

A Dehumidifying System, a Method of Dehumidifying and A Cooling System

Technical Field

[0001] The present invention relates to a dehumidifying system, a method of dehumidifying and a cooling system using the dehumidifying system.

Background

[0002] Presently, a majority of dehumidification for building air-conditioning systems is based on conventional mechanical dehumidification. In order to remove the moisture from the supply air, the process air should be cooled below its dew-point temperature (condensation temperature), usually 12°C, and reheating is needed to ensure comfortable supply air temperature to a user. The cooling and reheating process wastes a large amount of electricity and suffers from high environmental cost. Moreover, the cooling coil that works under a wet condition may cause health problem since condensed water makes the coil surface a breeding ground for bacterial.

[0003] An alternative to the mechanical dehumidification is sorption dehumidification. Sorption dehumidification can be classified into two categories, namely, adsorption dehumidification and absorption dehumidification. Adsorption occurs when the physical or chemical, generally solid, remains unchanged in the dehumidification process; absorption conversely is when a change occurs, generally with liquid substances. Both methods utilize the difference of the vapour pressure between process air and desiccants to realize the humidity control. When the desiccant material is cold and dry, its vapour pressure is lower than process air and moisture may be transferred from the process air to the desiccant for dehumidification. On the contrary, when the desiccant is warm and moist, the pressure gradient is inverted and water vapour migrates from the desiccant to the air flow for regeneration. Comparatively, a liquid desiccant offers several advantages over a solid desiccant, namely the liquid desiccant has a higher capacity to hold moisture than that of the solid desiccant; the liquid desiccant requires lower regenerating temperature, mostly around 80°C while the solid desiccant is in the range of 100°C, this allows the exploitation of low-grade heat sources such as solar energy or waste heat; the pressure drop of process air through the liquid desiccant is lower than the solid desiccant; the liquid desiccant can be

stored in the form of a concentrated desiccant for use during periods when no suitable regenerating heat source is available, and thus offer more flexible operational characteristics.

[0004] In conventional liquid desiccant dehumidification system, the concentrations of the desiccants make a very small change after the dehumidification and regeneration processes, usually less than 0.5%. Much of energy in such schemes is wasted in unnecessary cooling and heating of the desiccant between dehumidification and regeneration processes.

Summary

[0005] A first aspect of the present invention provides a dehumidifying system having a dehumidifier having a desiccant, the dehumidifier configured to dehumidify a process airflow, the dehumidifier having a dehumidifier inlet and a dehumidifier outlet connected to the dehumidifier inlet such that the desiccant is configured to flow out of the dehumidifier via the dehumidifier outlet and to enter the dehumidifier via the dehumidifier inlet, a regenerator configured to regenerate the desiccant, the regenerator having a regenerator inlet and a regenerator outlet connected to the regenerator inlet such that the desiccant is configured to flow out of the regenerator via the regenerator outlet and to enter the regenerator via the regenerator inlet, a cooler connected to the dehumidifier, the cooler designed to cool the desiccant, such that the desiccant is cooled by the cooler before entering the dehumidifier via the dehumidifier inlet, a heater connected to the regenerator, the heater designed to heat the desiccant, such that the desiccant is heated by the heater before entering the regenerator via the regenerator inlet, a desiccant transfer conduit connected to the dehumidifier and the regenerator for establishing fluid communication between the dehumidifier and the regenerator, and a desiccant supply conduit connected to the dehumidifier and the regenerator for establishing fluid communication between the dehumidifier and the regenerator, such that the desiccant transfer conduit and the desiccant supply conduit forms a desiccant transfer loop through the dehumidifier and the regenerator, such that the desiccant loop is configured to provide transfer of desiccant from the dehumidifier to the regenerator via the desiccant transfer conduit and supply of desiccant from the regenerator to the dehumidifier via the desiccant supply conduit.

[0006] A second aspect of the invention provides an air cooling system comprising a dehumidifying system in the first aspect, an air conditioning system having a compressor for compressing a refrigerant, a condenser adapted to condense the refrigerant from the compressor from a vapour state into a liquid state, a vapour conduit connected to the compressor and the condenser for establishing fluid communication between the compressor and the condenser, an evaporator in fluid communication with the condenser, the evaporator for evaporating the refrigerant from the condenser from a liquid state to a vapour state, such that the heater of the dehumidifying system is in thermal communication with the vapour conduit, such that the heater is configured to receive heat from the vapour conduit, such that the desiccant through the heater receives heat from the refrigerant in the vapour conduit, such that the cooler of the dehumidifying system is in thermal communication with the evaporator, such that the cooler is configured to be cooled by the evaporator, such that the desiccant through the cooler is cooled by the refrigerant through the evaporator.

[0007] The present invention provides a method of dehumidifying a process airflow having the steps of dehumidifying the process airflow by removing vapour from the process airflow by a desiccant in a dehumidifier, channelling the desiccant out of the dehumidifier, cooling the desiccant, channelling the cooled desiccant into the dehumidifier, transferring the desiccant from the dehumidifier to the regenerator, regenerating the desiccant by removing vapour from the desiccant by a regenerating airflow, channelling the desiccant out of the regenerator, heating the desiccant, channelling the heated desiccant into the regenerator, and supplying the regenerated desiccant from the regenerator to the dehumidifier.

