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(54) **TEMPERATURE CONTROL APPARATUS AND TEMPERATURE CONTROL METHOD**

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(57) **ABSTRACT**

A temperature control apparatus controls, through heat exchange between a medium subject to temperature control and a heat medium in a heat exchanger, a temperature $T_{H\text{-}out}$ of the medium subject to temperature control discharged from the heat exchanger. The temperature control apparatus adjusts a temperature based on expression (1): $T_{H\text{-}in}-R=E\times(T_{H\text{-}in}-SV)$ [in expression (1), $T_{H\text{-}in}$ denotes a temperature of the medium subject to temperature control supplied to the heat exchanger, R denotes a target temperature of the medium subject to temperature control discharged from the heat exchanger, E denotes a heat exchange rate of the heat exchanger, and SV denotes a temperature of the heat medium supplied to the heat exchanger].

FIG. 1

FIG. 2

START

ACQUIRE INFORMATION FROM EACH SENSOR ⟋ S101

CALCULATE HEAT EXCHANGE RATE E ⟋ S102

S103

IS DIFFERENCE BETWEEN TEMPERATURE T_{H-out} AND TARGET TEMPERATURE R SMALLER THAN PREDETERMINED VALUE? — Y

N

CALCULATE TEMPERATURE SV ⟋ S104

OUTPUT TEMPERATURE SV TO CHILLER ⟋ S105

RETURN

FIG. 3A

FIG. 3B

TEMPERATURE CONTROL APPARATUS AND TEMPERATURE CONTROL METHOD

TECHNICAL FIELD

[0001] The present disclosure relates to a temperature control apparatus and a temperature control method.

BACKGROUND ART

[0002] Conventionally, it is known that the feedforward control scheme is used to control the temperature of a medium subject to temperature control by using a heat exchanger (see, for example, Patent Literature 1). According to the feedforward control scheme, the speed of response can be increased as compared to the feedback control scheme.

RELATED-ART LITERATURE

Patent Literature

[0003] Patent Literature 1: JP 2003-313204

SUMMARY OF INVENTION

Technical Problem

[0004] In conventional temperature control, a logarithmic average temperature difference, which is common in a basic formula for heat exchange, is used. As a result of repeated intensive studies, we have found that it is difficult to control the temperature with high accuracy by using a logarithmic average temperature difference.

[0005] The present disclosure addresses the issue described above, and a purpose thereof is to provide a technology of improving the accuracy of temperature control.

