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(54) **Title:** APPARATUSES AND METHODS FOR USING RESIDUAL HEAT IN GAS COMPRESSION SYSTEMS

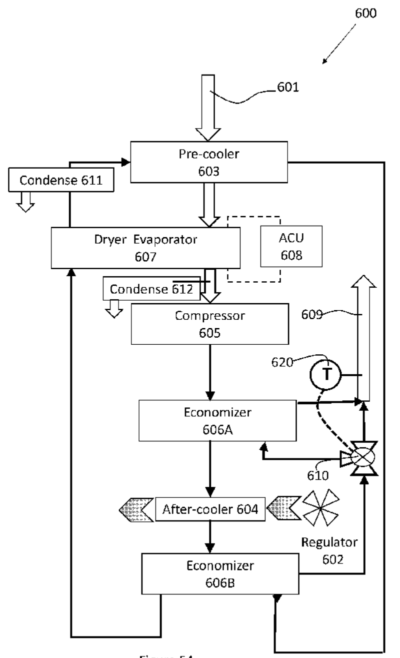


Figure 5A

(57) **Abstract:** The present disclosed subject matter relates to energy efficiency improvements in compressed air systems and methods to implement them. According to an aspect of the present disclosure, improving the efficiency is performed by recovering the "wasted energy" in the compressed air and/or condensed water energy streams produced by the compressor and the cooling drying process.

APPARATUSES AND METHODS FOR USING RESIDUAL HEAT IN GAS COMPRESSION SYSTEMS

TECHNICAL FIELD

[0001] The present subject matter relates to compressed air systems. More particularly, the present disclosed subject matter relates to systems and methods of using waste heat in compressed systems; thus, improving the systems efficiency.

BACKGROUND

[0002] According to CAGI (Compressed Air & Gas Institute), compressed air in industry is often referred to, as the fourth utility after electricity, natural gas and water. Compressed air is energy of choice. It is used widely throughout the world. Almost every industrial plant has some type of compressed air system. The compressed air systems are used in thousands of applications and are vital to the productivity of industries around the globe. According to D.O.E. (U.S.A. Department of Energy), 10 percent of the global electrical bill is compressed air. The efficiency of producing compressed air is very low. Only 4% converts to useful energy (compressed dry air), the rest 96% is wasted as heat to the surrounding. Energy savings by system improvements is therefore required. All the compressed air experts (as describe in the literature, master works, symposiums and patents), claim that cooling the inlet air to the compressor and heating the air to the load, increase the efficiency of the compression prosses.

[0003] Along the history of compressed air, many patents describe solutions to cool the inlet air to the compressor, and heat the compressed air sent to the load. There are two popular compression technologies that are used in the industrial world:

1. Positive displacement compressor, and
2. Dynamic compressor

[0004] Rotary screw compressor is in a type of positive displacement compressor, in which a given quantity of air or gas is trapped in a compression chamber and the occupied space is mechanically reduced, causing a corresponding rise in pressure prior to discharge.

[0005] The compression principle of the rotary screw compressor consists of two rotors in a stator house have an inlet port at one end and a discharge port at the other. The male has helical lobes shape and the female screw has helical grooves shape. The air that flows into the inlet port, fills the spaces between the screws. As rotation advances, a lobe on one screw rolls into a groove on the other screw and the point of intermeshing moves progressively along the axial length of the screws, reducing the space occupied by the air, resulting in increased pressure. Compression continues until the trap spaces exposed to the discharge port. Every rotation of the screws causes the same amount of volume to be compressed. Cooling the air that enters the compressor increases the number of molecules in this volume. On the other hand, lowering the air temperature reduces air volume while in order to compress this volume of air, the screw compressor needs fewer rotations. In positive displacement compressors, electric power is proportional to the flow. When the flow of air goes down, the electric energy reduces and efficiency is increase.

[0006] Centrifugal compressors are the most popular dynamic compressors. They are used in industry were stable supply of compressed air in massive amount is needed.

[0007] The compression principle: ambient air enters the center (eye) of an impeller and accelerates radially by the rotating wings. When leaving the impellers wing, the flow has kinetic energy. After leaving the impeller the flow enters a volute canal that expands and the air to slow down. As a result, the air pressure goes up (potential energy). Half of the pressure comes from the kinetic energy and half of it comes from the potential energy.

[0008] Cooling the intake air that enters the compressor, increases the power to accelerate the air in the impeller (the need to overcome higher air density) and decrease the power to rotate the impeller (less volume to compress, less impeller rotations).

According to “Bernoulli’s law”, the power increase is linear with increase in density and density increase with pressure.

[0009] According to the "affinity laws”, the power decrease is proportional to the cube of impeller speed and flow is proportional to the impeller speed. The result of the two is less energy and higher efficiency.

BRIEF SUMMARY

[0010] The present disclosed subject matter relates to energy efficiency improvements in compressed air systems. According to an aspect of the present disclosure, improving the efficiency is performed by recovering the “wasted energy” in the compressed air and/or condensed water energy streams produced by the compressor and the cooling drying process.

[0011] It is therefore provided in accordance with a preferred embodiment an apparatus for enhancing efficiency of an air compressor comprising:

a pre-cooler though which ambient air is cooled before entering the compressor using a coolant fluid;

an after-cooler receiving compressed air from the compressor, wherein the compressed air is cooled;

an economizer for exchanging heat receiving a first stream of the compressed air from the after-cooler and a second stream from the pre-cooler, wherein the second stream is of heated air that was heated in the pre-cooler by exchanging heat with the ambient air, and wherein said economizer outlets a third stream of the compressed air heated by the first stream and a fourth stream of cooled air; and

a cooling dryer receiving the fourth stream from the economizer, configured to further cool the fourth stream and direct it to said pre-cooler, wherein said forth stream passed through the dryer acts as the coolant fluid,

wherein heat is exchanged in the pre-cooler and the economizer by residual heat.

[0012] In accordance with another preferred embodiment of the present subject matter, the pre-cooler cools the ambient air to approximately 9-11°C.

[0013] In accordance with another preferred embodiment of the present subject matter, energy that is used for cooling the ambient air in the pre-cooler is harvested from residual energy of the cooling dryer.

[0014] In accordance with another preferred embodiment of the present subject matter, the compressed air exiting the compressor and enters the after-cooler is cooled by a regulator.

[0015] In accordance with another preferred embodiment of the present subject matter, the cooling dryer is configured to reduce the compressed air temperature to a dew point of 2-3°C that is used as the coolant.

[0016] In accordance with another preferred embodiment of the present subject matter, the after-cooler and the economizer are combined to a single unit.

[0017] In accordance with another preferred embodiment of the present subject matter, the single unit is regulated by a regulator selected from a group of a fan, a blower, a heat-sink, and any combination thereof.

[0018] In accordance with another preferred embodiment of the present subject matter, an auxiliary cooling unit is adjunct to the cooling dryer to facilitate cooling.

[0019] In accordance with another preferred embodiment of the present subject matter, the pre-cooler combined with the auxiliary cooling unit cools the ambient air to approximately 6°C.

[0020] It is provided also in accordance with yet another preferred embodiment, a method of using residual heat to increase efficiency of air compression process comprising:

cooling the atmospheric air in a pre-cooler before entering the compression process using the compressed air from the compression process that is dried and cooled; and

heating an outlet stream from the compression process using residual heat that was taken from an after-cooler that receives the compressed air from the compression process.

[0021] In accordance with another preferred embodiment of the present subject matter, the method further comprising cooling the compressed air that leaves the compressing process by a regulator.

[0022] In accordance with another preferred embodiment of the present subject matter, the regulator is controlling a temperature in which the compressed air enters an economizer, wherein the economizer produces a stream of compressed air that is heated.

[0023] In accordance with another preferred embodiment of the present subject matter, cooling of the atmospheric air in a pre-cooler in about 13 degrees Celsius and heating the outlet stream from the compression process in about 9 degrees Celsius increase the efficiency of the compression process in about 7-9%.

[0024] Additionally, it is also provided in accordance with another embodiment of the present subject matter, an apparatus for enhancing efficiency of an air compressor comprising:

a pre-cooler through which ambient air is cooled before entering the compressor using a coolant fluid;

an after-cooler receiving compressed air from the compressor through a first economizer that is provided between the compressor and the after cooler for exchanging heat, wherein the compressed air from the compressor is cooled in the first economizer and further cools in the after-cooler;

a second economizer that receives compressed air from the after-cooler, wherein the compressed air from the after-cooler is further cooled in the second economizer and wherein the

first economizer is receiving a first stream of the compressed air from the compressor and a second cooler stream from the second economizer;
an outlet of compressed air having a pre-determined temperature, wherein the pre-determined temperature is a result of a mixture of compressed air from the second economizer that pass through the first economizer with a first temperature and the compressed air from the second economizer having a second temperature;
a mixing valve receiving the compressed air from the second economizer and splitting the compressed air so as a first portion flows directly to the outlet with the second temperature and a second portion that flows to the outlet through the first economizer having the first temperature and wherein a predetermined temperature of the air in said outlet controls a ratio between the first portion and the second portion;
wherein the compressed air from the compressor that was cooled in the second economizer is directed to the evaporator and heated air from the pre-cooler is directed to the second economizer so as to reduce the compressed air temperature sent to the evaporator,
wherein heat is exchanged in the pre-cooler and the economizers by residual heat.

[0025] In accordance with another preferred embodiment of the present subject matter, condensed water is collected from the cooling process in a cold condense tank.

[0026] In accordance with another preferred embodiment of the present subject matter, the cold condense tank is provided with an exit valve having a flowrate that is controlled by the height of the condensed water in the cold condense tank.

[0027] In accordance with another preferred embodiment of the present subject matter, the condensed water that exits the cold condense tank pass through the after cooler so as to cool the compressed air that passes through.

[0028] In accordance with another preferred embodiment of the present subject matter, the mixing valve is controlled by a value of the predetermined temperature.

[0029] In accordance with another preferred embodiment of the present subject matter, air from the pre-cooler passes through the evaporator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] Some embodiments of the disclosed subject matter described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present disclosed subject matter only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the disclosed subject matter. In this regard, no attempt is made to show structural details of the disclosed subject matter in more detail than is necessary for a fundamental understanding of the disclosed subject matter, the description taken with the drawings making apparent to those skilled in the art how the several forms of the disclosed subject matter may be embodied in practice.