Brief Description of Drawings

[0008] Fig. 1 shows an exemplary embodiment of a dehumidifying system;

[0009] Fig. 2 shows another exemplary embodiment of the dehumidifying system of Fig. 1;

[0010] Fig. 3 shows another exemplary embodiment of the dehumidifying system of Fig. 1;

[0011] Fig. 4 shows another exemplary embodiment of the dehumidifying system of Fig. 1;

[0012] Fig. 5 shows another exemplary embodiment of the dehumidifying system of Fig. 1;

[0013] Fig. 6 shows an exemplary embodiment of an air cooling system integrated with the dehumidifying system of Fig. 1;

[0014] Fig. 7 shows another exemplary embodiment of an air cooling system integrated with the dehumidifying system of Fig. 1;

[0015] Fig. 8 shows an exemplary embodiment of an air cooling system integrated with the dehumidifying system of Fig. 1;

[0016] Fig. 9 shows an exemplary method of dehumidifying a process airflow by the various embodiments in Figs. 1-6;

[0017] Fig. 10 shows a test result of a test for heat exhaustion from a compressor against cooling load;

[0018] Fig. 11 shows a test result of a test for regeneration rate against concentration of desiccant; and

[0019] Fig. 12 shows a test result of a test for performance of dehumidifier against the concentration of desiccant.

Detailed Description

[0020] Fig. 1 shows a dehumidifying system 10. Dehumidifying system 10 may use a desiccant 20 to dehumidify an airflow. Dehumidifying system 10 may be a liquid desiccant dehumidifying system (LDDS) which uses a liquid desiccant. Dehumidifying system 10 has a dehumidifier 100 which is configured to dehumidify a process airflow 180, which is an airflow through the dehumidifier 100, such that vapour in the process airflow 180 is removed from the process airflow by the desiccant 20. Dehumidifier 100 has a dehumidifier inlet 102 and a dehumidifier outlet 104 connected to the dehumidifier inlet 102. Desiccant 20 is configured to flow out of the dehumidifier 100 via the dehumidifier outlet 104 and to enter the dehumidifier 100 via the dehumidifier inlet 102. Desiccant 20 in the dehumidifier 100 may flow directly from the outlet 104 into the inlet 102.

[0021] Dehumidifying system 10 further includes a regenerator 200 which is configured to regenerate the desiccant 20, such that vapour is removed from the desiccant 20 by a regenerating airflow 280. Regenerator 200 has a regenerator inlet 202 and a regenerator outlet 204 connected to the regenerator inlet 202 such that desiccant 20 is configured to flow out of the regenerator 200 via the regenerator outlet 204 and to enter the regenerator 200 via the regenerator inlet 202. Desiccant 20 in the regenerator 200 may flow directly from the outlet 204 into the inlet 202.

[0022] Dehumidifying system 10 further includes a cooler 300 connected to the dehumidifier 100. Cooler 300 is designed to cool the desiccant 20. Desiccant 20 is cooled by the cooler 300 before entering the dehumidifier 100 via the dehumidifier inlet 102. Cooler 300 may be in thermal contact with the dehumidifier 100 to cool the desiccant 20. In this example, desiccant 20 in the dehumidifier 100 may flow directly from the outlet 104 into the inlet 102.

[0023] Dehumidifying system 10 further includes a heater 400 connected to the regenerator 200. Heater 400 is designed to heat the desiccant 20. Desiccant 20 is heated by the heater 400 before entering the regenerator 200 via the regenerator inlet 202. Desiccant 20 in the regenerator 200 may flow directly from the outlet 204 into the inlet 202. Heater 400 may be in thermal contact with the regenerator 400 to heat the desiccant 20. In this example, desiccant 20 in the regenerator 200 may flow directly from the outlet 204 into the inlet 202.

[0024] Dehumidifying system 10 further includes a desiccant transfer conduit 110 connected to the dehumidifier 100 and the regenerator 200. Desiccant transfer conduit 110 is adapted to establish fluid communication between the dehumidifier 100 and the regenerator 200.

[0025] Dehumidifying system 10 further includes a desiccant supply conduit 210 connected to the dehumidifier 100 and the regenerator 200. Desiccant supply conduit 210 is adapted to establish fluid communication between the dehumidifier 100 and the regenerator 200.

[0026] Desiccant transfer conduit 110 and the desiccant supply conduit 210 forms a desiccant transfer loop 22 through the dehumidifier 100 and the regenerator 200, such that

the desiccant loop 22 is configured to provide transfer of desiccant 20 from the dehumidifier 100 to the regenerator 200 via the desiccant transfer conduit 110 and supply of desiccant 20 from the regenerator 200 to the dehumidifier 100 via the desiccant supply conduit 210.

[0027] Desiccant transfer conduit 110 and desiccant supply conduit 210 may include pumps along the conduit to pump the desiccant 20 along the conduits.

[0028] Dehumidifier 100 and regenerator 200 may include vessels 106,206. Vessels 106,206 may be filled with desiccant 20. Vessel 106 of dehumidifier 100 may include packing column 112. Vessel 206 of regenerator 100 may include packing column 212.

[0029] In the dehumidifier 100, the pre-cooled desiccant 20, e.g. liquid desiccant, may be sprayed above the packing column 106. Process airflow 180, e.g. ambient air, drawn into the dehumidifier 100 by a fan 108, directly contacts the falling desiccant 20. As surface vapour pressure of the process airflow 180 is higher than that of desiccant 20, e.g. liquid desiccant, both heat and mass transfer occur from the process airflow 180 to the desiccant 20.