Solution to Problem

[0006] An embodiment of the present disclosure relates to a temperature control apparatus that controls, through heat exchange between a medium subject to temperature control and a heat medium in a heat exchanger, a temperature $T_{H\text{-}out}$ of the medium subject to temperature control discharged from the heat exchanger. The apparatus adjusts a temperature SV based on expression (1): $T_{H\text{-}in}-R=E\times(T_{H\text{-}in}-SV)$ [in expression (1), $T_{H\text{-}in}$ denotes a temperature of the medium subject to temperature control supplied to the heat exchanger, R denotes a target temperature of the medium subject to temperature control discharged from the heat exchanger, E denotes a heat exchange rate of the heat exchanger, and SV denotes a temperature of the heat medium supplied to the heat exchanger].
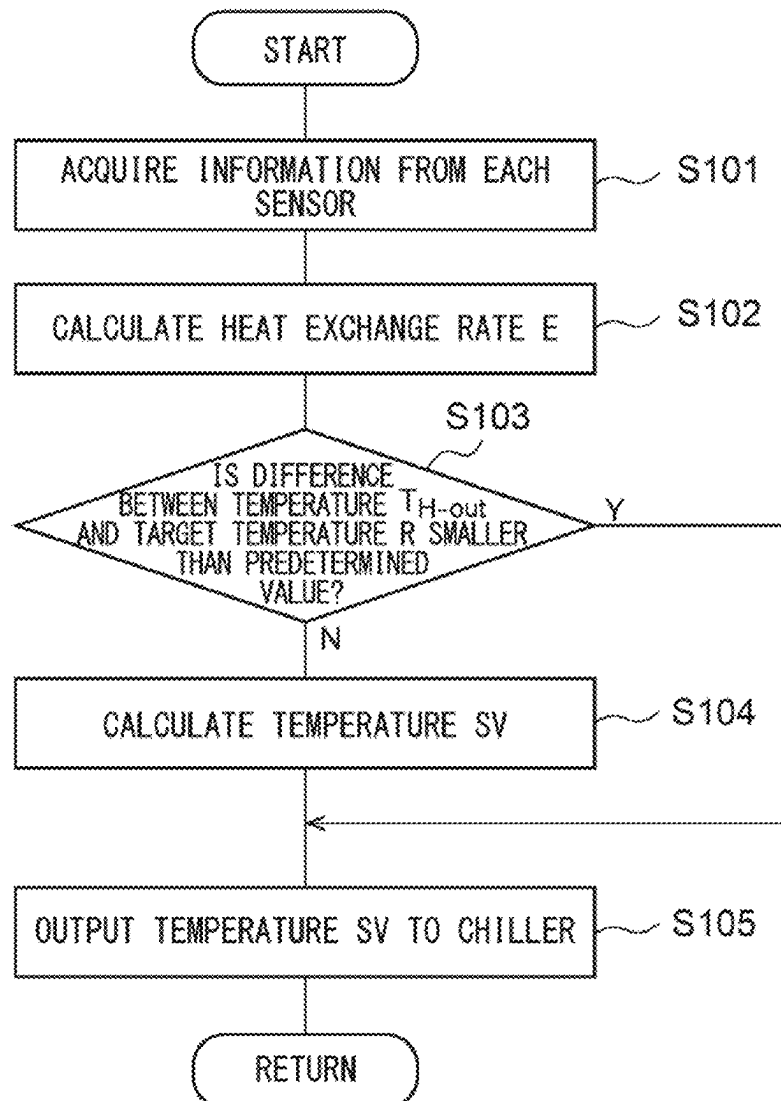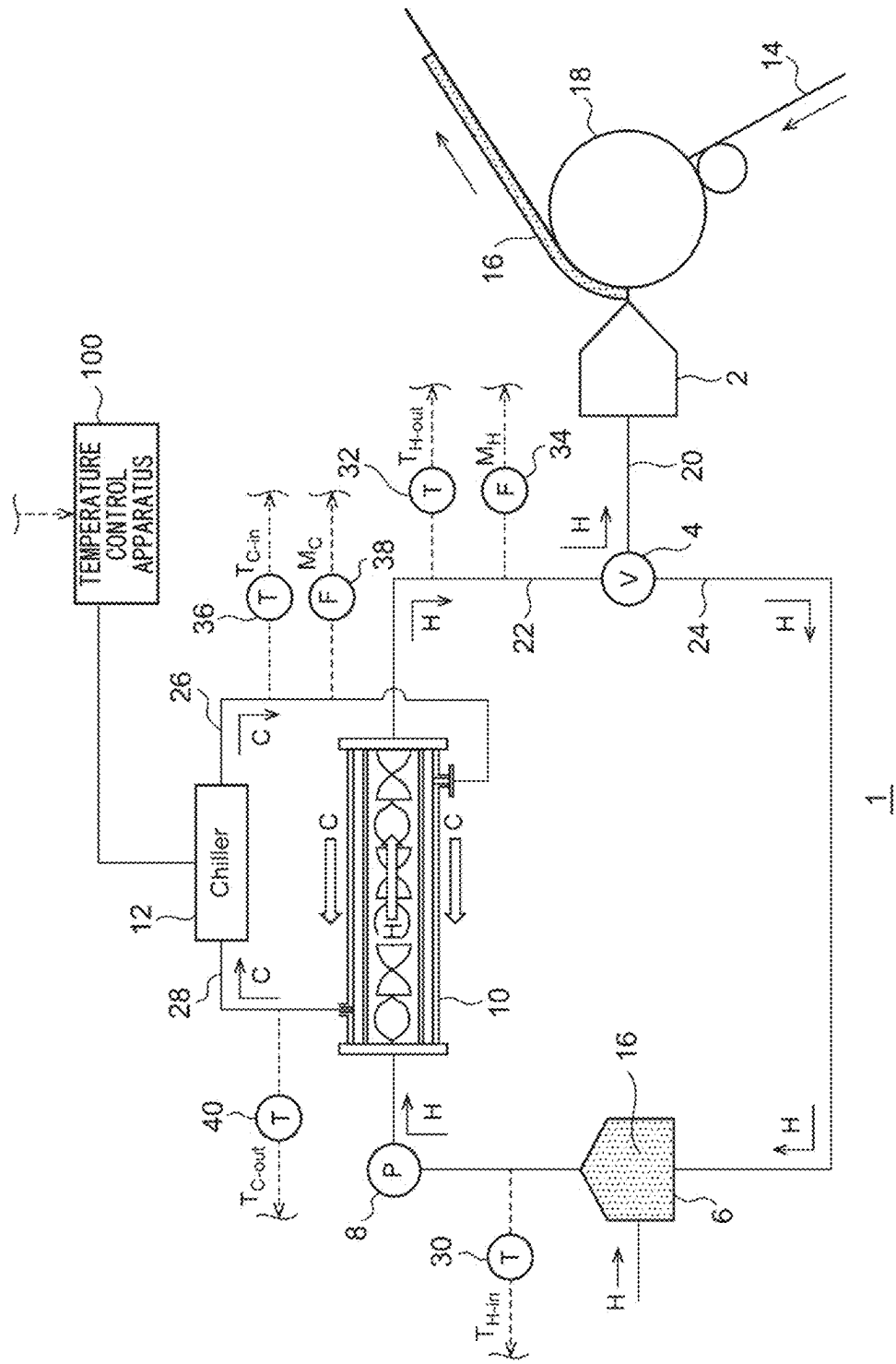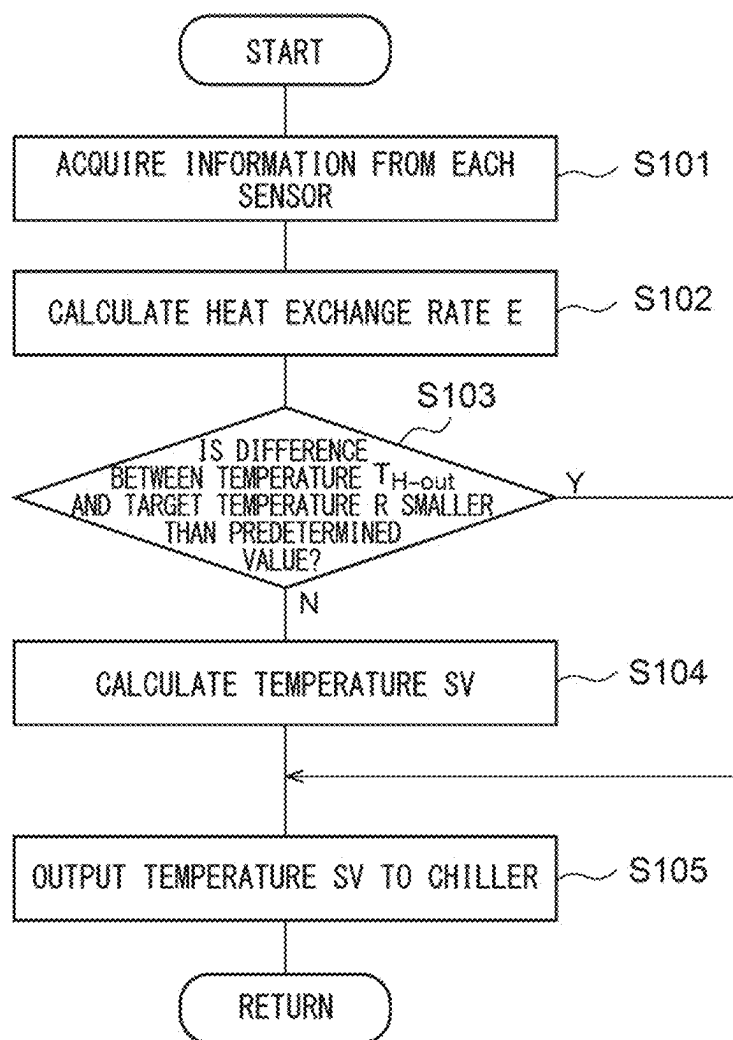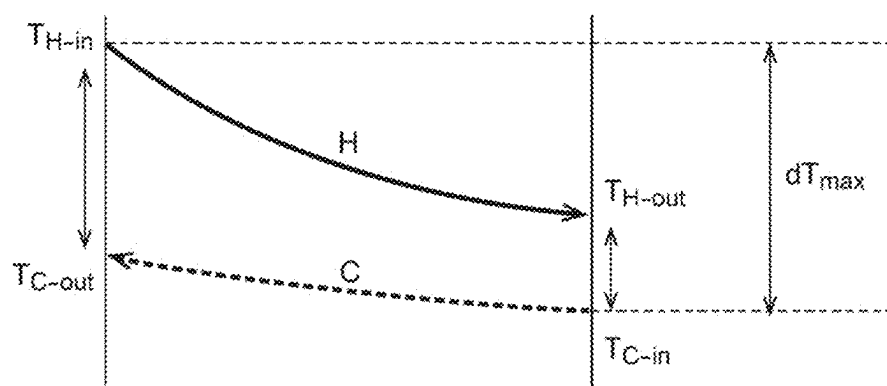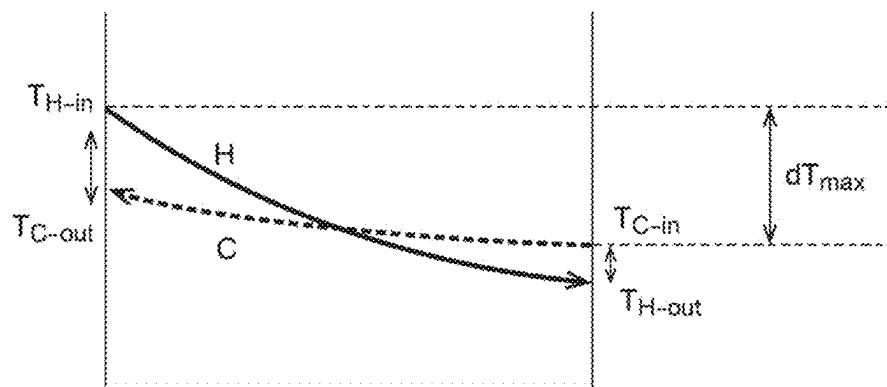
[0007] Another embodiment of the present disclosure relates to a temperature control method that controls, through heat exchange between a medium subject to temperature control and a heat medium in a heat exchanger, a temperature $T_{H\text{-}out}$ of the medium subject to temperature control discharged from the heat exchanger. The method includes adjusting a temperature SV based on expression (1): $T_{H\text{-}in}-R=E\times(T_{H\text{-}in}-SV)$ [in expression (1), $T_{H\text{-}in}$ denotes a temperature of the medium subject to temperature control supplied to the heat exchanger, R denotes a target temperature of the medium subject to temperature control discharged from the heat exchanger, E denotes a heat exchange

