THERMO-CHEMICAL HEAT PUMP

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Summary

Reason for Technology Implementation: The thermo-chemical heat pump geothermal—based process should provide environmentally safe and renewable baseline electrical power at costs less than other technologies. It can be employed on a large scale. Utilization of heated water surfaced from Texas presently drilled oil and gas wells has potential to provide 2,000 megawatts electrical generating capacity. Further, the process may give economic life to wells that have past their fossil fuel delivery usefulness.

Technology: Lower temperature liquids from existent sources can be used to produce higher temperatures suitable for electricity generation. The liquids heat exchange with air thereby raising its temperature while the air is maintained saturated with water. Desiccant is employed to raise the temperature of the moisture-saturated air by its dehumidification. This air may be employed directly or exchange its heat with turbine loop fluids.

Technology Status: The technology has been advanced during the past 20 years with over 40 patents granted internationally and three additional including the heat pump are pending. All except one proprietary module of the thermo-chemical heat pump have had commercial application.

Commercialization: The patent pending technology is to be licensed to an entity with technology and commercial adequacies.

Why Geothermal Energy?

"Geothermal power – using the enormous heat generated in the earth's core by the radioactive decay of unstable elements - could prove to be the cleanest, greenest, and most abundant source of energy we have ever used."[1] "It currently produces 65 percent more power than solar and wind combined."[2] "In addition to the benefits, however, geothermal power also has some risks. The up-front investment required to start up a geothermal facility is very high, and the risk of the system's under-producing is non-trivial.[3]

Why Utilize Geothermal Water from Oil and Gas Wells?

Lower cost, risk reduction, and resource abundance. The wells are already drilled. Their characteristics have been plotted. The guess work of water flow and temperature has been removed. The USDOE Geothermal Technologies Program reports that more than 12 billion barrels of water are currently produced each year from oil and gas wells in Texas.[4] The *Oil and Gas Journal* reports the possibility of generating 500MW up to 2,000 MW of electricity from existing Texas oil and gas wells.[5] These studies are based on a minimum acceptable well head temperature. For example, a Southern Methodist University Geothermal Laboratory report limits review of geothermal electrical production from hydrocarbon wells to temperatures above 225°F.[6]

Why Elevate Geothermal Water Temperature?

First, the resource base is expanded. A plot of temperature-depth points from over 5,000 wells in eight Texas counties placed the highest concentration of wells with liquid temperatures between 160°F and 225°F [7]. Second, process efficiency is significantly improved. As discussed later, elevation of top process temperature from 225°F to 345°F increases theoretical efficiency by 60%. Together, resource expansion and temperature elevation should allow increased potential of geothermal fluids utilization for electricity production.

Electrical Supply

The need for electricity is projected to jump by 50% by 2030.[8] Present electricity production is dominated by coal, gas, and nuclear. Gas is not a long term option as the US Energy Information Administration reports natural gas to be supply limited with expected growth to be only two percent per year through 2030 with this growth derived from imports of LNG.[9] Nuclear expansion is uncertain. According to the Oxford Research Group “Another way of putting it is to say that if all the electrical energy used today were to be obtained from nuclear power, all known useful reserves of uranium would be exhausted in less than three years.” [10] This leaves coal as the fall-back energy source. The “Christian Science Monitor” states the United States is on track to add 72 coal-fired plants in the next eight years and 1,200 300 megawatt power plants over the next 25 years.[11] This may not be an economical fix. There will probably be rulings regarding CO_2 capture that will drive up costs. An 800 megawatt plant consumes 2.5 million tons of coal per year leading to emission of 6 million tons of carbon dioxide.[12] The Electric Power Research Institute places the cost of power to be 60 to 80% higher as a result of CO_2 capture and sequester.[13] This is supported in a report by MIT which estimates expenditures of $30 per ton (America’s utilities produce 1.5 billion tons a year) with the cost of coal-based electricity increasing from $0.05 to $0.08 per kilowatt hour.[14] Additionally, the price of coal is increasing. Merrill Lynch reports the 2008 contract price of coal for Asian utilities has increased from $55 per ton to $135 a ton in the past year.[15]