[0030] In the regenerator 200, the pre-heated desiccant 20, e.g. liquid desiccant, from the dehumidifier 100 may be sprayed above the packing column 206. Regenerating airflow 280, e.g. ambient air, drawn into the regenerator 200 by a fan 208, directly contacts the falling desiccant 20. As surface vapour pressure of the desiccant 20 is higher than that of regenerating airflow, e.g. ambient air, both heat and mass transfer occur from the desiccant 20 to regenerating airflow 280 and the process condenses the desiccant 20.

[0031] Referring to Fig. 1, dehumidifier 100 may include a first transfer conduit 120. First transfer conduit 120 may be connected to the dehumidifier 100 via the dehumidifier outlet 104 and cooler 300. First transfer conduit 120 establishes fluid communication between dehumidifier 100 and cooler 300. Dehumidifier may include a first supply conduit 122 connected to dehumidifier 100 via the dehumidifying inlet 102 and cooler 300. First supply conduit 122 establishes fluid communication between the dehumidifier 100 and cooler 300.

[0032] First transfer conduit 120 and first supply conduit 122 may form a dehumidifying loop 124 through the dehumidifier 100 and cooler 300 (see Fig. 2) such that dehumidifying

loop 124 provides flow of desiccant 20 from the dehumidifier 100 to cooler 300 via the first transfer conduit 120, through cooler 300 to cool the desiccant 20 and back into the dehumidifier 100 via the first supply conduit 122.

[0033] As shown in Fig. 1, a second transfer conduit 220 may be connected to the regenerator 200 via the regenerator outlet 204 and heater 400. Second transfer conduit 220 establishes fluid communication between the regenerator 200 and heater 400. Second supply conduit 222 may be connected to the regenerator 200 via the regenerator inlet 202 and heater 400. Second supply conduit 222 establishes fluid communication between the regenerator 200 and heater 400.

[0034] Second transfer conduit 220 and second supply conduit 222 may form a regenerating loop 224 through the regenerator 200 and heater 400 (see Fig. 2) such that regenerating loop 224 provides flow of desiccant 20 from the regenerator 200 to heater 400 via the second transfer conduit 220, through heater 400 to heat up the desiccant 20 and back into the regenerator 200 via the second supply conduit 224.

[0035] As mentioned, dehumidifier 100 removes the moisture/vapour from the process airflow 180. As more moisture is absorbed by the desiccant 20, the concentration of the desiccant 20 drops. In other words, the desiccant 20 is diluted. Regenerator 200 condenses the diluted desiccant 20 from the dehumidifier 100 to an acceptable concentration. The working principle of the dehumidifier system 10 is briefly described as follows:

[0036] In the dehumidifier 100, the pre-cooled desiccant, e.g. liquid desiccant, which has low surface vapour pressure may be sprayed above the packing column 106. Process airflow 180, drawn into the dehumidifier 100 by a fan 108, directly contacts the falling desiccant 20. As the surface vapour pressure of cooled desiccant 20 is lower than that of process airflow 180, e.g. ambient air, both heat and mass transfer take place from process airflow 180 to the sprayed desiccant 20. The surface vapour difference between the process airflow 180 and the desiccant 20 acts as the driving force for the mass transfer.

[0037] Fig. 3 shows another exemplary embodiment of dehumidifying system 10. Dehumidifying system 10 may include a concentrated desiccant reservoir 510 for storing desiccant 20. Desiccant 20 may be concentrated desiccant 20. Concentrated desiccant

reservoir 510 may be disposed along desiccant supply conduit 210 such that fluid communication is established between the concentrated desiccant reservoir 510 and the dehumidifier 100 and between the concentrated desiccant reservoir 510 and the regenerator 200 via the desiccant supply conduit 210. Desiccant supply conduit 210 may be adapted to supply desiccant 20 from regenerator 200 to dehumidifier 100 via the concentrated desiccant reservoir 510. Concentrated desiccant reservoir 510 may contain desiccant 20 having concentration of about 40% and below. Crystallization may occur when the concentration is more than 42%.

[0038] As seen from the exemplary embodiments, desiccant may be circulated continuously in each packing column 112,212 until certain concentrations are reached. Since the desiccant are cycled in the respective loops, i.e. dehumidifying loop and regenerating loop, for most of the time, no energy crossover between the loops occurs. As such, cooling and heating demands are required only to maintain the desiccants at the specified temperatures. Therefore, the energy consumption in the dehumidifying system 10 may be much lower than that in conventional systems.

[0039] As shown in Fig. 3, dehumidifying system 10 may include a diluted desiccant reservoir 520 for storing desiccant 20. Diluted desiccant reservoir 520 may be disposed along the desiccant transfer conduit 110 such that fluid communication is established between diluted desiccant reservoir 520 and dehumidifier 100 and between diluted desiccant reservoir 510 and regenerator 200 via the desiccant transfer conduit 110. Desiccant transfer conduit 110 may be adapted to transfer desiccant 20 from the dehumidifier 100 to regenerator 200 via diluted desiccant reservoir 520. Diluted desiccant reservoir 520 may contain desiccant 20 having concentration of about 25% and above. Dehumidification requirement may not be met if the concentration is less than 25%.