rate of the heat exchanger, and SV denotes a temperature of the heat medium supplied to the heat exchanger].

[0008] Optional combinations of the aforementioned constituting elements, and implementations of the present disclosure in the form of methods, apparatuses, and systems may also be practiced as additional modes of the present disclosure.

Advantageous Effects of Invention

[0009] According to the present disclosure, the accuracy of temperature control can be improved.

BRIEF DESCRIPTION OF DRAWINGS

[0010] FIG. 1 is a schematic diagram of a coating apparatus provided with a temperature control apparatus according to the embodiment.

[0011] FIG. 2 is a flowchart showing an example of temperature control according to the embodiment.

[0012] FIGS. 3A and 3B are diagrams showing the temperature states of the medium subject to temperature control and the heat medium.

DESCRIPTION OF EMBODIMENTS

[0013] Hereinafter, the present disclosure will be described based on preferred embodiments with reference to the accompanying drawings. The embodiments are not intended to limit the scope of the present disclosure but exemplify the present disclosure. Not all of the features and the combinations thereof described in the embodiments are necessarily essential to the present disclosure. Identical or like constituting elements, members, processes shown in the drawings are represented by identical symbols and a duplicate description will be omitted as appropriate. The scales and shapes of the parts shown in the figures are defined for convenience's sake to make the explanation easy and shall not be interpreted limitatively unless otherwise specified. Terms like "first", "second", etc. used in the specification and claims do not indicate an order or importance by any means unless specified otherwise and are used to distinguish a certain feature from the others. Those of the members that are not material to the description of the embodiments are omitted in the drawings.