Electric power from renewable sources is either baseline such as hydro and geothermal or intermittent such as or wind or solar. In value to the electrical grid, baseline generation is worth three to four times the indefinite supplies. Beyond irregularity, wind peaks in the hour after midnight. “Transmission lines are rated for the peak load that a wind farm might produce… In Texas, wind farms use just 8% of their grid capacity because it’s often blowing at the wrong time.”[16] Photovoltaic or thermal solar power follows human living patterns but peaks nearly three hours before maximum summer grid loading.[17] Capital costs of wind and solar are based on “nameplate” capacity, where it appears that capital costs are similar to costs of a coal-fired plant. Recent reported price reductions for wind and solar towards $1.00 a kilowatt for equipment plus another $1.00 for installation[18] do not represent true capital costs. The reason is dictated by nature. Wind is effective 30% of the time[19] so real capital costs are not $2.00 but rather $6.70 a kilowatt or $6,700 a megawatt. Solar is slightly worse, being effective 25% to 30% of the time.[20] Also, there are grid problems. As reported in *The Economist*, “Parts of America’s dumb and fragmentary electricity grid are so vulnerable to load variations that their owners think they may be able to cope with no more than about 2% of intermittent wind power.” [21]

Effective capital costs per kilowatt for geothermal electrical plants are somewhat lower owing to an operational rate of 90% to 95%. A recent 13 megawatt project was constructed in Nevada with capital costs being $4.00 per kW. The majority of the costs related to permitting, site preparation, and the drilling of multiple hot water supply and reinjection wells.[22] Cost of the turnkey power plant including heat exchangers, dual stage turbines and generator set was $1.70 per kilowatt[23] that when adjusted for effective usage becomes $1.85. Turbine and generator sets in the 250 kW range are marketed at approximately half this cost owing to use of a modified mass produced air conditioner chiller.[24]

Geothermal Efficiency Improvements

As postulated by Sadi Carnot in 1824, theoretical efficiency of heat engines relates to the spread between the high and low process temperatures. One calculation method takes the highest temperature less the minimum temperature with the resultant divided by absolute temperature (460°F) plus the highest temperature. For electrical generation the minimum temperature is related to cooling water which is generally assumed to be approximately100°F. The minimum high temperature assumed by Southern Methodist University Geothermal Laboratory is 225°F.[16] At these conditions maximum efficiency would be 18% (225 less 100 divided by 225 plus 460). Were this 225°F increased to 345°F through employment of the heat pump, maximum efficiency increases to 30%, This represents an improvement of 67% allowing a similar reduction in turbine and generation equipment size. Additionally, lower temperatures become practical. For instance, 185°F is calculated to increase to 345°F and 160°F to 275°F. The upward temperature increase has been limited by the desiccant presently employed and may be expanded in the future.

Adiabatic Processes

The heat pump is an offshoot of a very ancient technology. Hanging wetted sheets in air flows to reduce temperatures was documented in the Middle East some 4,500 years ago. This activity is now known as evaporative cooling and the exchange is referred to as “adiabatic” as there is no energy change in the air. In thermodynamics this process of changing moisture for heat is known to be reversible. Adding moisture to air will cause its temperature to reduce. Conversely, removing moisture from the air will cause its temperature to increase. In the first, air is subjected to water; in the second, air is in contact with a desiccant. The technology employed herein makes use of both but also changes energy content of the air by adding and taking away heat.

Heat Pump Structure

A process to utilize a range of low temperature resources (140 degrees to 225 degrees F) to produce elevated temperatures (to 345 degrees) suitable for electrical power generation is described. As seen in the following diagram, temperature elevation is accomplished by maintaining a saturated airflow while extracting energy from the low temperature resource. This higher temperature saturated air is subjected to a counter-current flow of liquid desiccant that provides an adiabatic exchange by absorbing moisture from saturated air thereby elevating its temperature.

The high temperature air exchanges heat with the second closed loop that supplies energy to the turbine. The air, with a reduced energy, is cycled to again contact the low temperature resource. An ambient air stream, once heated by the low temperature resource to reduce its relative humidity, is utilized to evaporate moisture from the desiccant.