[0040] Concentrated desiccant reservoir 510 and diluted desiccant reservoir 520 may be storage tanks. Concentrated desiccant reservoir 510 and diluted desiccant reservoir 520 may provide independent operation of the two packing columns 112,212. By allowing independent operation of the two packing columns 112,212 in the dehumidifier 100 and regenerator 200 respectively, it is possible for distributed operation of the dehumidifier 100

and regenerator 200 to determined locations, i.e. centralized regeneration and decentralized dehumidification.

[0041] As shown in Fig. 3, diluted desiccant reservoir 520 may be thermally connected to the concentrated desiccant reservoir 510 such that heat may be transferred between the diluted desiccant reservoir 520 and the concentrated desiccant reservoir 510. Diluted desiccant reservoir 520 may be connected to the concentrated desiccant reservoir 510 via a finned plate 530.

[0042] By thermally connecting the diluted desiccant reservoir 520 and the concentrated desiccant reservoir 510, it is possible to transfer heat energy between the diluted desiccant reservoir 520 and the concentrated desiccant reservoir 510 as the temperature between the desiccant 20 in the diluted desiccant reservoir 520 and the concentrated desiccant reservoir 510 are different. Therefore, it is possible to recover heat energy from the desiccant 20 in the concentrated desiccant reservoir 510 to the desiccant in the diluted desiccant reservoir 520. This allows desiccant 20 in the concentrated desiccant reservoir 510 to be cooled before entering the dehumidifier 100 and the desiccant 20 in the diluted desiccant reservoir 520 to be warmed up before entering the regenerator 200.

[0043] Referring to Fig. 4, dehumidifying system 10 may further include an airflow channel 600. Airflow channel 600 may be connected to dehumidifier 100 and to regenerator 200. Airflow channel 600 establishes fluid communication between dehumidifier 100 and regenerator 200 such that the airflow channel 600 is able to channel the process airflow 180 from the dehumidifier 100 into regenerator 200. When the process airflow 180 enters the regenerator 200, process airflow 180 becomes the regenerating airflow 280. A zone 610 may be disposed along airflow channel 600 such that process airflow 180 flows into the zone 610 via airflow channel 600 before continuing along the airflow channel 600 into regenerator 200. Process airflow 180 may be warmed up after going through zone 610. Zone 610 may be a room, a container etc.

[0044] Referring to Fig. 5, dehumidifying system 10 may include a first heat exchanger 710. First heat exchanger 710 may be in thermal communication with the airflow channel 600 and the second transfer conduit 220 such that the first heat exchanger 710 provides transfer

of heat between process airflow 180 along the airflow channel 600 and the desiccant 20 along the second transfer conduit 220.

[0045] As shown in Fig. 5, dehumidifying system 10 may include a second heat exchanger 720. Second heat exchanger 720 may be in thermal communication with cooler 300 and the airflow channel 600 such that second heat exchanger 720 provides transfer of heat from the process airflow 180 along the airflow channel 600 to the desiccant 20 through cooler 300. Heat exchanger 720 may be in contact with the cooler 300 or connected to cooler 300 by a heat conductor 722.

[0046] In Fig. 5, dehumidifying system 10 may include a third heat exchanger 730. Third heat exchanger 730 may be in thermal communication with cooler 300. First transfer conduit 120 may be connected to third heat exchanger 730 and dehumidifier 100 to establish fluid communication between dehumidifier 100 and the third heat exchanger 730. First supply conduit 120 may be connected to third heat exchanger 730 and dehumidifier 100 to establish fluid communication between dehumidifier 100 and third heat exchanger 730. First transfer conduit 120 and first supply conduit 122 may form the dehumidifying loop 124 through dehumidifier 100 and third heat exchanger 730 such that dehumidifying loop 124 provides flow of desiccant 20 from dehumidifier 100 to third heat exchanger 730 via first transfer conduit 120, through third heat exchanger 730 to cool the desiccant 20 and back into dehumidifier 100 via first supply conduit 122.

[0047] Fig. 6 shows an air cooling system 800. Air cooling system 800 includes an air conditioning system 850, e.g. HVAC system, for conditioning, e.g. cooling, a process airflow. Air cooling system 800 includes dehumidifying system 10 which may be integrated with the air conditioning system 850.

[0048] Air conditioning system 850 includes a compressor 852 for compressing a refrigerant, a condenser 854 adapted to condense the refrigerant from the compressor 852 from a vapour state into a liquid state. A vapour conduit 856 is connected to compressor 852 and condenser 854 for establishing fluid communication between compressor 852 and condenser 854. Air conditioning system 850 includes an evaporator 858 which is in fluid communication with condenser 854. Evaporator 858 evaporates the refrigerant from the

condenser 854 from a liquid state to a vapour state thereby lowering the temperature of the refrigerant. Air conditioning system 850 includes an expansion valve 860 for controlling the amount of refrigerant into the evaporator 858.

[0049] As shown in Fig. 6, a fourth heat exchanger 740 may be in thermal communication with the vapour conduit 856 and fluid communication with second supply conduit 222. Desiccant 20 flowing along second supply conduit 222 may be heated by the refrigerant flowing along the vapour conduit 856 when the desiccant 20 flows through the fourth heat exchanger 740.