In the drawings:

[0031] Figure 1 illustrates a block diagram of a gas compression system as used in the prior art.

[0032] Figure 2 illustrates a block diagram of a an apparatus that effectively uses waste energy in gas compression system, in accordance with some exemplary embodiments of the disclosed subject matter;

[0033] Figure 3 illustrates a block diagram of another configuration of an improved apparatus of air compression, in accordance with some exemplary embodiments of the disclosed subject matter;

[0034] Figure 4 illustrates a block diagram of another apparatus that effectively uses waste energy in gas compression system, in accordance with some exemplary embodiments of the disclosed subject matter; and

[0035] Figure 5A illustrates yet another architecture of improved apparatus of air compression in accordance with some exemplary embodiments of the disclosed subject matter.

[0036] Figure 5B illustrates the architecture shown in Figure 5A with accumulated condensate.

[0037] Figure 6A illustrates yet another architecture of improved apparatus of air compression in accordance with some exemplary embodiments of the disclosed subject matter.

[0038] Figure 6B illustrates the architecture shown in Figure 6A with accumulated condensate.

[0039] Figure 7depicts an efficiency of an improved apparatus over time as measured in an apparatus built according to the architecture of Figure 5A as influenced by cooling the air in the compressor inlet.

[0040] Figure 8 depicts efficiencies of an improved apparatus over time as measured in an apparatus built according to the architecture of Figure 5A as influenced by cooling the air in the inlet and heat an outlet air stream from the compression process.

DETAILED DESCRIPTION

[0041] Before explaining at least one embodiment of the disclosed subject matter in detail, it is to be understood that the disclosed subject matter is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The disclosed subject matter is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting. The drawings are generally not to scale. For clarity, non-essential elements were omitted from some of the drawings.

[0042] One technical problem dealt with by the disclosed subject matter is the low efficiency of generating compressed air by commercially available air compressors. The efficiency of compressed air production can be calculated by a ratio between the energy in the compressed air and the electrical energy to produce this amount of compressed air.

[0043] The technical object of the present disclosure is improving the energy efficiency of a gas compressing apparatus by utilizing residual energy produced in the apparatus for cooling the air prior to its entering a compressor unit of the apparatus as well as heating the pressurized air just before exiting the apparatus and doing that using the residual heat in the air stream itself. In one exemplary embodiment as will be shown herein after, the efficiency can be increased by 10.8% at pressure 8.5 bar and outlet temperature of 30 degrees Celsius. In yet another exemplary embodiment, the efficiency can be increased by 17.5% at the same pressure and outlet temperature of 50 degrees Celsius.

[0044] As mentioned herein before, the purpose of the disclosed subject matter is to increase the efficiency of the compressed air system and particularly, the efficiency of the air compressor and cooling dryer using several possible actions:

- First, cooling the intake ambient air stream that enters the compressor with the cold compressed air stream that comes from the cooling dryer, or other air-cooling aperture. This can be performed with a radiator type heat exchanger or the like. As a result of cooling the intake air, its "mass flow rate" increases.
- Heating the compressed air that is sent to the load with the hot compressed air that leaves the after-cooler heat exchanger or the like. As a result, "volumetric flow rate" increases.
- Regulating the temperature of the hot compressed air that is sent to the load by regulating the ambient air flow that removes heat from the hot compressed air that flows in the after-cooler heat exchanger.
- Decreasing the temperature of the compressed air stream that enters the cooling dryer evaporator. The air cools first in the after-cooler and second, in the economizer. As a result of lowering the temperature before entering the evaporator, the dryer cooling energy is reduced.

[0045] Reference is now made to Figure 1 illustrating block diagram of a gas compression system as used in the prior art. Gas compression system 10 comprises an inlet 12 through which air enters several units until it outputs while first, it enters the compressor 14, where the air is compressed, its volume is decreased, and the temperature of the compressed air that outlets the compressor 15 is increased to a relatively high temperature. The compressed and hot air is then being cooled in an after-cooler 16 that can optionally be regulated by a regulator 18. After being cooled within the after-cooler 16, the cooled air is being transferred to a cooling dryer 20 that reduce the air temperature to a dew point close to zero Celsius and removes extra water vapor from the flowing air. The compressed and cooled air that flow through the output 24 is being used for industrial purposes, as desired. As mentioned herein before, the efficiency of the compression process is very low.

In the disclosed subject matter, there are several units aimed at increasing the efficiency of the compression process as follows:

- In order to cool down the atmospheric air that enters the compressor; an action that assists the compressor, a pre-cooler is provided before the compressor to cool the air. In order to effectively cool the air, compressed cold air from the apparatus is being used, in this case from the cooling dryer. The results are higher "Mass Flow Rate" and in case of high humidity, smaller amount of water vapor in the air that enters the compressor.

- The compressed air that leaves the compressor is being heated and sent to the load. As a result, the "Volumetric Flow Rete" is increased.
  The cooling rate of the hot air stream is controlled by regulating the cooling fan speed. Regulating the cooling rate of the hot air, results in a controlled temperature of the air that flows to the load.

[0046] According an embodiment of the present disclosure, an apparatus for enhancing efficiency of an air compressor is provided that comprises the following units:

- A pre-cooler though which ambient air is cooled before entering the compressor using a coolant fluid.
- An after-cooler that receives the compressed air from the compressor, wherein the compressed air is cooled.
- An economizer for exchanging heat. The economizer receives a first stream of the compressed air from the after-cooler and a second stream from the pre-cooler, wherein the second stream is of heated air that was heated in the pre-cooler by exchanging heat with the ambient air. The economizer outlets a third stream of the compressed air heated by the first stream to be used in industry or stored for a later use and a fourth stream of cooled air.
- A cooling dryer that receives the fourth stream from the economizer, configured to further cool the fourth stream and direct it to the pre-cooler. The fourth stream passed through the dryer is used as the coolant fluid in the pre-cooler unit.

[0047] Referring now to Fig. 2, illustrates a block diagram of an apparatus that effectively uses waste energy in gas compression system, in accordance with some exemplary embodiments of the disclosed subject matter. The block diagram illustrates a gas compression apparatus 100 having a cooling system, wherein the apparatus comprising an inlet 101 a pre-cooler 103, a compressor 105, an after-cooler 104 couples with a regulator 102, an economizer 106, a cooling dryer 107 and an outlet 109. In addition, the units are connected by a set of conductors depicted in solid lines, through which gas flows in the direction shown by an arrow. The conductors can be pipelines that conduct pressurized air, wherein the type of pipelines is dictated by pressure temperature and gas type that the apparatus 100 is set for. The pressure in the conductors that connect inlet 101 to compressor 105 via pre-cooler 103 is atmospheric pressure.

[0048] In some exemplary embodiments of the disclosed subject matter, pre-cooler 103, after cooler 104, economizer 106 and dryer 107 are heat-exchangers used for a process of transferring heat in different stages of processing the pressurized air. The heat-exchangers used in the present disclosure can be counter-flow heat-exchangers; parallel-flow, cross-flow and any combination of flow. In the present disclosure, the heat-exchangers are based on two fluid circuits mutually transferring heat generated, between one another. In some exemplary embodiments, a coolant fluid of the cooling dryer 107 (shown in dotted lines) is used for cooling the pressurized air that flows in dryer 107.

[0049] In some exemplary embodiments, atmospheric air at ambient temperature enters the pre-cooler 103 via inlet 101, where it is cooled down to approximately 9-11°C prior to entering compressor 105. Compressor 105 raises the pressure of the atmospheric air at its input, to a pressurized air at its output. The value of the pressurized air is a preset value typically derived by the application in which apparatus 100 is used for. It should be noted that the compressor 105 also raises the temperature of the pressurized air. In screw compressors, the temperature can be elevated to approximately 65°C above ambient temperature. Without the pre-cooler 103 unit (Figure 1), and inlet air temperature is about 27°C, the outlet temperature of the pressurized air would have been approximately 95°C. With the pre-cooler 103 unit and inlet air temperature of 10°C, the outlet temperature of the pressurized air would have been approximately 75°C. It should also be noted that the energy used for cooling the atmospheric air at the entrance to compressor 105, in the pre-cooler, is harvested from residual energy from the cooling dryer 107, as will be explained herein after.

[0050] It should be noted that cooling the air temperature before entering the compressor, increases the “mass flow rate” to the compressor, e.g. increasing the number of molecules in unit of volume, and increasing the volume to the load with the same amount of energy to compress the original volume.

[0051] In some exemplary embodiments, pressurized hot air exiting compressor 105 enters an after-cooler 104, cool down by a regulator as rotating fan 102 in order to control the gas outlet temperature, as explained herein before. Optionally, the compressed air from the after-cooler 104 enters an economizer 106 where it shall be further cooled, prior to entering the cooling dryer 107 while another stream of output 109 flows for use in industries. In some exemplary embodiments, the cooling dryer 107 is used to reduce the compressed air temperature to a dew point of 2-3°C, and drain the condensate that purges from the air. In some exemplary embodiments, the cooling technology is implemented with compression cooling, absorption cooling or any other type of cooling system. The cooling dryer 107 can be powered by residual energy.

[0052] As mentioned herein before, pressurized air exiting cooling dryer 107, enters pre-cooler 103 for cooling the atmospheric air that is flowing through pre-cooler 103.

[0053] It should be noted that, heating the pressurized air at the economizer 106 increases the air flow-rate to a load.

[0054] In some exemplary embodiments, regulator 102 can be activated to cool the pressurized air stream in the after-cooler 104, if lower temperature required at the load.

[0055] It should be noted that, evaluation the apparatus 100 of the present disclosure exhibits the following efficiency increase:

a. Up to 17.5% at 8.5 bar and outlet temperature of 50°C.
b. Up to 14.2% at 8.5 bar and outlet temperature of 40°C.
c. Up to 10.8% at 8.5 bar and outlet temperature of 30°C.

[0056] In some exemplary embodiments, regulator 102 is a fan, a blower, a heat-sink, and any combination thereof, or any known in the art device that is capable of removing heat from after-cooler 104.

[0057] It will be understood that heat-exchanger components of the present disclosure (pre-cooler 103, after cooler 104, economizer 106 and cooling dryer 107) are optionally comprised of at least two circuits, wherein the circuits of each heat-exchanger are mutually thermally coupled. That is to say that while a cold circuit cools other circuit, the other circuit heats the cold one. . Furthermore, components disclosed herein are designed, integrated, and connected to one another in a way that maximizes harvesting of residual energy.