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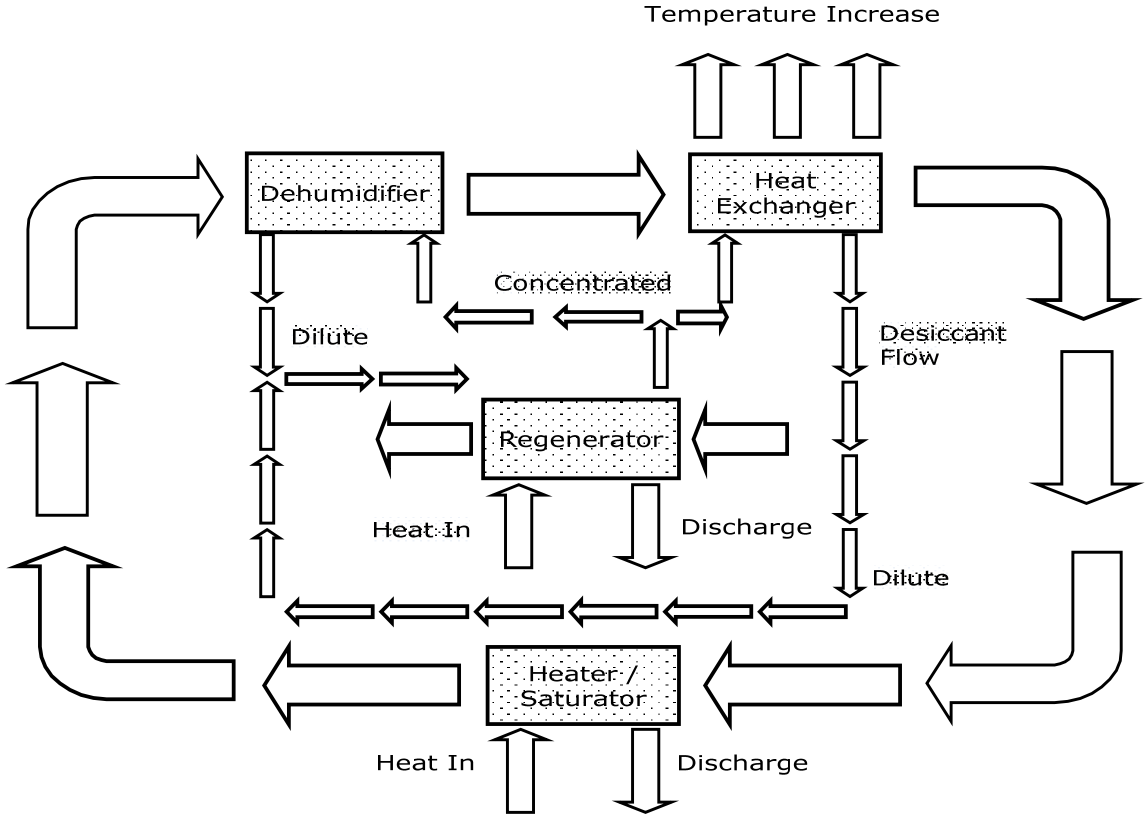
The thermo-chemical heat pump is projected to utilize 300 GPM to provide generation of 250 kW using a 185°F feed-stock elevated to 340°F (detailed in Appendix 1). A reduced temperature resource of 160°F allows the temperature increase to the turbine loop to 275°F The high temperature air exchanges heat with the second closed loop that supplies energy to the turbine. The air, with a reduced energy, is cycled to again contact the low temperature resource. An ambient air stream, once heated by the low temperature resource to reduce its relative humidity, is utilized to evaporate moisture from the desiccant. (Appendix 2) The resource flow rate can remain at approximately 300 gallons per minute for generation of 250 kW.

