansion valve connected through a pipe, the refrigerant evaporator includes a plurality of refrigerant evaporators to communicate with each process waste heat fluid supplied from the plurality of waste heat sources,

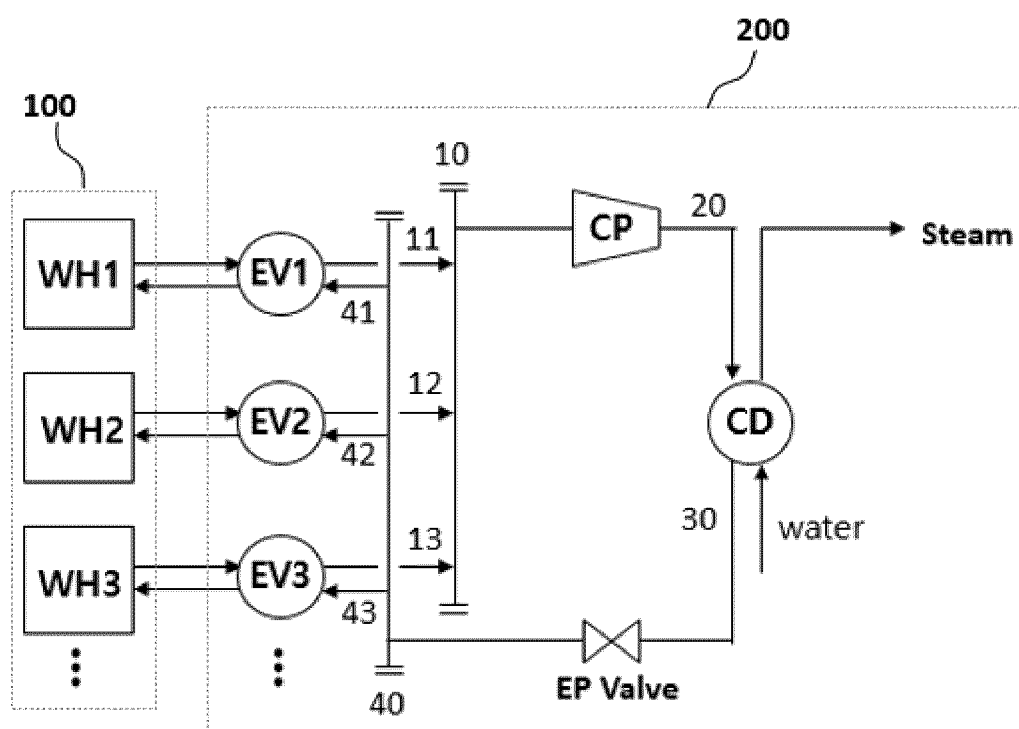
refrigerant streams flowing out of the pipe connected to the plurality of refrigerant evaporators are joined through an integrated pipe and transferred to the refrigerant compressor, the refrigerant stream passing through the refrigerant expansion valve is circulated to the plurality of refrigerant evaporators through a branched pipe, and the refrigerant condenser is connected to an additional steam compressor.

14. The system of claim 13, wherein the steam compressor compresses steam prepared by heat exchange between the refrigerant stream compressed in the refrigerant condenser and water and converts the compressed steam into saturated steam.

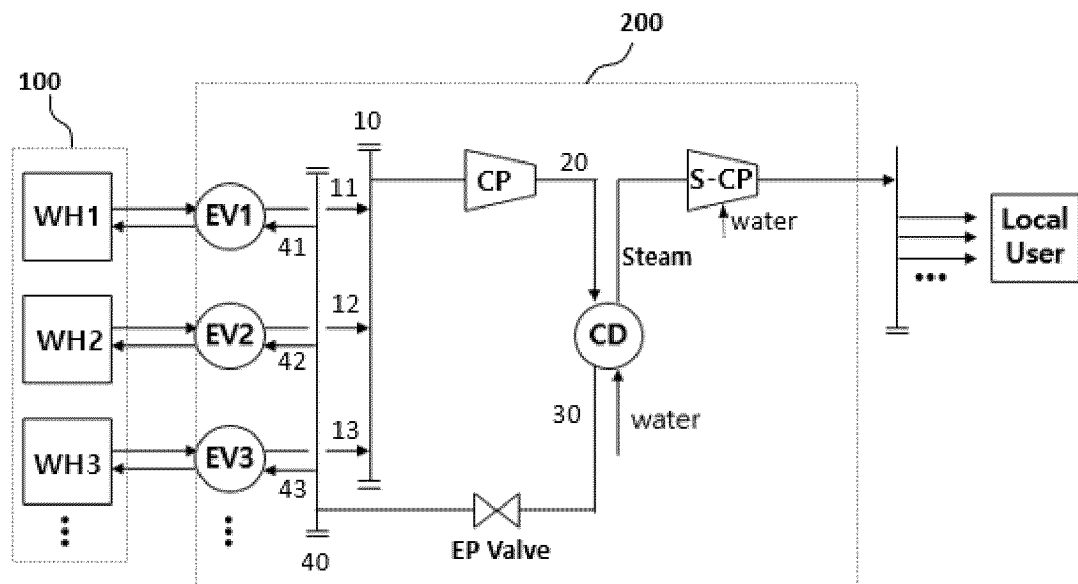
【FIG. 1】



【FIG. 2】



【FIG. 3】



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2023/020956

A. CLASSIFICATION OF SUBJECT MATTER

F22B 1/18(2006.01)i; F22B 31/04(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F22B 1/18(2006.01); F01K 25/08(2006.01); F22B 1/16(2006.01); F22B 3/00(2006.01); F23J 15/06(2006.01);
F25B 27/00(2006.01); F28C 3/04(2006.01)

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

Korean utility models and applications for utility models: IPC as above
Japanese utility models and applications for utility models: IPC as above

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

eKOMPASS (KIPO internal) & keywords: 폐열(waste heat), 히트펌프(heat pump), 증발기(evaporator), 복수(plural), 스팀(steam)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	CN 105444196 A (DINGLI SHICHUANG INTELLIGENT CONTROL TECHNOLOGY (BEIJING) CO., LTD.) 30 March 2016 (2016-03-30) See paragraphs [0034]-[0037] and figure 1.	1-14
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☐ Further documents are listed in the continuation of Box C.
 ☒ See patent family annex.

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Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

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