[0058] Reference is now made to Figure 3 illustrating a block diagram of another configuration of an improved apparatus of air compression, in accordance with some exemplary embodiments of the disclosed subject matter. Air compressing apparatus 300 is similar to the apparatus shown in Figure 2, however, two of the units or components are combined into a single unit. The apparatus comprises an inlet 301 through which atmospheric air flows into a pre-cooler 303, in which the air is cooled by a cold stream of compressed air coming from a cooling dryer 307 and into a compressor 305. From the compressor 305, the compressed air is flowing to a combined after-cooler and economizer 306 that is regulated by regulator 302.

[0059] Two streams of compressed air flow through the after-cooler and economizer 306. The first is hot air stream from the compressor 305 to the cooling dryer 307 and the second is cold air stream from the pre-cooler 303 to the outlet 309. The two streams exchange heat. As a result, the hot stream gets cooler and the cold stream is being heated. The temperature of the heated stream to the outlet 309 is regulated by regulator 302 that removes heat from the hot stream coming from the compressor 305, The compressed heated air sent to the outlet 309 is used in industry. The compressed cooled air is sent to the dryer 307 for further cooling. The cold air that leaves the cooling dryer 307, flow through the pre-cooler 303.

[0060] To emphasize again the features in the embodiments shown herein, there are two main features in which residual and waste energy is used in order to increase the efficiency of the compression process: cooling the inlet atmospheric air that enters the compressor. As a result, the "mass flow rate" is increased. Heating the outlet compressed air to the load causes an increase in "volume flow rate", which means higher volume at the outlet. Cooling the atmospheric air stream that enters the compressor, causes few consequences. First, increase "mass flow rate". Second, when the air temperature goes below “Dew Point”, extra water vapor will condense. The volume of air with the rest of the water vapor to be compressed is decreased, and the energy to compress the air to be sent to the load is reduced. Third, condensing the moisture reduces the enthalpy (internal energy) of the air and decreases the cooling energy of an auxiliary cooling unit ACU 308 that is adjunct to the cooling dryer. Cooling the atmospheric air is done with the cold compressed air stream from the cooling dryer by the pre-cooler or by the combined pre-cooler and cooling dryer-ACU unit.

[0061] As for the outlet heating - by heating the compressed air sent to the load, the volume flow rate is increased. The thermal energy to heat the outlet compressed air stream, coming from the compressed hot air that leaves the compressor.

[0062] Reference is now made to Figure 4 illustrating a block diagram of another apparatus that effectively uses waste energy in gas compression system, in accordance with some exemplary embodiments of the disclosed subject matter. The apparatus for gas compression 400 is similar to the system that was shown in Figure 3, wherein the units through which the air flows, compressed, and going through temperature changes are the same - an inlet 401 through which air flows into a pre-cooler 403, in which the air is cooled by a cool stream of air coming from within the apparatus, and into a compressor 405. From the compressor 405, the compressed air is flowing to a combined after-cooler and economizer 406 that is regulated by regulator 402. Compressed air flows from the combined after-cooler and economizer 406 to the output 409 to be used in industry. Additional features are introduced to apparatus 400: 1. Air that enters to the compressor 405 through the pre-cooler 403 are filtered in filter 404; 2. Compressed air from the combined after cooler and economizer 406 that are outgoing through outlet 409 are transferred into a tank 402. The compressed air is held in the tank until called into use.

Reference is now made to Figure 5A illustrating yet another architecture of improved apparatus of air compression in accordance with some exemplary embodiments of the disclosed subject matter. Exemplary temperature values are indicated; however, it should be noted that the temperatures are based on simulations and can change according to the properties of specific parameters such as ambient temperature, relative humidity, and other parameters. Air compressing apparatus 600 comprises an inlet 601 through which atmospheric air in an ambient temperature of about 27^{o} Celsius flows into a pre-cooler 603, cools down and exits in about 8-10^{o} Celsius. Then, the cooled air passes through an evaporator 607 so as to be further cooled to about 5-6^{o} Celsius before entering the compressor 605. The pre-cooler and the evaporator are located in the stream line of the atmospheric air. As shown herein before, the evaporator 607 is one of the elements of the ACU 608 that together function as a cooling dryer. In a similar principle indicated herein before, the pre-cooler is cooled by the cold compressed air that is supplied by the evaporator 607, and the ACU 608 is cooled by the cooling process. As indicated, the atmospheric cooled air enters the compressor 605 in a temperature that is lower in about 20^{o} Celsius from the ambient temperature while using the energy resources of the system itself. The compressed and hot air that flows from the compressor 605 in a temperature of about 90^{o} Celsius enters a first economizer 606A, in which it starts the cooling process (the temperature of the compressed air exit from the economizer A is about 70^{o} Celsius depending on the amount of energy extracted from it) and from which it passes through an after-cooler 604 where the air is further cooled to about 34° Celsius and enters in compressed state into a second economizer 606B. Economizer 606A receives a first hot compressed air stream from the compressor 605 in about 90° Celsius and a partial part of a second compressed and cold air stream from the second economizer 606B in about 23° Celsius.. The two streams exchange heat. The compressed cold air stream from the economizer 606B, Split into two streams. the Split is performed through a tree-way mixing valve 610 by which a portion of the cold compressed air is directed directly to an outlet 609 to be used in industry and the second one is directed to the outlet 609 through the first economizer 606A in which the air exchanges heat with the hot compressed air from the compressor 605. The temperature of the air in output 609 is measured by a temperature sensor 620. The temperature of the stream to be cool that passes through the after-cooler 604 is regulated by regulator 602 that removes heat from the hot stream coming from the compressor 605 through the first economizer 606A.

[0063] The temperature of the outlet is determined by the proportions of the two streams coming directly from the second economizer 606B and the first economizer 606A and mixes in the three-way mixing valve 610. The temperature in the temperature sensor 620 is directed as indicated in the dash line to a controller in the mixing valve 610 that controls the proportions of the two streams so as to determine the temperature of the outlet, as dictated by the consumer that gets the compressed air through the output 609.

[0064] Two streams enter the second economizer 606B. A relatively hot first stream from the after-cooler 604 and relative colder second stream from the pre-cooler 603. The two streams exchange heat. The stream from the after-cooler 604, continues and flow through the evaporator 607, cools down, releases condense 611 and enters the pre-cooler 603.

[0065] The evaporated water vapor that are formed during the cooling process can be condensed to condense 611 and condense 612 and accumulated as will be shown herein after.

[0066] Reference is now made to Figure 5B illustrating the architecture shown in Figure 5A with accumulated condensate. As mentioned herein before, the condense 611 and condense 612 are extract from humid air that exceed relative humidity of 100%. When air is cooled the relative humidity increases. This condense can be accumulated and collected for further use in the process itself and for other reasons. Condense 611 and condense 612 are collected from the units and flow preferably by gravitation to be accumulated in a cold condense tank 615. The condensed water from the cold condensed tank 615 are streaming from the tank 615 through an FV valve 616 that is preferably an exit valve that its flowrate controlled by the height of the condensate in the tank. The water is flowing out of the tank 615 passing through the after-cooler 604 so as to exchange heat with the relatively hot and compressed air stream from the compressor 605. This facilitates additional cooling of the air that enters economizer 606B.

[0067] The condensed water can be accumulated within an additional tank 617 for additional use.

[0068] In order to fully understand the heat exchange processes in the improved air compression apparatus illustrated in Figures 5A and 5B: The atmospheric air stream with ambient temperature of 27°C is pumped into the air compressing apparatus 600 through an air canal.

[0069] The atmospheric air stream passes through a pre-cooler 603, which is a heat exchanger that performs heat exchange with the cold compressed air stream that flows in the pre-cooler 603 that is cooled before in the evaporator 607. As a result, the atmospheric air cools and the excess water vapor in the air condenses and is collected in a condense tank 615 in about 8-12° Celsius, which is under atmospheric pressure.

[0070] The air from the pre-cooler 603 continues to flow through the air canal and passes through the evaporator 607 heat exchanger of the cooling circuit ,which is a part of the cooling drying facility 608 (ACU).

[0071] The atmospheric air stream that passes through the evaporator 607 performs heat exchange with the coolant refrigerant of the ACU 608, and exits the evaporator 607 in about 5-7° Celsius.

[0072] The rest of the excess water vapor in the atmospheric air condenses and is also collected in the condense tank 615.

[0073] The cold atmospheric air stream enters the compressor 605, compressed and heats up. The compressed air comes out of the compressor hot and enters one side of the economizer 606A heat changer.

[0074] A second compressed air stream exits cold from the economizer 606B heat exchanger and splits into two streams. A first split stream enters the second side of the economizer 606A heat exchanger, exchange heat with the hot compressed air from the compressor 605 and exits the economizer 606A hotter. The second split stream overrides the economizer 606A and connects to the first stream after it exits the economizer 606A. The two streams combine and flows as a single stream to the facility, where it is being used.

[0075] The fragmentation of the flows is performed by a proportionally mixing valve 610 with an electric actuator, controlled by a temperature sensor 620 that is provided to the exit line to the facility.

[0076] The proportion between the flows controlled by sensor 620 that measures the temperature of the single combined stream.

[0077] The temperature of the compressed air stream to the facility is determined by a temperature controller preferably administered by the facility manager.

[0078] The compressed air from the compressor 605 exits the economizer 606A in a colder state and enters the after-cooler 604.

[0079] The compressed air from the compressor 605 continues to cool by replacing heat with the flow of the cold condensate and the flow of the atmospheric air flowing over the after-cooler 604 heat changer.

[0080] The cooling rate of the compressed air passing in the after-cooler 604 is controlled by changing the speed of the air flowing on the after-cooler 604 with the fan motor.

[0081] Controlling the temperature of the compressed air that exits the after-cooler 604 enables to reduce the amount of energy that is consumed by the compressed air system.

[0082] the condensate flows from the condense tank 615 through the after-cooler 604 by gravity.

[0083] At the outlet of the condense tank 615, a float-valve FV 616 is installed, which controls the water flowrate out of the tank 615. The flow is a function of the height of the water level in the tank.