[0014] FIG. 1 is a schematic diagram of a coating apparatus 1 provided with a temperature control apparatus 100 according to the embodiment. FIG. 1 depicts the temperature control apparatus 100 as a functional block. The functional blocks may be implemented by an element such as a CPU or memory of a computer or by a circuit as a hardware configuration, and by a computer program or the like as a software configuration. It will be understood by those skilled in the art that the functional block may be implemented in a variety of forms by combinations of hardware and software.

[0015] The coating apparatus 1 includes a coating die 2, a valve 4, a tank 6, a pump 8, a heat exchanger 10, a chiller 12, and a temperature control apparatus 100. The coating die 2 is an instrument for applying a paint 16 to a coated body 14. The materials and applications of the coated body 14 and the paint 16 are not particularly limited. The coating die 2 is arranged so that the discharge port faces the circumferential surface of a backup roll 18 at a predetermined distance. By way of one example, the coated body 14 is strip-shaped and

is continuously transported by the rotation of the backup roll **18** to a position where the backup roll **18** and the discharge port face each other.

[0016] A valve **4** is connected to the coating die **2** via a die supply pipe **20**. The valve **4** can switch between supplying and not supplying the paint **16** to the coating die **2**. The coating apparatus **1** can discharge the paint **16** from the coating die **2** to the coated body **14** while the paint **16** is being supplied to the coating die **2**. That is, the valve **4** can be used to coat the coated body **14** with the paint **16** intermittently.

[0017] The tank **6** is connected to the valve **4** via a feed pipe **22** and a return pipe **24**. The tank **6** stores the paint **16**. The paint **16** is fed to the tank **6** from a paint regulation apparatus (not shown) provided upstream of the coating apparatus **1**. A pump **8** is provided in the feed pipe **22**. By driving the pump **8**, the paint **16** is fed from the tank **6** to the valve **4**. The valve **4** supplies the paint **16** supplied from the tank **6** to the coating die **2** via the die supply pipe **20**. Alternatively, the valve **4** returns the paint **16** supplied from the tank **6** to the tank **6** via the return pipe **24**.

[0018] The feed pipe **22** is provided with the heat exchanger **10**. The heat exchanger **10** is comprised of a known double pipe heat exchanger by way of one example. Therefore, the heat exchanger **10** has an inner pipe and an outer pipe. The inner pipe is connected to the feed pipe **22**, and the paint **16** is distributed in the inner pipe. Further, a static mixer element is built into the inner pipe, and the paint **16** is stirred in the process of passing through the inner pipe. The known chiller **12** is connected to the inlet of the outer pipe via an outbound pipe **26**. Further, the chiller **12** is connected to the outlet of the outer pipe via an inbound pipe **28**. A heat medium C flows from the chiller **12** into the outer pipe via the outbound pipe **26** and returns to the chiller **12** via the inbound pipe **28** after passing through the outer pipe. The heat medium C is, for example, water.

[0019] The heat exchanger **10** of this embodiment is of a counter-flow type in which the flow of the paint **16** and the flow of the heat medium C are substantially opposite but may be of a parallel-flow type in which the flows are substantially in the same direction. Further, the heat exchanger **10** is not limited to a double pipe heat exchanger but may be a known plate heat exchanger, a multi-pipe heat exchanger, an air-cooled heat exchanger, an evaporator or a condenser that induces a phase change, etc. Further, the paint **16** (in other words, a medium H subject to temperature control described later) and the heat medium C distributed in the heat exchanger **10** are liquids by way of one example. However, the paint **16** and the heat medium C are not limited to liquids and may be gases, gas-liquid mixed two-phase flows, liquids that include a phase change, etc.

[0020] In the heat exchanger **10**, heat is exchanged between the paint **16** and the heat medium C. Therefore, the paint **16** represents the medium H subject to temperature control, i.e., a fluid subject to temperature control in the heat exchanger **10**. By way of one example, the medium H subject to temperature control and the heat medium C is such that the medium H subject to temperature control is at a high temperature and the heat medium C is at a low temperature before heat exchange. However, the embodiment is not particularly limited to this configuration, and the temperature relationship between the medium H subject to temperature control and the heat medium C before heat exchange may be opposite.

[0021] A first temperature sensor **30** is provided on the upstream side of the heat exchanger **10** in the feed pipe **22**. The first temperature sensor **30** measures the temperature $T_{H\text{-}in}$ [° C.] of the medium H subject to temperature control supplied to the heat exchanger **10**, i.e., the temperature of the medium H subject to temperature control on the inlet side of the inner pipe. A second temperature sensor **32** is provided on the downstream side of the heat exchanger **10** in the feed pipe **22**. The second temperature sensor **32** measures the temperature $T_{H\text{-}out}$ [° C.] of the medium H subject to temperature control discharged from the heat exchanger **10**, i.e., the temperature of the medium H subject to temperature control on the outlet side of the inner pipe. Further, a first flow sensor **34** is provided on the downstream side of the heat exchanger **10** in the feed pipe **22**. The first flow sensor **34** measures the mass flow rate Mu [kg/sec] of the medium H subject to temperature control discharged from the heat exchanger **10**.