[0050] Heater 400 (not shown in Fig. 6) of dehumidifying system 10 may be in thermal communication with the vapour conduit 856 via fourth heat exchanger 740. Fourth heat exchanger 740 may be heater 400 and connected to the second transfer conduit 220 and second supply conduit 222 (part of regenerating loop 224) such that heat is provided to desiccant 20 that flows along second transfer conduit 220, through the fourth heat exchanger 740 and along second supply conduit 222. Heater 400 is therefore configured to receive heat from the vapour conduit 856 so that desiccant 20 flowing through the heater 400 receives heat from the refrigerant in the vapour conduit 856.

[0051] As shown in Fig. 6, first heat exchanger 710 may be in thermal communication with fourth heat exchanger 740 such that desiccant 20 along the regenerating loop 224 flows through the first heat exchanger 710 and fourth heat exchanger 740 before entering regenerator 200. In this way, desiccant 20, after leaving regenerator 200, may be heated up in steps. More importantly, the first and fourth heat exchangers 710, 740 may be used to recover the waste heat from e.g. the air conditioning system 850 and dehumidifying system 10.

[0052] Humidity and temperature of regenerating airflow have great influences on the performance of regeneration. The lower the humidity of regenerating airflow is, the higher the regenerating rate. Whenever low humidity exhaust air can be used, regenerating rate will be increased. On the other hand, higher temperature results in lower relative humidity for the same regenerating airflow that can increase the mass transfer coefficient. An effect in heating up the regenerating airflow 280 is that the heat passed from the desiccant to the

regenerating airflow 280 becomes much smaller, hence reducing the energy required to heat up the desiccant 20. Dehumidifying system 10 makes use of the waste heat from compressor 852 to heat both the desiccant 20 and the regenerating airflow 280 so as to reduce the regenerating temperature to about 55°C.

[0053] Referring to Fig. 6, third heat exchanger 730 may be in thermal communication with evaporator 858. Cooler 300 of the dehumidifying system 10 may be third heat exchanger 730. Cooler 300 may be in thermal communication with evaporator 858. Third heat exchanger 730 or cooler 300 may be configured to be cooled by evaporator 858 such that desiccant 20 through third heat exchanger 730 or cooler 300 may be cooled by the refrigerant through evaporator 858. Cooler 300 in the dehumidifying system 10 may be the evaporator 858 whereby the second heat exchanger 720 may be in thermal communication with the evaporator 858.

[0054] As shown in Fig. 7, a fifth heat exchanger 750 may be in thermal communication with the second heat exchanger 720. Chilled water from second heat exchanger 720 may be directed to the fifth heat exchanger 750, i.e. outlet of second heat exchanger 720 may be connected to the inlet of the fifth heat exchanger 750. Fifth heat exchanger 750 may be connected to the evaporator 858 in air conditioning system 850, e.g. HVAC system. In this way, chilled water from the fifth heat exchanger 750 may be used to cool the desiccant 20 before entering the evaporator 858 in the air conditioning system 850. Fifth heat exchanger 750 may be used to make use of the return chilled water in air conditioning system 850.

[0055] As shown in Fig. 8, dehumidifying system 10 may include a heat pipe heat exchanger 760. Heat pipe heat exchanger 760 may include ducts 762,764. Outlet 204 and inlet 202 of regenerator 200 may be connected to the ducts 762,764 of the heat pipe heat exchanger 760 respectively such that regenerating air flow 280 at the outlet 204 of regenerator 200 may flow through duct 762 of heat pipe heat exchanger 760 to heat up the heat pipe heat exchanger 760. Regenerating air flow 280 of regenerator 200 may flow through the other duct 764 which may be in thermal connection with duct 762. In this way, regenerating air flow 280 may be heated by the flow at the outlet 204 before entering regenerator 200. Heat pipe heat exchanger 760 may be used to recover the waste heat from regenerating air flow 280 at the outlet 204 of the regenerator 200 and transfer the waste heat back to the

regenerating air flow 280. Heat pipe heat exchanger 760 may be directly connected to the inlet 202 and outlet 204 of the regenerator 200.

[0056] Fig. 9 shows a method 1000 of dehumidifying a process airflow. Method 1000 includes the following steps.

[0057] In step 1010, the process airflow is dehumidified by removing vapour from the process airflow by a desiccant in a dehumidifier. Sprayed desiccant interacts with the process airflow 180 and removes vapour from the process airflow 180.

[0058] In step 1020, desiccant is channelled out of the dehumidifier. Referring to Fig. 6, desiccant 20 in vessel 106 at the bottom of dehumidifier 100 may be pumped by a pump 130 out of dehumidifier 100. The humidity of process airflow 180 leaving the dehumidifier 100 may be controlled through adjusting the desiccant flow rate and the temperature in the dehumidifier 100.

[0059] In step 1030, the desiccant is cooled. Desiccant 20 flows along first transfer conduit 120 after being pumped out of dehumidifier 100 and cooled by third heat exchanger 730.

[0060] In step 1040, the cooled desiccant is channelled into the dehumidifier. After being cooled, desiccant 20 flows along first supply conduit 122 and being sprayed on the topside of the dehumidifier 100 after being cooled by third heat exchanger 730.