[0084] After the compressed air exits the after-cooler 604, it enters the economizer 606B, in which a heat exchange is made between the compressed air from the after-cooler 604 and the compressed air from the pre-cooler 603.

[0085] the compressed air from the compressor 605 leave the after-cooler 604 is cooled and enters the evaporator 607. In the evaporator 607, the compressed air cools to a temperature that is near the freezing temperature of water.

[0086] As a result ,the remainder of the condense are condensed. This condensed water is also collected in the condense tank after being drained from the compressed air line.

[0087] Reference is now made to Figure 6A illustrating yet another architecture of improved apparatus of air compression in accordance with some exemplary embodiments of the disclosed subject matter. This architecture is similar to the former architecture shown in Figure 5A, however, in the air compressing apparatus 700 that comprises an inlet 701 through which atmospheric air in ambient temperature flows into the pre-cooler 703, the cold air flows straight into the compressor 705. The streaming of the air through the economizers 706A and 706B as well as through the after-cooler 704 is similar to the streaming described herein before in the explanation to Figure 5A. However, the evaporator 707 of the ACU 708 is not in the streamline of the compressor 705. Air from the second economizer 706B flows through the dryer evaporator 707 and enters the pre-cooler 703 so as to cool the atmospheric air that should enter the compressor 705. In this architecture, the temperature that enters the compressor is higher in about 5 degrees Celsius from the former system, which is very significant from the energy saving point of view, since as the temperature that enters the compressor is, higher the energy saving is lower.

[0088] Reference is now made to Figure 6B illustrating the architecture shown in Figure 6A with accumulated condensate. As mentioned herein before, the condense 711 and condense 712 are extract from humid air that exceed relative humidity of 100%. When air is cool the relative humidity increase. This condense can be accumulated and collected for further use in the process itself and for other reasons. Condense 711 and condense 712 are collected from the units and flow preferably by gravitation to be accumulated in a cold condense tank 715. The condensed water from the cold condensed tank 715 are streaming from the tank 715 through an FV valve 716 that is preferably a valve that its flowrate controlled by the height of the condensate in the tank., the water is flowing out of the tank 715 passing through the after-cooler 704 so as to exchange heat with the relatively hot and compressed air stream from the compressor 705. This facilitates additional cooling of the air that enters economizer 706B.

[0089] The condensed water can be accumulated within an additional tank 717 for additional use.

[0090] It should be mentioned that additional alternatives architectures can be developed on the same concept, which out limiting the scope of the present subject matter.

[0091] It should be noted that the efficiency of centrifugal compressor operated in hot and humid climate areas, is dramatically reduced. In some cases when the ambient temperature is getting relatively high, the compressor stops its operation automatically in order to protect it from surge and damage. Cooling the air to the compressor expands the centrifugal compressors limits.

[0092] It should also be noted that heating the compressed air after it leaves the compressor raises the air's volume, increases its flow, and consequently, improve its efficiency.

[0093] A system of improved apparatus of air compression was built according to the presentation shown in Figure 5A in order to evaluate the efficiency of the compressor so as to illustrate its improvement over the prior art apparatuses. Different parameters such as ambient temperature, compressor entry temperature, compressor exit temperature, as well as relative humidity (%), flow (m^3/h), electric power (kW) for compressor and air dryer were changed and their influence on the efficiency of the compressor was established.

[0094] Reference is now made to Figure 7 depicting an efficiency of an improved apparatus over time as measured in an apparatus built according to the architecture of Figure 5A as influenced by cooling the air in the compressor inlet. When utilizing the architecture shown herein, the atmospheric air is cooler in about 13°C relative to the ambient air. As a result, during the 100 minutes of measurements, the compressor efficiency is increased in about 4.2-5.2% as shown in the graph of Figure 7 in reference to a base line (reference) that is a measure with inlet ambient temperature to the compressor and outlet ambient temperature to the consumer.

[0095] Reference is now made to Figure 8 depicting efficiencies of an improved apparatus over time as measured in an apparatus built according to the architecture of Figure 5A as influenced by cooling the air in the inlet and heat the air that is sent to the consumer . The efficiencies of the improved apparatus were examined for the case in which the inlet was cooled similarly to the previous tests that resulted in similar results while heating the compressed outlet air in about 9°C increased the efficiency of the compressor in additional 2.5-3% so the total efficiency of the compressor was increased by 7-8%, which is highly significant in the compressor's industry.

[0096] Although the subject matter has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims. All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present subject matter.

CLAIMS

1. An apparatus for enhancing efficiency of an air compressor comprising:

    a pre-cooler though which ambient air is cooled before entering the compressor using a coolant fluid;

    an after-cooler receiving compressed air from the compressor, wherein the compressed air is cooled;

    an economizer for exchanging heat receiving a first stream of the compressed air from the after-cooler and a second stream from the pre-cooler, wherein the second stream is of heated air that was heated in the pre-cooler by exchanging heat with the ambient air, and wherein said economizer outlets a third stream of the compressed air heated by the first stream and a fourth stream of cooled air; and

    a cooling dryer receiving the fourth stream from the economizer, configured to further cool the fourth stream and direct it to said pre-cooler, wherein said forth stream passed through the dryer acts as the coolant fluid,

    wherein heat is exchanged in the pre-cooler and the economizer by residual heat.

2. The apparatus for enhancing efficiency according to claim 1, wherein the pre-cooler cools the ambient air to approximately 9-11°C.

3. The apparatus for enhancing efficiency according to claim 1, wherein energy that is used for cooling the ambient air in the pre-cooler is harvested from residual energy of the cooling dryer.

4. The apparatus for enhancing efficiency according to claim 1, wherein the compressed air exiting the compressor and enters the after-cooler is cooled by a regulator.

5. The apparatus for enhancing efficiency according to claim 1, wherein the cooling dryer is configured to reduce the compressed air temperature to a dew point of 2-3°C that is used as the coolant.

6. The apparatus for enhancing efficiency according to claim 1, wherein the after-cooler and the economizer are combined to a single unit.

7. The apparatus for enhancing efficiency according to claim 6, wherein the single unit is regulated by a regulator selected from a group of a fan, a blower, a heat-sink, and any combination thereof.

8. The apparatus for enhancing efficiency according to claim 1, wherein an auxiliary cooling unit is adjunct to the cooling dryer to facilitate cooling.

9. The apparatus for enhancing efficiency according to claim 1, wherein the pre-cooler combined with the auxiliary cooling unit cools the ambient air to approximately 6°C.

10. A method of using residual heat to increase efficiency of air compression process comprising:

cooling the atmospheric air in a pre-cooler before entering the compression process using the compressed air from the compression process that is dried and cooled; and

heating an outlet stream from the compression process using residual heat that was taken from an after-cooler that receives the compressed air from the compression process.

11. The method of using residual heat according to claim 10, further comprising cooling the compressed air that leaves the compressing process by a regulator.

12. The method of using residual heat according to claim 11, the regulator is controlling a temperature in which the compressed air enters an economizer, wherein the economizer produces a stream of compressed air that is heated.

13. The method of using residual heat according to claim 10, wherein cooling of the atmospheric air in a pre-cooler in about 13 degrees Celsius and heating the outlet stream from the compression process in about 9 degrees Celsius increase the efficiency of the compression process in about 7-9%.

14. An apparatus for enhancing efficiency of an air compressor comprising:

a pre-cooler through which ambient air is cooled before entering the compressor using a coolant fluid;

an after-cooler receiving compressed air from the compressor through a first economizer that is provided between the compressor and the after cooler for exchanging heat, wherein the compressed air from the compressor is cooled in the first economizer and further cools in the after-cooler;

a second economizer that receives compressed air from the after-cooler, wherein the compressed air from the after-cooler is further cooled in the second economizer and wherein the first economizer is receiving a first stream of the compressed air from the compressor and a second cooler stream from the second economizer;

an outlet of compressed air having a pre-determined temperature, wherein the pre-determined temperature is a result of a mixture of compressed air from the second economizer that pass through the first economizer with a first temperature and the compressed air from the second economizer having a second temperature;

a mixing valve receiving the compressed air from the second economizer and splitting the compressed air so as a first portion flows directly to the outlet with the second temperature and a second portion that flows to the outlet through the first economizer having the first temperature and wherein a predetermined temperature of the air in said outlet controls a ratio between the first portion and the second portion;

wherein the compressed air from the compressor that was cooled in the second economizer is directed to the evaporator and heated air from the pre-cooler is directed to the second economizer so as to reduce the compressed air temperature sent to the evaporator,

wherein heat is exchanged in the pre-cooler and the economizers by residual heat.

15. The apparatus for enhancing efficiency of an air compressor as claimed in Claim 14, wherein condensed water is collected from the cooling process in a cold condense tank.

16. The apparatus for enhancing efficiency of an air compressor as claimed in Claim 15, wherein the cold condense tank is provided with an exit valve having a flowrate that is controlled by the height of the condensed water in the cold condense tank.

17. The apparatus for enhancing efficiency of an air compressor as claimed in Claim 15, wherein the condensed water that exits the cold condense tank pass through the after cooler so as to cool the compressed air that passes through.

18. The apparatus for enhancing efficiency of an air compressor as claimed in Claim 14, wherein the mixing valve is controlled by a value of the predetermined temperature.

19. The apparatus for enhancing efficiency of an air compressor as claimed in Claim 14, wherein air from the pre-cooler passes through the evaporator.