[0022] A third temperature sensor **36** is provided in the outbound pipe **26**. The third temperature sensor **36** measures the temperature $T_{C\text{-}in}$ [° C.] of the heat medium C supplied to the heat exchanger **10**, i.e., the temperature of the heat medium C on the inlet side of the outer pipe. Further, a second flow sensor **38** is provided in the outbound pipe **26**. The second flow sensor **38** measures the mass flow rate M_C[kg/sec] of the heat medium C supplied to the heat exchanger **10**. A fourth temperature sensor **40** is provided in the inbound pipe **28**. The fourth temperature sensor **40** measures the temperature $T_{C\text{-}out}$ [° C.] of the heat medium C discharged from the heat exchanger **10**, i.e., the temperature of the heat medium C on the outlet side of the outer pipe.

[0023] Each temperature sensor can be comprised of a known thermometer. Further, each mass sensor can be comprised of a known mass flow meter. The signal indicating the measurement result of each temperature sensor and each mass sensor is fed to the temperature control apparatus **100**. Information on the mass flow rate M_C may be fed from the chiller **12** to the temperature control apparatus **100**.

[0024] The temperature control apparatus **100** may be comprised of a digital processor. For example, temperature control apparatus **100** may be comprised of a combination of a microcomputer, including a CPU, and a software program. The temperature control apparatus **100** may alternatively be comprised of a FPGA (Field Programmable Gate Array), an ASIC (Application Specified IC), etc. The temperature control apparatus **100** controls the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control through heat exchange between the medium H subject to temperature control and the heat medium C in the heat exchanger **10**.

[0025] The heat exchanger **10** adjusts, based on the following expression (1), the temperature SV of the heat medium C supplied to the heat exchanger **10** and, in other words, the temperature SV of the heat medium C that is brought into thermal contact with the medium H subject to temperature control. The temperature SV of the heat medium C corresponds to the temperature $T_{C\text{-}in}$ of the heat medium C measured by the third temperature sensor **36**. The temperature control apparatus **100** can adjust the temperature SV of the heat medium C fed from the chiller **12** to the heat exchanger **10** by controlling how the chiller **12** is driven. The temperature SV of the heat medium C can also be regarded as the preset temperature of the chiller **12**.

$$T_{H-in} - R = E \times \left(T_{H-in} - SV\right) \qquad \text{Expression (1)}$$

[0026] Referring to expression (1), T_{H-in} is the temperature of the medium H subject to temperature control supplied to the heat exchanger **10**. As described above, the temperature T_{H-in} is measured by the first temperature sensor **30**. R denotes a target temperature of the medium H subject to temperature control discharged from the heat exchanger **10**. The target temperature R is set in advance by the user of the coating apparatus **1**, etc. E denotes the heat exchange rate of the heat exchanger **10**. The heat exchange rate E [%] is calculated based on the following expression (2) and is repeatedly updated according to a predetermined timing schedule. Expression (2) is a known calculation expression and can be appropriately changed according to the format of the heat exchanger **10**.

$$E \times 100 = [1 - \exp\{-NTU(1 - Cr)\}]/ \qquad \text{Expression (2)}$$

$$[1 - Cr\exp\{-NTU(1 - Cr)\}]$$

[0027] Referring to expression (2), NTU denotes the number of transfer units [dimensionless]. The number of transfer units NTU is calculated based on the following expression (3).

$$NTU = U \times A / C_{min} \qquad \text{Expression (3)}$$

[0028] Referring to expression (3), U denotes the overall heat transfer coefficient [W/m²K]. The overall heat transfer coefficient U is a known coefficient calculated from the thermal resistance of the wall surface sandwiching the medium H subject to temperature control and the heat medium C in the heat exchanger **10**, and the thermal resistance, temperature, etc. of the medium H subject to temperature control and the heat medium C. The overall heat transfer coefficient U is calculated each time the heat exchange rate E is calculated. A denotes the heat transfer area [m²] of the heat exchanger **10**, which is set in advance. C_{min} denotes the heat capacity flow rate [W/K], which is the heat capacity flow rate C_H of the medium H subject to temperature control or the heat capacity flow rate C_C of the heat medium C, whichever has a smaller value. In this embodiment, the flow capacity flow rate C_H is assumed to be C_{min} by way of one example.

[0029] The heat capacity flow rate C_H is calculated based on the following expression (4). Further, the heat capacity flow rate C_C is calculated based on the following expression (5).

$$C_H = M_H \times Cp_H \qquad \text{Expression (4)}$$

$$C_C = M_C \times Cp_C \qquad \text{Expression (5)}$$

[0030] Referring to expression (4), Mm denotes the mass flow rate [kg/sec] of the medium H subject to temperature control. As described above, the mass flow rate MH is measured by the first flow sensor **34**. Cp_H denotes the specific heat [J/(kg·K)] of the medium H subject to temperature control, which is set in advance. Referring to expression (5), M_C denotes the mass flow rate [kg/sec] of the heat medium C. As described above, the mass flow rate M_C is measured by the second flow sensor **38**. The specific heat Cp_C is the specific heat [J/(kg·K)] of the heat medium C, which is set in advance.

[0031] Referring to expression (2), Cr denotes a heat capacity ratio [dimensionless]. The heat capacity ratio Cr is calculated based on the following expression (6)

$$Cr = C_{min}/C_{max} \qquad \text{Expression (6)}$$

[0032] Referring to expression (6), C_{min} is as described above. C_{max} denotes the heat capacity flow rate [W/K], which is the heat capacity flow rate C_H of the medium H subject to temperature control or the heat capacity flow rate C_C of the heat medium C, whichever has a larger value. In this embodiment, the heat capacity flow rate C_C is assumed to be C_{max} by way of one example.