[0061] In step 1050, the desiccant is transferred from the dehumidifier to the regenerator. Once the concentration of the desiccant 20 in dehumidifier 100 (in vessel 106) drops to about 25% and below, about 80% of the desiccant 20 in dehumidifier 100 may be pumped by a pump 140 into the diluted desiccant reservoir 520 via desiccant transfer conduit 110. During this process, the remaining about 20% of desiccant 20 (diluted desiccant) may be kept in the dehumidifier 100 to keep the dehumidifier working without disruption. Desiccant 20 may then be transferred from diluted desiccant reservoir 520 to regenerator 200. About 80% of the diluted desiccant 20 in the diluted desiccant reservoir 520 may be transferred from the diluted desiccant reservoir 520 to regenerator 200. A valve 522 adapted to control flow between diluted desiccant reservoir 520 and regenerator 200 and

located along desiccant transfer conduit 110 may be opened to transfer about 80% of the diluted desiccant 20 from the diluted desiccant reservoir 520 to regenerator 200.

[0062] In step 1060, the desiccant is regenerated by removing vapour from the desiccant by a regenerating airflow. Desiccant 20 may be sprayed at about the topside of the regenerator 200 to interact with the regenerating airflow 280 to remove vapour from the desiccant 20.

[0063] In step 1070, the desiccant is channelled out of the regenerator. In the regeneration process, the cycle starts by pumping desiccant 20 out of regenerator 200 by a pump 150. Pump 150 may be attached along second transfer conduit 220.

[0064] In step 1080, the desiccant is heated. Desiccant 20 pumped out of regenerator 200 flows along second transfer conduit 220 towards first heat exchanger 710 to heat the desiccant 20 when desiccant 20 flows through first heat exchanger 710. Thereafter, desiccant flow along second transfer conduit 220 towards fourth heat exchanger 740 and may be heated by fourth heat exchanger 740.

[0065] In step 1090, the heated desiccant is channelled into the regenerator. After being heated, desiccant 20 is channelled back to regenerator 200 and sprayed onto the packing column 212 of regenerator 200.

[0066] In step 1100, regenerated desiccant is supplied from the regenerator to the dehumidifier. Once concentration of the desiccant 20 in regenerator 200 reaches to about 40% and above, about 80% of the desiccant 20 in the vessel 206 of regenerator may be pumped by a pump 160 into concentrated desiccant reservoir 510. During this process, the remaining about 20% of desiccant 20 (concentrated desiccant) may be kept in the regenerator 200 to keep regenerator 200 working without disruption. Desiccant 20 or concentrated desiccant may be supplied to the dehumidifier 100 from the concentrated desiccant reservoir 510. A valve 512 adapted to control flow between concentrated desiccant reservoir 520 and dehumidifier 100 and located along desiccant supply conduit 210 may be opened to supply about 80% of concentrated desiccant from the concentrated desiccant reservoir 520 to the dehumidifier 100.

[0067] An effect of the dehumidifying system 10 being integrated with air cooling system 800 may be the application of low grade heat such as waste heat from compressor 852 which may not be used in conventional dehumidifying system for regeneration. Dehumidifying system 10 may reduce the regeneration temperature to less than about 55°C and may substantially increase the system Coefficient of Performance (COP) to at least 3 by recovering the waste heat from compressor 852.

[0068] Regeneration of desiccant depends heavily on the operation of air conditioning system 850, e.g. HVAC system. During night time, outdoor air has low temperature and high relative humidity. With LDDS, air conditioning system 850 may work at off-peak mode and less waste heat can be supplied to regenerator 200, thus resulting in much slower regeneration rates. However, dehumidification load may still be large due to high relative humidity. Concentrated desiccant reservoir 510 and diluted desiccant reservoir 520 may store the concentrated and diluted desiccants, respectively, such that the concentrated desiccant regenerated during peak operating hours can be used for dehumidification during the off-peak hours.

[0069] Large buildings normally have chillers located at the plant room and many air handling units (AHU) for different zones to treat the air. For conventional LDDS, dehumidifier and regenerator may be installed together in order to facilitate the exchange of concentrated and diluted desiccants. Dehumidifying system may have a reservoir for each tower and thus allowing the regenerator to be located near the chiller to use wasted heat for regeneration while the dehumidifier may be distributed with different AHUs to handle the latent load. In this way, the centralized regeneration at plant room and distributed dehumidification at AHU rooms is made possible.

[0070] In the dehumidifying system, the concentration span in each tower is about 10%. For energy efficient operation, automation technologies, including modelling, automatic start/stop logic, performance monitoring, control and optimization, may have been developed. The model may use self-turning controllers and optimize the system performance during the operation. The optimization and dynamic control technologies may ensure that the dehumidifying system may be integrated under different working conditions and may always be running most efficiently, smoothly and safely.

[0071] The energy savings from the dehumidifying system with applications to the mass building HVAC market may be tremendous and may commercially viable.

[0072] Experimental Results

[0073] A first test for heat exhausted from compressor through a mechanical refrigeration cycle test bed (refrigerant R134a) was conducted. In Fig. 10, the test results show that if the cooling load is no less than half of the max cooling capacity, the heat of 60°C or above can be recovered from the outlet of the compressor which may be used for regeneration if the regeneration temperature can be kept around or below 60°C.