Prior art

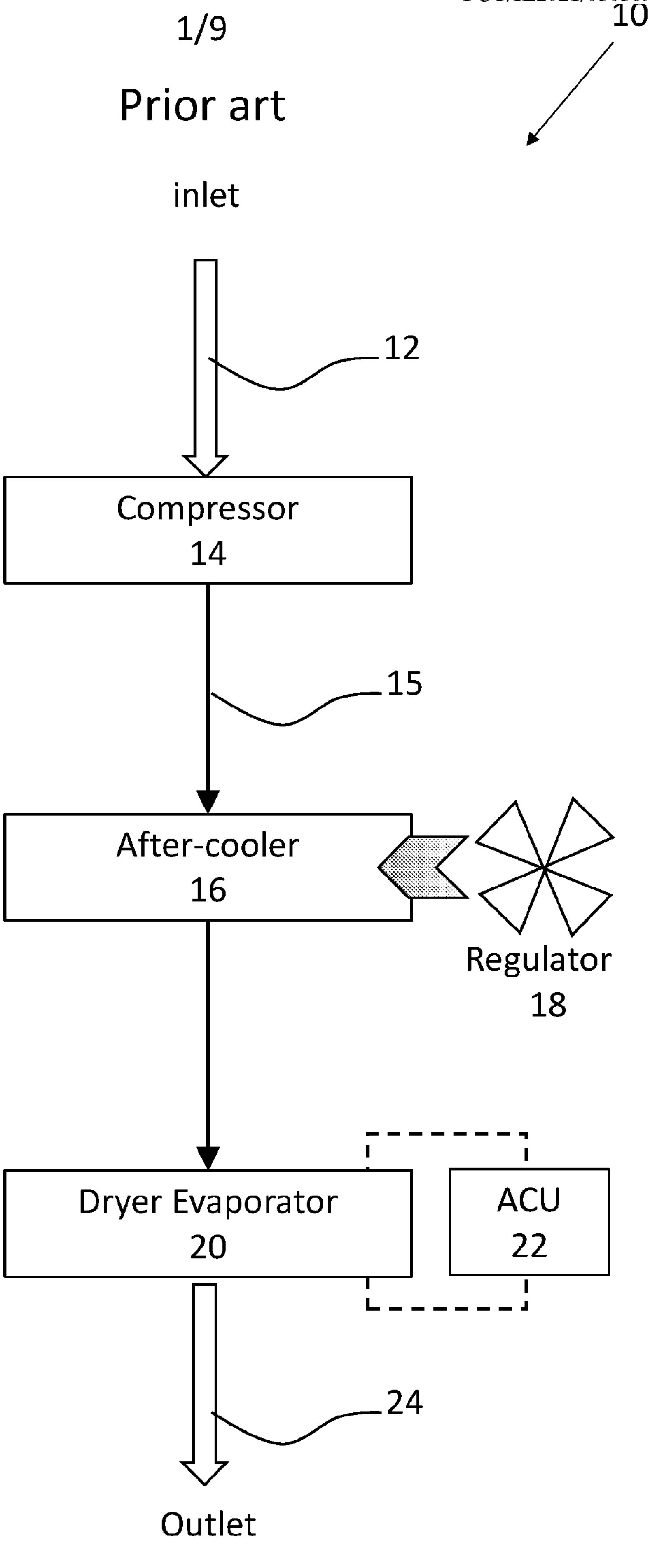
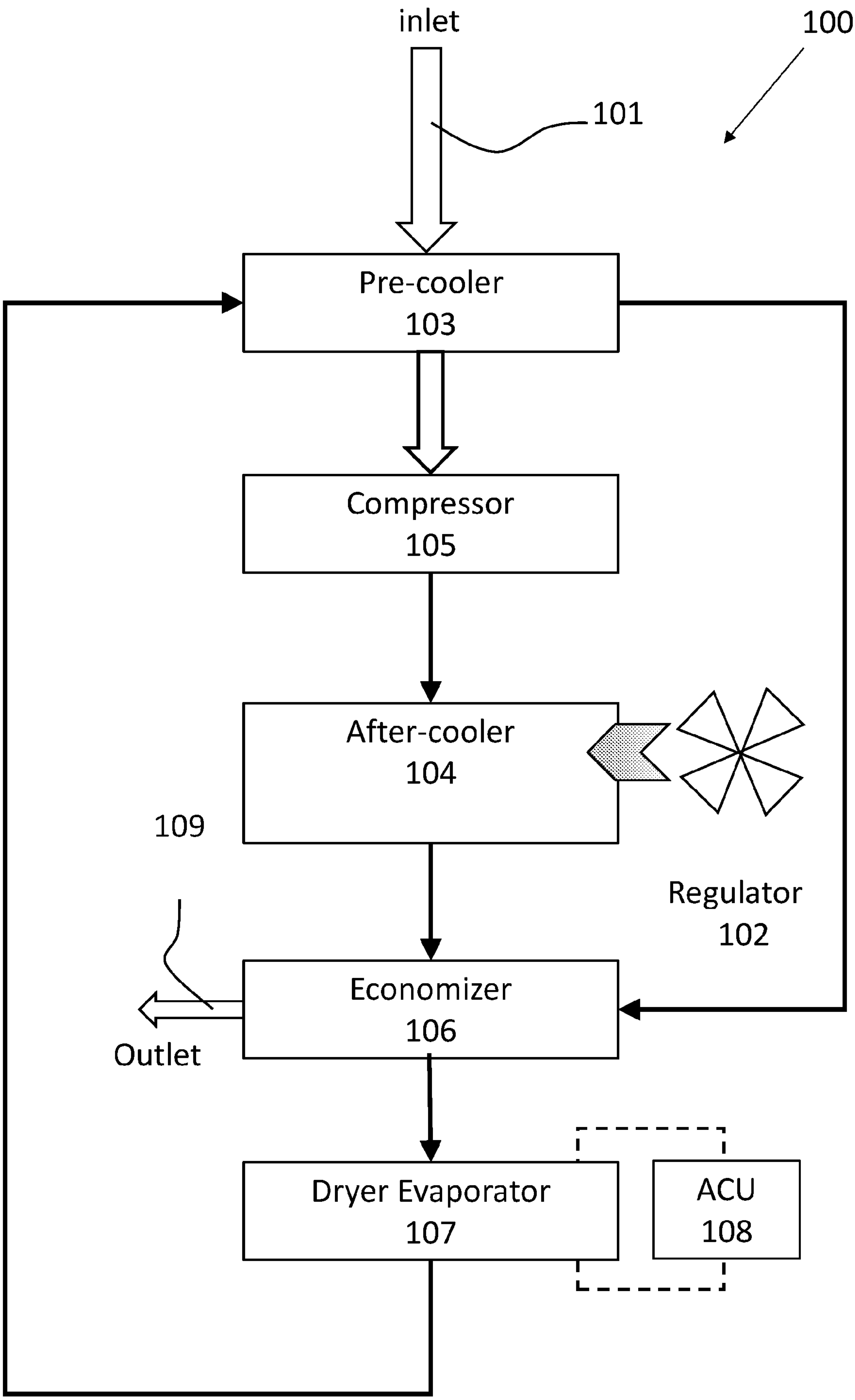


Figure 1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Compressor
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Economizer
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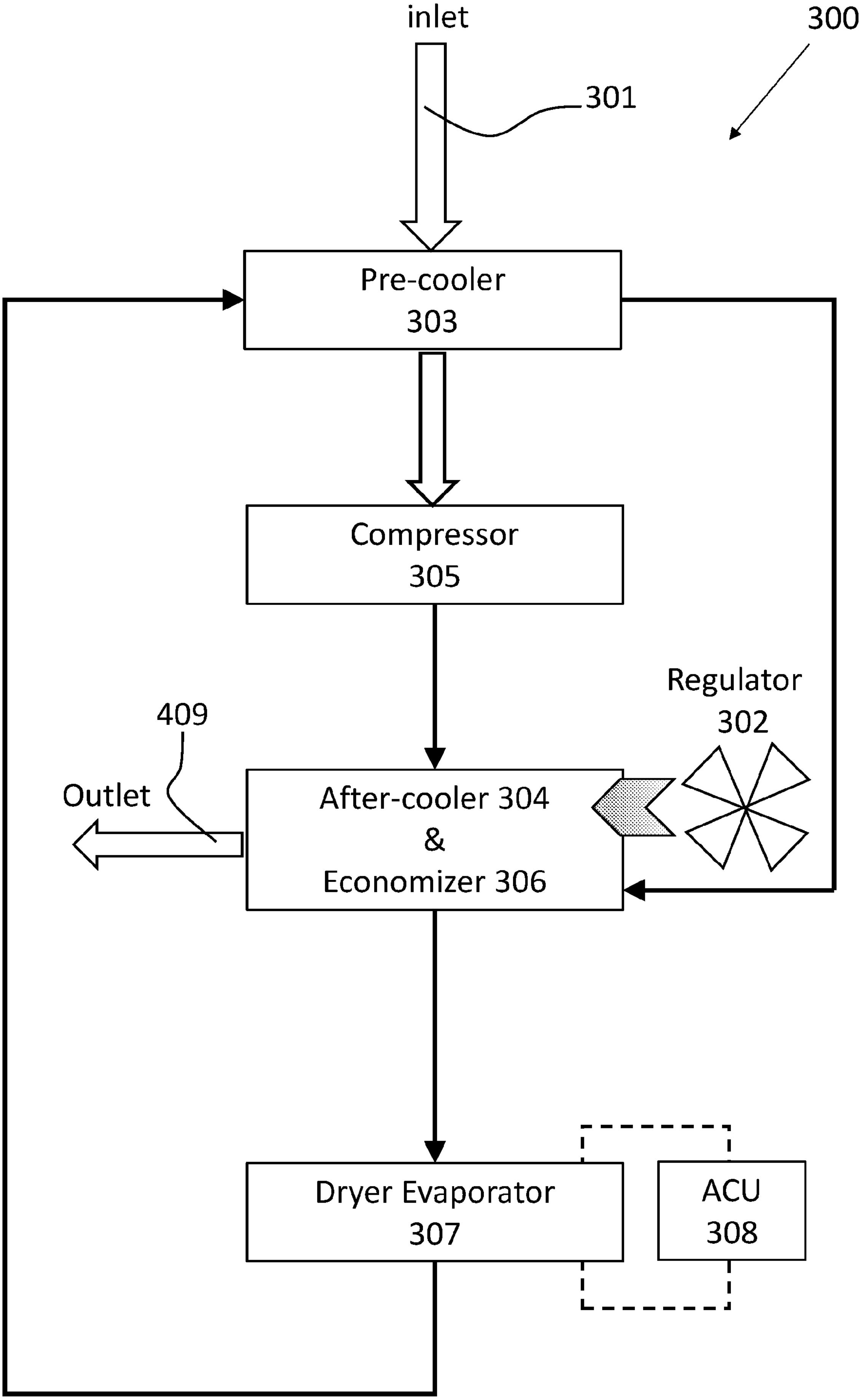
Dryer Evaporator
107
ACU
108