[0033] Expression (1) is based on the basic formula of heat exchange shown in expression (7) below.

$$C_{min} \times \left(T_{H-in} - T_{H-out}\right) = E \times C_{min} \times dT_{max} \qquad \text{Expression (7)}$$

[0034] Referring to expression (7), C_{min}, T_{H-in}, T_{H-out} and E are as described above. dT_{max} denotes the maximum temperature difference between the medium H subject to temperature control and the heat medium C in the heat exchanger **10**, which is calculated based on the following expression (8).

$$dT_{max} = T_{H-in} - T_{C-in} \qquad \text{Expression (8)}$$

[0035] Referring to expression (8), T_{H-in} and T_{C-in} are as described above. That is, the maximum temperature difference dT_{max} is the difference between the temperature of the medium H subject to temperature control flowing into the heat exchanger **10** and the temperature of the heat medium C flowing into the heat exchanger **10**.

[0036] When the medium H subject to temperature control is at a higher temperature than the heat medium C, the left side of expression (7) means the amount of heat that the medium H subject to temperature control is deprived of by the heat medium C. Further, the right side of expression (7) means the amount of heat exchange that occurs in the heat exchanger **10**. The temperature T_{H-out} of the medium H subject to temperature control can be replaced by a target temperature R. Further, the temperature T_{C-in} of the heat medium C can be replaced by the temperature SV of the heat medium C. Therefore, expression (1) is obtained from expression (7).

[0037] The temperature control apparatus **100** receives a measurement result from each temperature sensor and each flow sensor and calculates the heat exchange rate E. The temperature control apparatus **100** then substitutes the measured temperature T_{H-in}, the calculated heat exchange rate E, and the preset target temperature R into expression (1) and

calculates the temperature SV of the heat medium C. Thereafter, the temperature control apparatus **100** controls the chiller **12** so that the calculated temperature SV results. In this control, the circulating water of the chiller **12** is adjusted to a temperature corresponding to the temperature SV. This realizes feedforward control of causing the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control discharged from the heat exchanger **10** to approach the target temperature R.

[0038] For example, the temperature control apparatus **100** controls the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control to be in a range higher than the target temperature R−0.1° C. and lower than the target temperature R+0.1° C. by adjusting the temperature SV of the heat medium C. This suppresses a change in the dimension of the coating die **2** caused by the heat of the medium H subject to temperature control and an uneven coating thickness of the medium H subject to temperature control more effectively.

[0039] FIG. 2 is a flowchart showing an example of temperature control according to the embodiment. This flow is repeatedly executed by the temperature control apparatus **100** according to a predetermined timing schedule. First, the temperature control apparatus **100** acquires temperature information and flow rate information from each temperature sensor and each flow sensor (S**101**). The information thus obtained is then substituted into expression (2) to calculate the heat exchange rate E (S**102**). When the temperature control apparatus **100** does not maintain the heat exchange rate E, the initial heat exchange rate E is calculated by this calculation. When the temperature control apparatus **100** maintains the heat exchange rate E calculated in the previous routine, the heat exchange rate E is updated or corrected by this operation.

[0040] The temperature control apparatus **100** then determines whether the difference between the temperature $T_{H\text{-}out}$ acquired from the second temperature sensor **32** and the target temperature R is smaller than a predetermined value (S**103**). By way of one example, the temperature control apparatus **100** determines whether the temperature $T_{H\text{-}out}$ satisfies a condition R−0.1<$T_{H\text{-}out}$<R+0.1. When the difference between the temperature $T_{H\text{-}out}$ and the target temperature R is equal to or greater than a predetermined value (N in S**103**), the temperature control apparatus **100** calculates the temperature SV of the heat medium C based on expression (1) (S**104**). The temperature control apparatus **100** then outputs information on the temperature SV to the chiller **12** (S**105**) and terminates the routine. This drives the chiller **12** so that the heat medium C reaches the temperature SV. When the difference between the temperature $T_{H\text{-}out}$ and the target temperature R is smaller than a predetermined value (Y in S**103**), the temperature control apparatus **100** proceeds to step S**105** without calculating the temperature SV, outputs information on the temperature SV calculated in the previous routine to the chiller **12** and terminates the routine. Therefore, the drive state of the chiller **12** is maintained. The first routine may be controlled to execute step S**104** without exception.

[0041] Subsequently, the difference between conventional temperature control using a logarithmic average temperature difference dTlm for calculation of the temperature SV and temperature control according to this embodiment using the maximum temperature difference d_{Tmax} for calculation of the temperature SV will be described. In conventional temperature control, the temperature SV of the heat medium

C brought into thermal contact with the medium H subject to temperature control is adjusted based on the following expression (9).

$$C_{min}\left(T_{H\text{-}in} - T_{H\text{-}out}\right) = U \times A \times dTlm \qquad \text{Expression (9)}$$

[0042] Referring to expression (9), C_{min}, $T_{H\text{-}in}$, $T_{H\text{-}out}$, U and A are as described above. dTlm [° C.] is a logarithmic average temperature difference, which is calculated based on the following expression (10).

$$dTlm = \{(T_{H\text{-}in} - T_{C\text{-}out}) - (T_{H\text{-}out} - T_{C\text{-}in})\}/ \qquad \text{Expression (10)}$$

$$\ln\{(T_{H\text{-}in} - T_{C\text{-}out})/(T_{H\text{-}out} - T_{C\text{-}in})\}$$

[0043] Referring to expression (10), $T_{H\text{-}in}$, $T_{H\text{-}out}$, $T_{C\text{-}in}$, and $T_{C\text{-}out}$ are as described above.