[0074] Next, a second test was carried out to find out about low temperature regeneration from initial desiccant concentration of 30% to the final desiccant concentration of 39% using the LDDS testing bed while keeping the desiccant locally circulated in the regenerator under the following conditions:

- 50°C regenerating temperature with the outdoor air (30°C and RH 80%);
- 50°C regenerating temperature with exhaust air (25°C and RH 55%);
- 50°C regenerating temperature with heated exhaust air (45°C and RH 18.7%);
- 60°C regenerating temperature with the outdoor air (30°C and RH 80%),
- 60°C regenerating temperature with the heated outdoor air (45°C and RH 35.41%);

[0075] Fig. 11 shows the testing results from the second test. It is shown that, with desiccant locally circulated, desiccant may be concentrated to about 40% even at 50°C regenerating temperature and humid outdoor air. However, the regeneration rate is lower than that of absorption. Additional, concentrated desiccant will be needed in dehumidifier. In addition, the regeneration rate increases when less humid building exhaust air is used to regenerate the desiccant. Also, the regeneration performance can be improved if both outdoor air and building exhaust air is heated, waste heat from compressor may be used as the energy source. If regeneration temperature is increased to 60°C, the regeneration rate is higher than the absorption rate even with untreated outdoor air. An additional advantage of

using heated air is that the temperature drop in desiccant is smaller, thus reducing the energy used in heating up the desiccant.

[0076] A third test is performed to test the performance of dehumidifier using the LDDS testing bed while keeping the desiccant locally circulated in the dehumidifier. For mass building HVAC applications, the humidity of dehumidifier outlet air is normally controlled at around 8.8g/(kg dry air) (relative humidity around 45% at 25°C).

[0077] A fourth test is performed to test the performance of heat pipe heat exchanger and its effect on the regeneration rate using the LDDS testing bed combined with heat pipe heat exchanger. For a heat pipe heat exchanger with 8 rows of pipes, the heat recovery efficiency is 50%. The regeneration speed is increased by about 30% when the desiccant concentration is from 25% to 37%.

[0078] Fig. 12 shows the testing results for the third test. Three factors will affect the outlet air humidity, namely, desiccant concentration, flow rate and temperature for a given supply air flow rate. If the range of desiccant concentration is fixed between about 28%-36.5%, the outlet air humidity can be controlled by adjusting the temperature in the range about 16-32°C and flow rate in the range 17-29L/min, respectively.

Claims

1. A dehumidifying system comprising

a dehumidifier having a desiccant, the dehumidifier configured to dehumidify a process airflow, the dehumidifier having a dehumidifier inlet and a dehumidifier outlet connected to the dehumidifier inlet wherein the desiccant is configured to flow out of the dehumidifier via the dehumidifier outlet and to enter the dehumidifier via the dehumidifier inlet;

a regenerator configured to regenerate the desiccant, the regenerator having a regenerator inlet and a regenerator outlet connected to the regenerator inlet wherein the desiccant is configured to flow out of the regenerator via the regenerator outlet and to enter the regenerator via the regenerator inlet;

a cooler connected to the dehumidifier designed to cool the desiccant before the desiccant enters the dehumidifier via the dehumidifier inlet;

a heater connected to the regenerator designed to heat the desiccant before the desiccant enters the regenerator via the regenerator inlet;

a desiccant transfer conduit connected to the dehumidifier and the regenerator; and

a desiccant supply conduit connected to the dehumidifier and the regenerator;

wherein the desiccant transfer conduit and the desiccant supply conduit forming a desiccant transfer loop through the dehumidifier and the regenerator, wherein the desiccant loop is configured to provide transfer of desiccant from the dehumidifier to the regenerator via the desiccant transfer conduit and supply of desiccant from the regenerator to the dehumidifier via the desiccant supply conduit;

a concentrated desiccant reservoir for storing the desiccant, the concentrated desiccant reservoir being disposed along the desiccant supply

conduit, wherein fluid communication is established between the concentrated desiccant reservoir and the dehumidifier and between the concentrated desiccant reservoir and the regenerator via the desiccant supply conduit, wherein the desiccant supply conduit is adapted to supply the desiccant from the regenerator to the dehumidifier via the concentrated desiccant reservoir;

a diluted desiccant reservoir for storing the desiccant, the diluted desiccant reservoir being disposed along the desiccant transfer conduit, wherein fluid communication is established between the diluted desiccant reservoir and the dehumidifier and between the diluted desiccant reservoir and the regenerator via the desiccant transfer conduit, wherein the desiccant transfer conduit is adapted to transfer the desiccant from the dehumidifier to the regenerator via the diluted desiccant reservoir;

wherein the diluted desiccant reservoir is thermally connected to the concentrated desiccant reservoir, wherein heat is transferrable between the diluted desiccant reservoir and the concentrated desiccant reservoir.

2. The dehumidifying system of claim 1, further comprising a first transfer conduit connected to the dehumidifier via the dehumidifier outlet and the cooler, the first transfer conduit being designed to establish fluid communication between the dehumidifier and the cooler, a first supply conduit connected to dehumidifier via the dehumidifying inlet and the cooler, the first supply conduit being designed to establish fluid communication between the dehumidifier and the cooler, the first transfer conduit and the first supply conduit forming a dehumidifying loop through the dehumidifier and the cooler, wherein the dehumidifying loop is configured to provide flow of desiccant from the dehumidifier to the cooler via the first transfer conduit, through the cooler to cool the desiccant and back into the dehumidifier via the first supply conduit.
3. The dehumidifying system of claim 1 or 2, further comprising a second transfer conduit connected to the regenerator via the regenerator outlet and the heater, the

second transfer conduit being designed to establish fluid communication between the regenerator and the heater, a second supply conduit connected to the regenerator via the regenerator inlet and the heater, the second supply conduit being designed to establish fluid communication between the regenerator and the heater, the second transfer conduit and the second supply conduit forming a regenerating loop through the regenerator and the heater, wherein the regenerating loop is configured to provide flow of desiccant from the regenerator to the heater via the second transfer conduit, through the heater to heat up the desiccant and back into the regenerator via the second supply conduit.