Figure 2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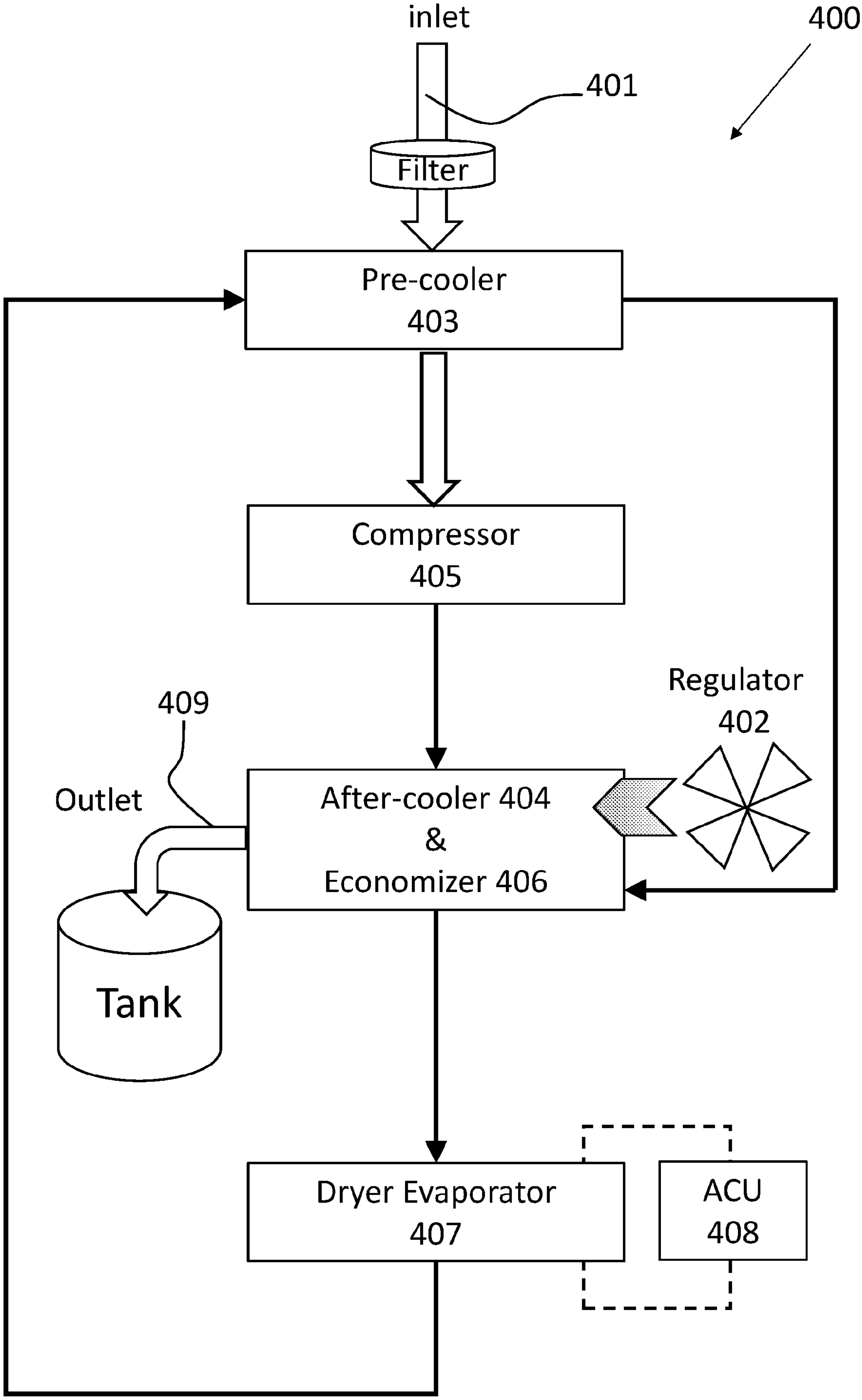
Dryer Evaporator
307
ACU
308

Figure 3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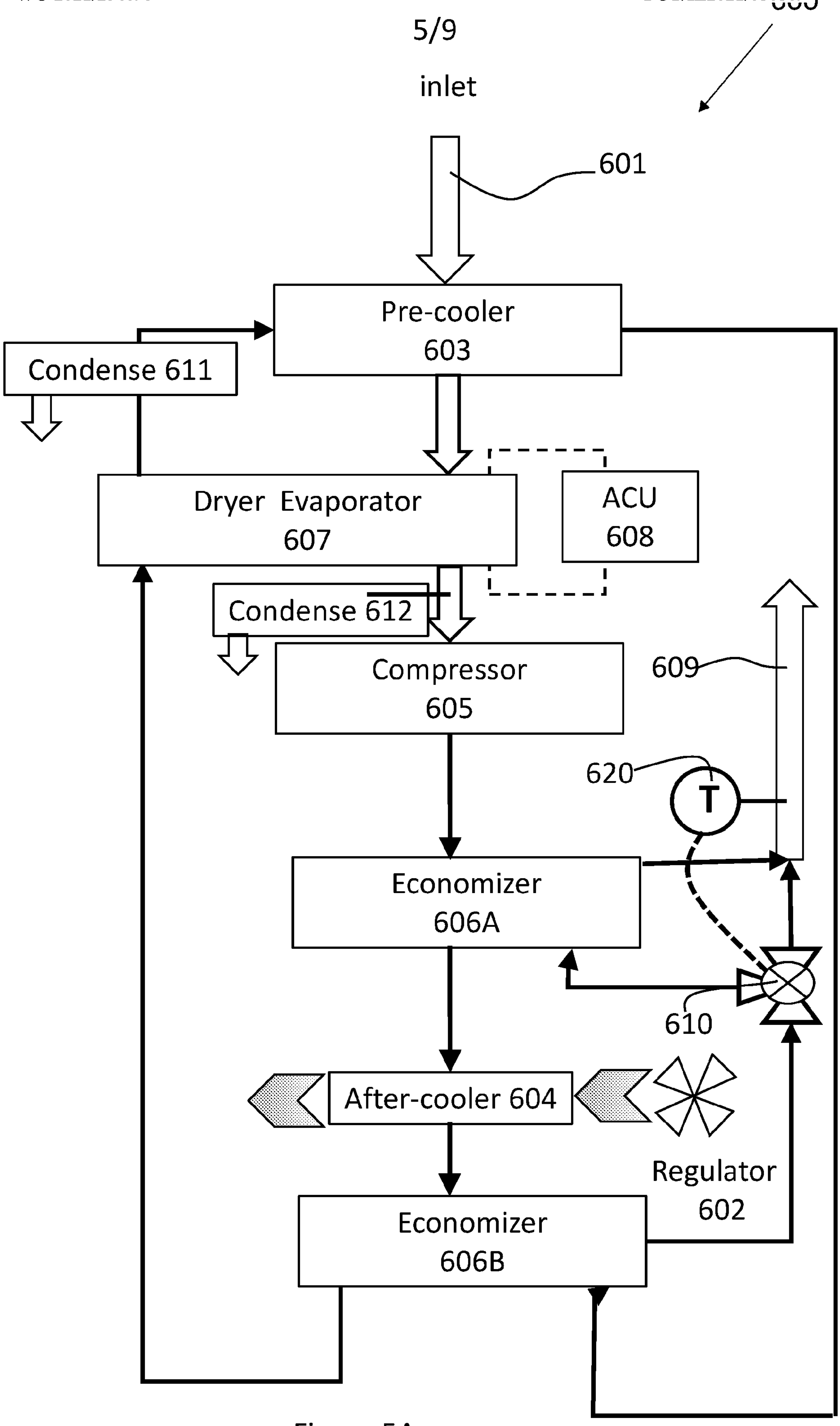
Tank
Dryer Evaporator
407
ACU
408

Figure 4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Dryer Evaporator
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ACU
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Condense 612
Compressor
605
609
620
T
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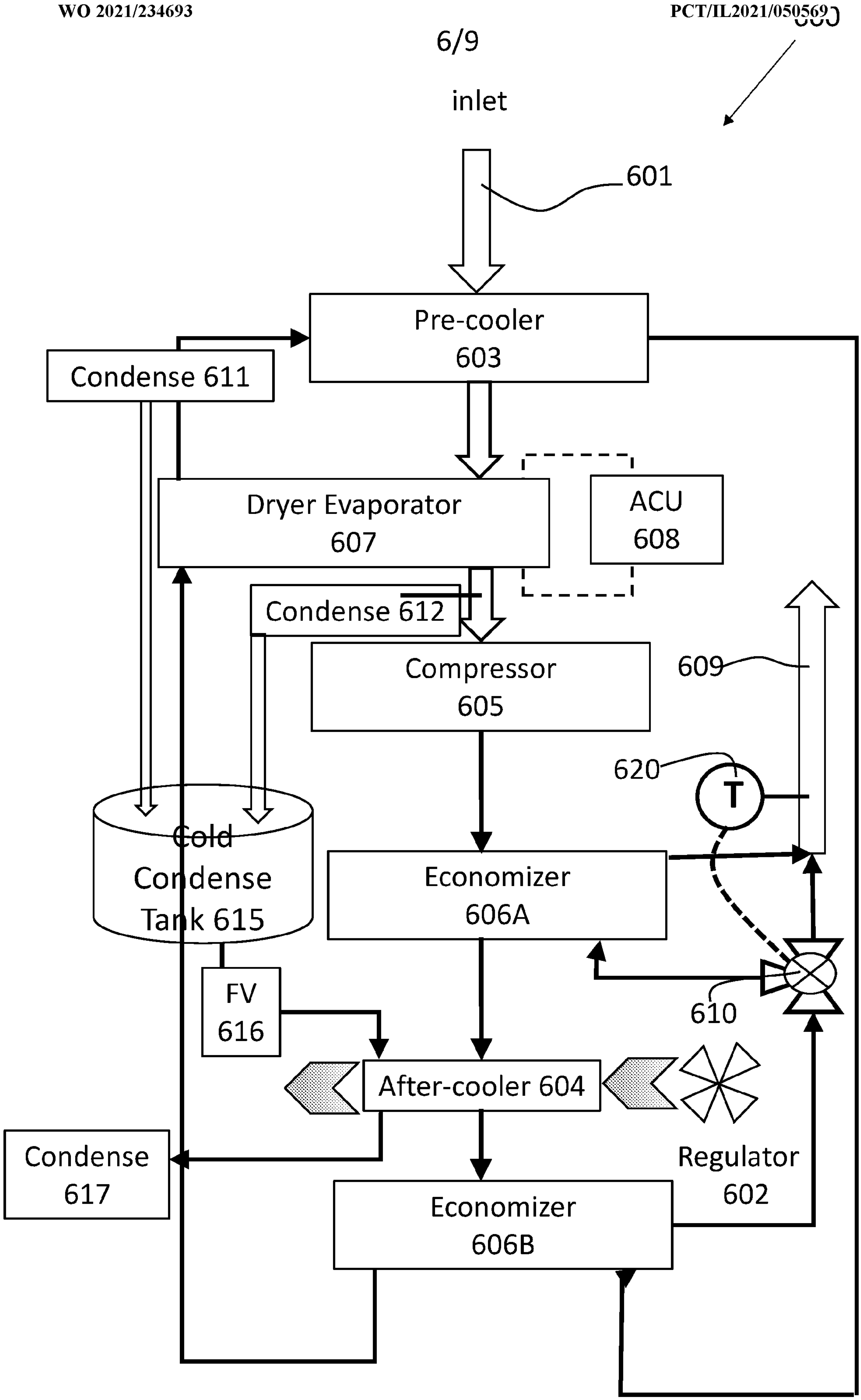
606A
610
After-cooler 604
Regulator
602
Economizer
606B