[0044] The left side of expression (9) means the amount of heat that the medium H subject to temperature control is deprived of by the heat medium C. Further, the right side of expression (9) means the amount of heat exchange that occurs in the heat exchanger **10**. The temperature $T_{H\text{-}out}$ of the medium H subject to temperature control can be replaced by the target temperature R. Further, the temperature $T_{C\text{-}in}$ of the heat medium C can be replaced by the temperature SV of the heat medium C. Therefore, the temperature SV of the heat medium C can be calculated based on expression (9).

[0045] The overall heat transfer coefficient U included in expression (9) is an extension of the heat transfer coefficient used in the fields of heat conduction and convective heat transfer. Specifically, the overall heat transfer coefficient U is the reciprocal of a sum of thermal resistance, comprising the thermal conductivity of the wall surface sandwiching the mediums in the heat exchanger **10**, the convective heat transfer coefficient between each medium and the wall surface, etc. Therefore, the overall heat transfer coefficient U is a coefficient derived in general heat transfer theory. On the other hand, $C_{min} \times dT_{max}$ on the right side of expression (7) can be defined as the maximum amount of heat exchange Q_{max} in the heat exchanger **10**. Further, the left side of expression (7) can be defined as the amount of heat exchange Q that occurs in the heat exchanger **10**. Therefore, the heat exchange rate E included in expressions (1) and (7) is defined as the ratio of the amount of heat exchange Q relative to the maximum amount of heat exchange Q_{max} (Q/Q_{max}) in the heat exchanger **10**. Therefore, the heat exchange rate E is a coefficient unique to the heat exchanger **10**.

[0046] Further, the logarithmic average temperature difference dTlm included in expression (9) is an extension of temperature difference used in the fields of heat conduction and convective heat transfer. Specifically, the logarithmic average temperature difference dTlm is obtained by integrating and averaging the local heat transfer balance in the heat exchanger **10** from one end to the other end of the heat exchanger **10**. Therefore, the logarithmic mean temperature difference dTlm is a temperature difference derived in general heat transfer theory. On the other hand, the maximum temperature difference dT_{max} included in expression (7) is, as described above, a difference between the temperature of the medium H subject to temperature control flowing into

the heat exchanger **10** and the temperature of the heat medium C flowing into the heat exchanger **10**. Therefore, the maximum temperature difference dT_{max} is a temperature difference unique to the heat exchanger **10**. That is, in temperature control of this embodiment, the temperature SV of the heat medium C and, ultimately, the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control is controlled by using, instead of the logarithmic average temperature difference dTlm, the maximum temperature difference dT_{max}, which is a coefficient unique to the heat exchanger **10**.

[0047] FIGS. **3A** and **3B** are diagrams showing the temperature states of the medium H subject to temperature control and the heat medium C. FIG. **3A** shows a case where the temperature difference between the medium H subject to temperature control and the heat medium C is relatively large. FIG. **3B** shows a case where the temperature difference between the medium H subject to temperature control and the heat medium C is relatively small. In general heat exchange, the medium H subject to temperature control is always cooled by the heat medium C when the medium H subject to temperature control is at a higher temperature than the heat medium C. Therefore, as shown in FIG. **3A**, the temperature difference between the medium H subject to temperature control and the heat medium C is set to be relatively large. In this case, the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control does not fall below the temperature $T_{C\text{-}in}$ of the heat medium C, and the difference between the temperature $T_{H\text{-}out}$ and the temperature $T_{C\text{-}in}$ takes a positive value. Further, naturally, the temperature $T_{H\text{-}in}$ of the medium H subject to temperature control does not fall below the temperature $T_{C\text{-}out}$ of the heat medium C.

[0048] When the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control is controlled to fit within an extremely small error of, for example, +0.1° C. with respect to the target temperature R, on the other hand, it may be necessary to heat the medium H subject to temperature control as well as cooling the medium H subject to temperature control. Therefore, as shown in FIG. **3B**, the temperature difference between the medium H subject to temperature control and the heat medium C is set to be relatively small. In this case, the temperature of the medium H subject to temperature control and the temperature of the heat medium C approach an equilibrium state, and the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control could fall below the temperature $T_{C\text{-}in}$ of the heating medium C. Therefore, the difference between the temperature $T_{H\text{-}out}$ and the temperature $T_{C\text{-}in}$ could take a negative value. Further, the temperature $T_{H\text{-}in}$ of the medium H subject to temperature control could possibly fall below the temperature $T_{C\text{-}out}$ of the heat medium C.

[0049] Expression (9) used in conventional temperature control includes a logarithmic average temperature difference dTlm. If the difference between the temperature $T_{H\text{-}out}$ and the temperature $T_{C\text{-}in}$ or the difference between the temperature $T_{H\text{-}in}$ and the temperature $T_{C\text{-}out}$ takes a zero or negative value, therefore, the logarithmic average temperature difference dTlm diverges, making normal temperature control difficult. On the other hand, expression (1) used in temperature control of this embodiment does not include a logarithmic function. For this reason, normal temperature control can be stably executed even if the difference between the temperature $T_{H\text{-}out}$ and the temperature $T_{C\text{-}in}$ or the

difference between the temperature $T_{H\text{-}in}$ and the temperature $T_{C\text{-}out}$ takes a negative value.