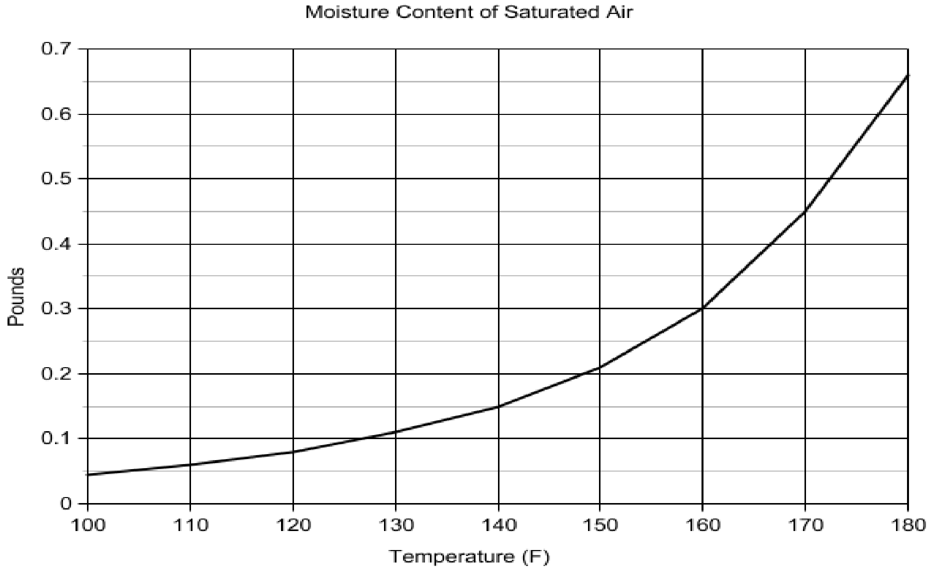


Process Detail

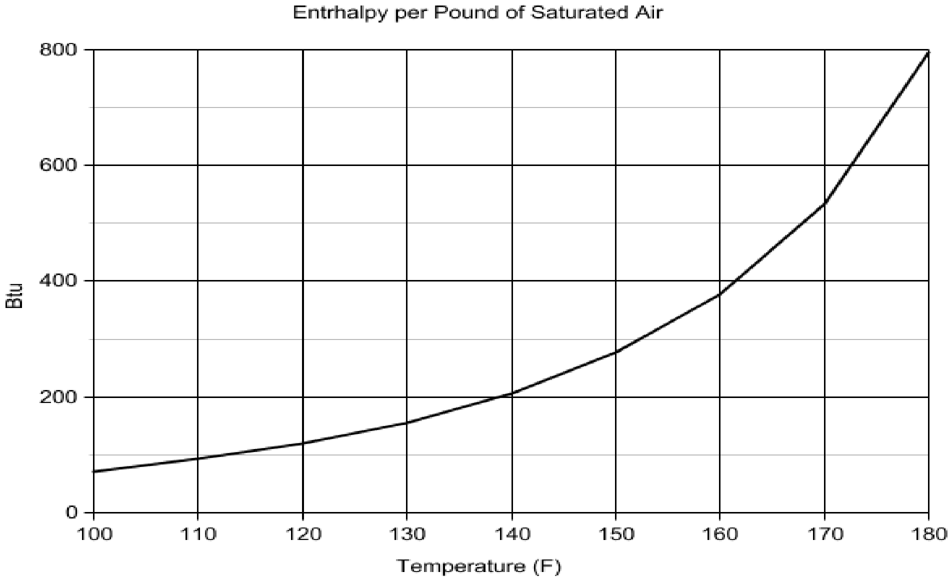
The process employees a gas stream of generally air but may include other gas such as carbon dioxide, nitrogen or helium. This gas circulates through the device and operates under nearly constant pressure with pressure change caused by frictional losses. The gas is used as a sensible and latent heat transfer media. As is generally understood, heat transfer is the movement of energy that cools or heats a fluid (liquid or gas) or evaporates a liquid or condenses a vapor that exchanges through a gas/liquid interface. Mass transfer is the movement of an evaporating liquid from the liquid phase into the gas phase or movement of a condensing vapor from a gas phase into the liquid phase.

In the first instance of its flow through the process, the air is saturated by being contacted with water. As employed herein, saturated air is a mixture of dry air and water vapor at its maximum concentration for the prevailing temperature and pressure. A gas in this context is referred to as saturated when vapor pressure of the water in the air is at the equilibrium vapor pressure for water vapor at the temperature of the gas and water mixture. Heat exchange of this air with a thermal resource occurs in the heater / saturator. Heat exchange may be may be direct or indirect. In the direct mode, which is preferred owing to its simplicity and inexpensive cost, contact not only raises the air temperature but evaporates water vapor into the air as the saturation condition of the air continually changes. In the indirect mode there is separate heat exchange between the thermal source and the air while saturation at increasing temperatures is caused by contact with a dedicated wetting means. In either case, the closest temperature approaches between the air and the thermal source are created if the two streams pass counter-currently one to the other.