Figure 5A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ACU
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T
Cold
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Tank 615
Economizer
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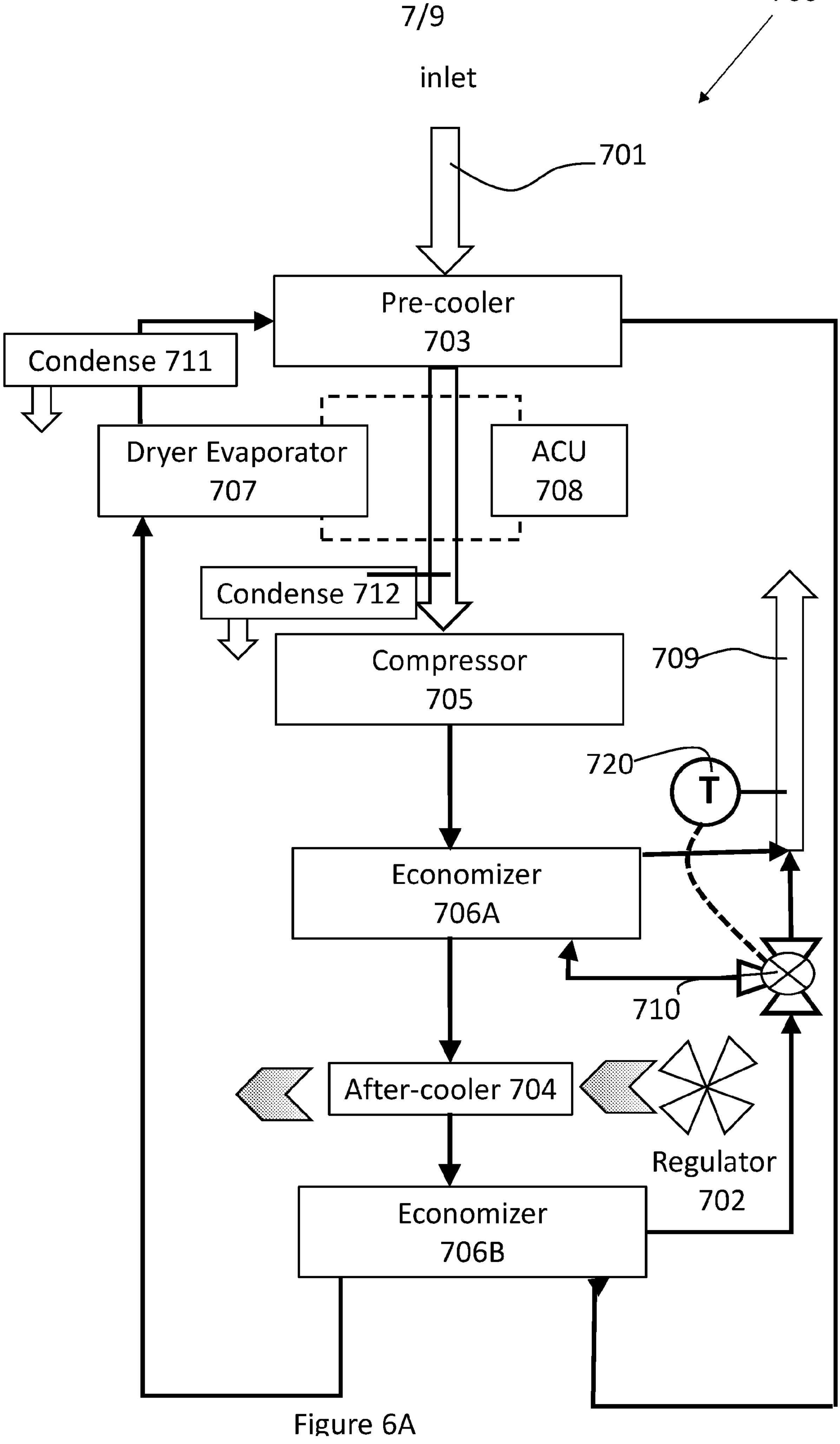
FV
616
610
After-cooler 604
Condense
617
Regulator
602
Economizer
606B

Figure 5B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Condense 711
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ACU
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Condense 712
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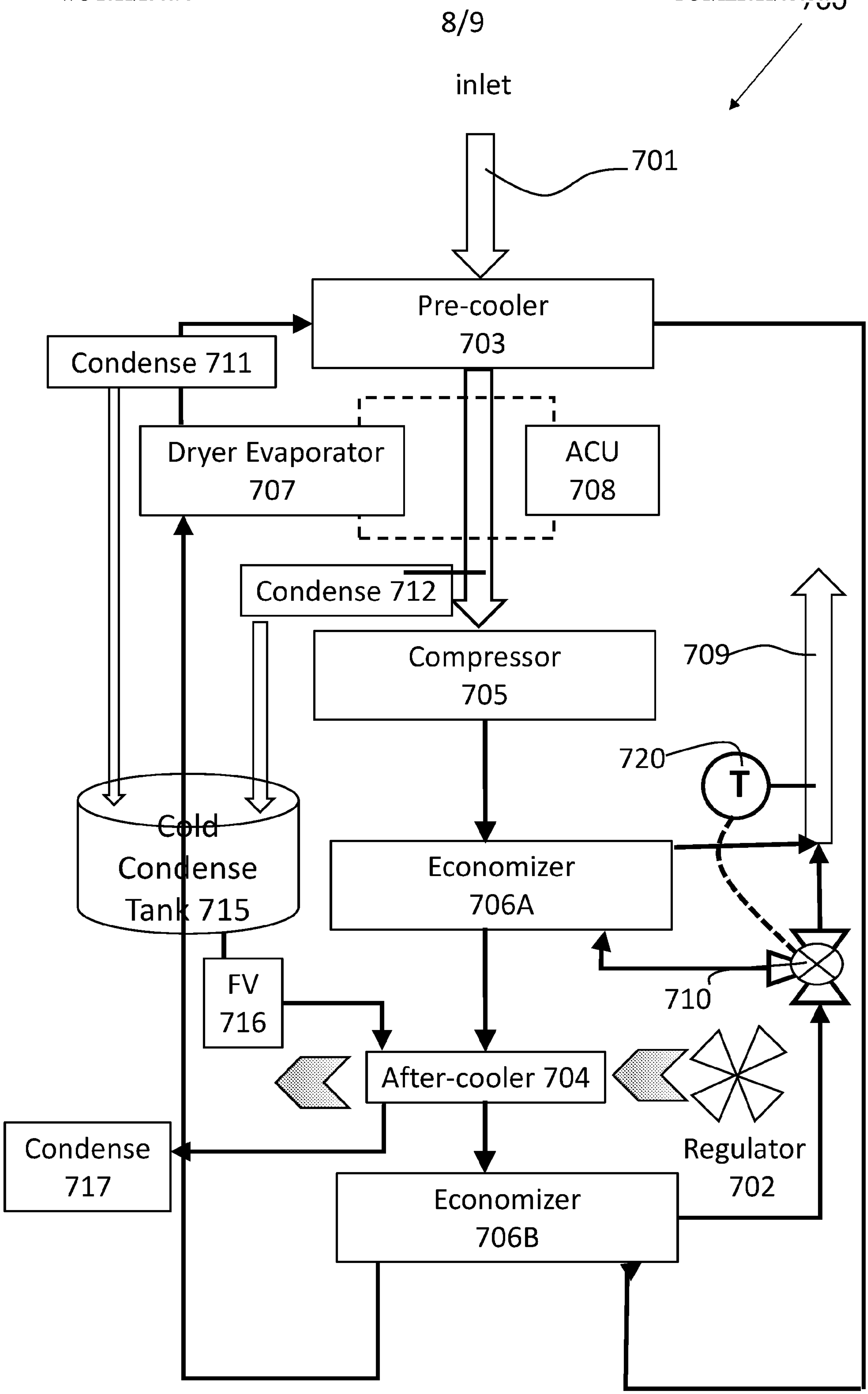
706A
710
After-cooler 704
Regulator
702
Economizer
706B

Figure 6A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Condense 711
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ACU
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Compressor
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T
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Economizer
706B