[0050] As described above, the temperature control apparatus **100** according to this embodiment controls the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control discharged from the heat exchanger **10** by adjusting the temperature SV of the heat medium C based on the above expression (1). This makes it possible to control the temperature $T_{H\text{-}out}$ of the medium H subject to temperature control more accurately and more stably as compared to conventional feedforward temperature control using the logarithmic average temperature difference dTlm. Further, numerical analysis using the Newtonian method, etc. is necessary when the logarithmic average temperature difference dTlm is used. In temperature control of this embodiment, on the other hand, the temperature SV can be calculated by a simpler algebraic operation. Accordingly, the processing load on the temperature control apparatus **100** can be reduced. It also makes it easier to integrate control into a programmable logic controller (PLC).

[0051] Embodiments of the present disclosure have been described above in detail. The embodiment described above is merely a specific example of practicing the present disclosure. The details of the embodiment shall not be construed as limiting the technical scope of the present disclosure. A number of design modifications such as modification, addition, deletion, etc. of constituting elements may be made to the extent that they do not depart from the idea of the present disclosure defined by the claims. New embodiments with design modifications will provide the combined advantages of the embodiment and the variation. Although the details subject to such design modification are emphasized in the embodiment by using phrases such as "of this embodiment" and "in this embodiment", details not referred to as such are also subject to design modification. Any combination of the above constituting elements is also useful as an embodiment of the present disclosure. Hatching in the cross section in the drawings should not be construed as limiting the material of the hatched object.

[0052] The invention according to the embodiment described above may be defined by the following items.

[Item 1]

[0053] A temperature control apparatus (**100**) that controls, through heat exchange between a medium (H) subject to temperature control and a heat medium (C) in a heat exchanger (**10**), a temperature $T_{H\text{-}out}$ of the medium (H) subject to temperature control discharged from the heat exchanger **10**, wherein a temperature SV is adjusted based on

$$T_{H\text{-}in} - R = E \times (T_{H\text{-}in} - SV) \qquad \text{expression (1)}$$

[in expression (1), $T_{H\text{-}in}$ denotes a temperature of the medium (H) subject to temperature control supplied to the heat exchanger (**10**), R denotes a target temperature of the medium (H) subject to temperature control discharged from the heat exchanger (**10**), E denotes a heat exchange rate of the heat exchanger (**10**), and SV denotes a temperature of the heat medium (C) supplied to the heat exchanger (**10**)].

[Item 2]

[0054] The temperature control apparatus (10) according to Item 1, wherein the temperature $T_{H\text{-}out}$ is controlled to be in a range higher than the target temperature R−0.1° C. and lower than the target temperature R+0.1° C. by adjusting the temperature SV.

[Item 3]

[0055] A temperature control method that controls, through heat exchange between a medium (H) subject to temperature control and a heat medium (C) in a heat exchanger (10), a temperature $T_{H\text{-}out}$ of the medium (H) subject to temperature control discharged from the heat exchanger 10,

[0056] the method including adjusting a temperature SV based on

$$T_{H-in} - R = E \times \left(T_{H-in} - SV\right) \qquad \text{expression (1)}$$

[in expression (1), $T_{H\text{-}in}$ denotes a temperature of the medium (H) subject to temperature control supplied to the heat exchanger (10), R denotes a target temperature of the medium (H) subject to temperature control discharged from the heat exchanger (10), E denotes a heat exchange rate of the heat exchanger (10), and SV denotes a temperature of the heat medium (C) supplied to the heat exchanger (10)].

INDUSTRIAL APPLICABILITY

[0057] The present disclosure can be used in a temperature control apparatus and a temperature control method.

REFERENCE SIGNS LIST

[0058] 1 coating apparatus, 2 coating die, 4 valve, 6 tank, 8 pump, 10 heat exchanger, 12 chiller, 100 temperature control apparatus, C heat medium H medium subject to temperature control

What is claimed is:

1. A temperature control apparatus that controls, through heat exchange between a medium subject to temperature control and a heat medium in a heat exchanger, a tempera-ture $T_{H\text{-}out}$ of the medium subject to temperature control discharged from the heat exchanger,

wherein a temperature SV is adjusted based on

$$T_{H-in} - R = E \times \left(T_{H-in} - SV\right) \qquad \text{expression (1)}$$

[in expression (1), $T_{H\text{-}in}$ denotes a temperature of the medium subject to temperature control supplied to the heat exchanger, R denotes a target temperature of the medium subject to temperature control discharged from the heat exchanger, E denotes a heat exchange rate of the heat exchanger, and SV denotes a temperature of the heat medium supplied to the heat exchanger].

2. The temperature control apparatus according to claim 1,

wherein the temperature $T_{H\text{-}out}$ is controlled to be in a range higher than the target temperature R−0.1° C. and lower than the target temperature R+0.1° C. by adjust-ing the temperature SV.

3. A temperature control method that controls, through heat exchange between a medium subject to temperature control and a heat medium in a heat exchanger, a tempera-ture $T_{H\text{-}out}$ of the medium subject to temperature control discharged from the heat exchanger,

the method including adjusting a temperature SV based on

$$T_{H-in} - R = E \times \left(T_{H-in} - SV\right) \qquad \text{expression (1)}$$

[in expression (1), $T_{H\text{-}in}$ denotes a temperature of the medium subject to temperature control supplied to the heat exchanger, R denotes a target temperature of the medium subject to temperature control discharged from the heat exchanger, E denotes a heat exchange rate of the heat exchanger, and SV denotes a temperature of the heat medium supplied to the heat exchanger].

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