4. The dehumidifying system of claim 1, wherein the diluted desiccant reservoir is connected to the concentrated desiccant reservoir via a finned plate.
5. The dehumidifying system of any one of claims 1 to 4, further comprising an airflow channel connecting the dehumidifier to the regenerator thereby establishing fluid communication between the dehumidifier and the regenerator, wherein the airflow channel is adapted to channel the process airflow from the dehumidifier into the regenerator.
6. The dehumidifying system of claim 5, further comprising a first heat exchanger in thermal communication with the airflow channel and the second transfer conduit, wherein the first heat exchanger is designed to provide transfer of heat from the process airflow along the airflow channel to the desiccant along the second transfer conduit.
7. The dehumidifying system of claim 5 or 6, further comprising a second heat exchanger in thermal communication with the cooler and the airflow channel, wherein the second heat exchanger is designed to provide transfer of heat the process airflow along the airflow channel to the desiccant through the cooler.

8. The dehumidifying system of any one of claims 2 to 7, further comprising a third heat exchanger in thermal communication with the cooler, the first transfer conduit being connected to the third heat exchanger and the dehumidifier to establish fluid communication between the dehumidifier and the third heat exchanger, the first supply conduit being connected to the third heat exchanger and dehumidifier to establish fluid communication between the dehumidifier and the third heat exchanger, wherein the first transfer conduit and the first supply conduit forming the dehumidifying loop through the dehumidifier and the third heat exchanger, wherein the dehumidifying loop is configured to provide flow of desiccant from the dehumidifier to the third heat exchanger via the first transfer conduit, through the heat exchanger to cool the desiccant and back into the dehumidifier via the first supply conduit.
9. An air cooling system comprising
- a dehumidifying system as claimed in any one of claims 1 to 8;
 - an air conditioning system comprising,
 - a compressor for compressing a refrigerant;
 - a condenser adapted to condense the refrigerant from the compressor from a vapour state into a liquid state;
 - a vapour conduit connected to the compressor and the condenser for establishing fluid communication between the compressor and the condenser;
 - an evaporator in fluid communication with the condenser, the evaporator for evaporating the refrigerant from the condenser from a liquid state to a vapour state;
 - wherein the heater of the dehumidifying system is in thermal communication with the vapour conduit, wherein the heater is configured to

receive heat from the vapour conduit, wherein the desiccant through the heater receives heat from the refrigerant in the vapour conduit;

wherein the cooler of the dehumidifying system is in thermal communication with the evaporator, wherein the cooler is configured to be cooled by the evaporator, wherein the desiccant through the cooler is cooled by the refrigerant through the evaporator.

10. The air cooling system as claimed in claim 9, wherein the cooler in the dehumidifying system is the evaporator, wherein the second heat exchanger is in thermal communication with the evaporator.
11. The dehumidifying system of claim 9 or 10, further comprising a fifth heat exchanger in thermal communication with the second heat exchanger wherein chilled water from the second heat exchanger cools the fifth heat exchanger such that the fifth heat exchanger is designed to cool the desiccant along the dehumidifying loop.
12. The dehumidifying system of any one of claims 9 to 11, further comprising a heat pipe heat exchanger connected to the inlet and outlet of the regenerator, the heat pipe heat exchanger being designed to heat up the regenerating airflow of regenerator before entering the regenerator.
13. A method of dehumidifying a process airflow comprising
dehumidifying the process airflow by a desiccant in a dehumidifier;
channelling the desiccant out of the dehumidifier;
cooling the desiccant;
channelling the cooled desiccant into the dehumidifier;
transferring the desiccant from the dehumidifier to the regenerator comprising,

channelling the desiccant from the dehumidifier into a diluted desiccant reservoir and channelling the desiccant from the diluted desiccant reservoir into the regenerator;

regenerating the desiccant by a regenerating airflow;

channelling the desiccant out of the regenerator;

heating the desiccant;

channelling the heated desiccant into the regenerator;

supplying the regenerated desiccant from the regenerator to the dehumidifier comprising,

channelling the desiccant from the regenerator into a concentrated desiccant reservoir and channelling the desiccant from the concentrated desiccant reservoir into the dehumidifier;

wherein the diluted desiccant reservoir is thermally connected to the concentrated desiccant reservoir, wherein heat is transferrable between the diluted desiccant reservoir and the concentrated desiccant reservoir.

14. The method of claim 13, wherein channelling the desiccant out of the dehumidifier includes channelling the desiccant into and along a first transfer conduit and channelling the desiccant into the dehumidifier includes channelling the desiccant from a first supply conduit and into the dehumidifier, wherein the desiccant is cooled by a cooler when the desiccant flows from the first transfer conduit, through the cooler and into the first supply conduit.
15. The method of claim 13 or 14, wherein channelling the desiccant out of the regenerator includes channelling the desiccant into and along a second transfer conduit and channelling the desiccant into the regenerator includes channelling the desiccant from a second supply conduit and into the regenerator, wherein the

desiccant is heated by a heater when the desiccant flows from the second transfer conduit, through the heater and into the second supply conduit.

16. The method of any one of claims 13 to 15, further comprising channelling the process airflow from the dehumidifier into the regenerator.