Figure 6B

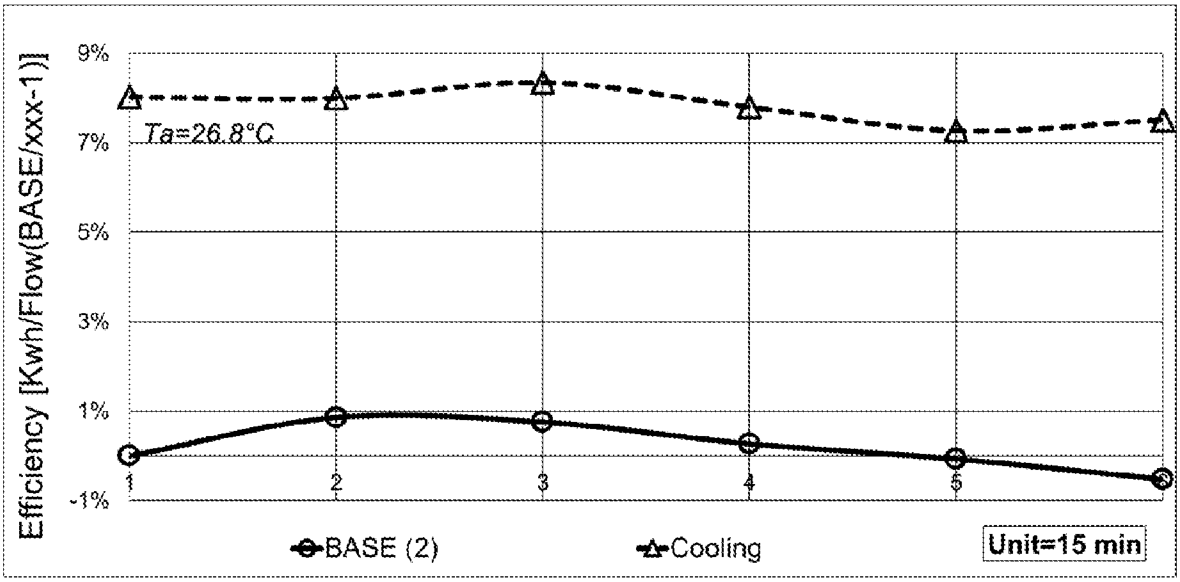

Figure 7

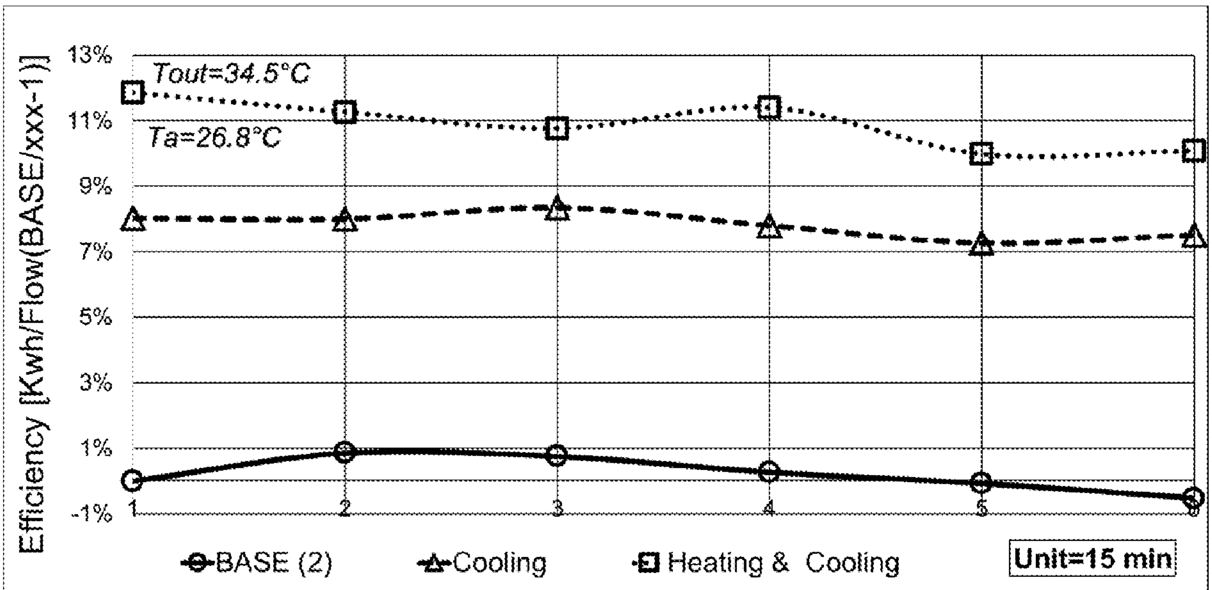

Figure 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL 21/50569

A. CLASSIFICATION OF SUBJECT MATTER

IPC - B01D 53/26, F25B 39/02, F25B 25/00, F28D 1/047, F25D 27/00 (2021.01)

CPC - B01D 53/265, B01D 53/26, F25 B39/02, F28D 1/0477, F28D 1/047, F28D 2021/0038

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)
See Search History document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	US 6,895,774 B1 (Ares et al.) 24 May 2005 (24.05.2005), entire document, especially Fig. 1; column 6, line 44-50, column 7, line 1-26, line 31-36, line 51-55.	1-11, 13 --- 12
A	US 4,936,109 A (Longardner) 26 June 1990 (26.06.1990), entire document.	1-13
A	US 2,632,315 A (COBLENTZ) 24 March 1953 (24.03.1953), entire document.	1-13
A	US 2012/0210597 A1 (BISON et al.) 23 August 2012 (23.08.2012), entire document.	1-13
A	US 2019/0217246 A1 (Ingersoll-Rand Company) 18 July 2019 (18.07.2019), entire document.	1-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 September 2021 (27.09.2021)	OCT 15 2021
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Kari Rodriquez Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL 21/50569

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-13 directed to an apparatus for enhancing efficiency of an air compressor comprising: a second stream from a pre-cooler, wherein the second stream is of heated air that was heated in the pre-cooler by exchanging heat with an ambient air, and wherein an economizer outlets a third stream of the compressed air heated by a first stream and a fourth stream of cooled air; and a cooling dryer receiving the fourth stream from the economizer, configured to further cool the fourth stream and direct it to said pre-cooler, wherein said forth stream passed through the dryer acts as a coolant fluid.

Group II: Claims 14-19 directed to an apparatus for enhancing efficiency of an air compressor comprising: a first and a second economizer, a first cooler stream, a second cooler stream, and a mixing valve.

--- See Next Additional Box ---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-13

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

--- Continuation of Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet) ---

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

SPECIAL TECHNICAL FEATURES

The invention of Group I includes the special technical feature of an apparatus for enhancing efficiency of an air compressor comprising: a second stream from a pre-cooler, wherein the second stream is of heated air that was heated in the pre-cooler by exchanging heat with an ambient air, and wherein an economizer outlets a third stream of the compressed air heated by a first stream and a fourth stream of cooled air; and a cooling dryer receiving the fourth stream from the economizer, configured to further cool the fourth stream and direct it to said pre-cooler, wherein said forth stream passed through the dryer acts as a coolant fluid, not required by the claims of Group II.

The invention of Group II includes the special technical feature of an apparatus for enhancing efficiency of an air compressor comprising: an after-cooler receiving compressed air from the compressor through a first economizer that is provided between the compressor and the after cooler for exchanging heat, wherein the compressed air from the compressor is cooled in the first economizer and further cools in the after-cooler; a second economizer that receives compressed air from the after-cooler, wherein the compressed air from the after-cooler is further cooled in the second economizer and wherein the first economizer is receiving a first stream of the compressed air from the compressor and a second cooler stream from the second economizer; an outlet of compressed air having a pre -determined temperature, wherein the predetermined temperature is a result of a mixture of compressed air from the second economizer that pass through the first economizer with a first temperature and the compressed air from the second economizer having a second temperature; a mixing valve receiving the compressed air from the second economizer and splitting the compressed air so as a first portion flows directly to the outlet with the second temperature and a second portion that flows to the outlet through the first economizer having the first temperature and wherein a predetermined temperature of the air in said outlet controls a ratio between the first portion and the second portion; wherein the compressed air from the compressor that was cooled in the second economizer is directed to the evaporator and heated air from the pre-cooler is directed to the second economizer so as to reduce the compressed air temperature sent to the evaporator, not required by the claims of Group I.

COMMON TECHNICAL FEATURES

Groups I-II share the common technical features of an apparatus for enhancing efficiency of an air compressor comprising: a pre-cooler though which ambient air is cooled before entering the compressor using a coolant fluid; an after-cooler receiving compressed air from the compressor, an economizer for exchanging heat receiving a first stream of the compressed air from the after-cooler and a second stream from the pre-cooler, wherein heat is exchanged in the pre-cooler and the economizer by residual heat. However, this shared technical feature does not represent a contribution over prior art as being anticipated by US 6,895,774 B1 to Ares et al. (hereinafter Ares), which discloses an apparatus for enhancing efficiency of an air compressor comprising (entirety of Fig. 1 - an apparatus capable of enhancing efficiency of an air compressor): a pre-cooler ("Ambient air, having traversed cold tube circuit 30 of coil 56 is discharged from the ambient air discharge face 56D of coil 56 as cooled, dehumidified airstream 74", column 7, line 33-36; see a pre-cooler generally defined by dashed lines 56, as seen in Fig. 1) through which ambient air is cooled before entering the compressor ("Ambient air, having traversed cold tube circuit 30 of coil 56 is discharged from the ambient air discharge face 56D of coil 56 as cooled, dehumidified airstream 74", column 7, line 33-36; see how ambient air is cooled via the pre-cooler before entering the compressor via duct 78, as seen in Fig. 1) using a coolant fluid ("The compressor 20 withdraws refrigerant vapor from its cooling or evaporator coil 30 via suction line 32 and compresses it and delivers the compressed refrigerant vapor to condenser 22 where the refrigerant vapor is condensed to a liquid and stored temporarily in receiver 24. The liquid refrigerant in receiver 24 flows as required through liquid line 26 to expansion valve 28 where its pressure is reduced to a saturated temperature of 25 F", column 7, line 1-24; note a coolant fluid used, as further seen in Fig. 1); an after-cooler ("Cooled compressed air flows from desuperheater 44 to a heat exchanger 50 having first tube circuit 52 and second tube circuit 66", column 6, line 48-50; an after-cooler 44, Fig. 1) receiving compressed air from the compressor (see how the after-cooler receives compressed air from the compressor 40, as seen in Fig. 1), an economizer ("Cooled compressed air flows from desuperheater 44 to a heat exchanger 50 having first tube circuit 52 and second tube circuit 66,", column 6, line 48-50; an economizer 50, Fig. 1) for exchanging heat receiving a first stream of the compressed air from the after-cooler and a second stream from the pre-cooler (intended use, but note how heat is exchanged received by a first stream of compressed air from the after-cooler 48 and 52 and a second stream from the pre-cooler 57, 67, and 66, as seen in Fig. 1), wherein heat is exchanged in the pre-cooler and the economizer by residual heat (note how the pre-cooler and the economizer 50 have a plurality of coils and tubes that pass through both, and therefore inherently, heat is exchanged in the two via residual heat, as further seen in Fig. 1).

As the common technical features were known in the art at the time of the invention, these cannot be considered special technical feature that would otherwise unify the groups.

Therefore, Groups I-II lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.