Air saturation temperatures required for operation are far in excess of those typically encountered. For instance, at the harsh climatic test of 95°F and 40% relative humidity mentioned earlier, moisture content is 0.014 pounds of water per pound of air. In typical air conditioning operation this level is reduced such that interior space is maintained at approximately 0.011 pounds. For reference, a "pound" of air represents approximately 15 cubic feet or a cube 2.5 feet per side. The following graph displays moisture content of elevated saturated air temperature range from 100°F to 180°F. At 100°F, for example, air has a saturated moisture content of approximately 0.04 pounds water per pound of air, while at 180°F, moisture content is 0.66 pounds.



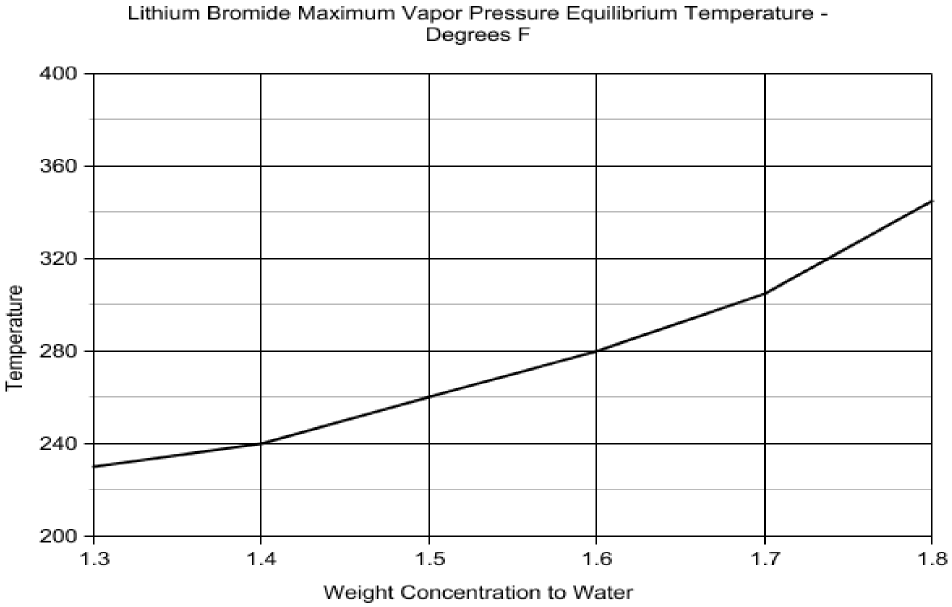
Energy content of saturated air greatly increases concurrent with its rise in temperature. This energy, spoken of as specific enthalpy, is the sum of the heat of the air and as well as the water vapor contained therein. Enthalpy is given in joules per kilogram of air or in Btu per pound of air. The enthalpy content of saturated air at higher temperatures is generally overlooked in the literature. As seen in the graph just shown, at 180°F the enthalpy of a pound of air is nearly 800 Btu, a level that represents 70% the enthalpy contained in a pound of steam.



Upon reaching the desired temperature and enthalpy level as found in the upper ranges of the above charts, the saturated gas exits the heater / saturator and contacts a liquid desiccant which is a hydroscopic substance capable of removing moisture from the air stream in a dehumidification module. Removal of water from air in this context is an adiabatic process and in thermodynamics, an adiabatic process is one in which the specific enthalpy (energy) of the air remains constant.

Continuous desiccant dehumidification can be accomplished using solid packed towers, rotating horizontal beds, multiple vertical beds, rotating wheels, as well as liquid desiccant approaches employing vertical spray towers or wetted media. Moisture reduction per volume of air utilized by the process can be up to 30 times greater than found in commercial dehumidification applications. Thus, the desiccant removal mechanism should possess multiple stages. Desiccant concentrations and their effects on the behavior of air streams are more easily determinable when employing liquid desiccant, which at present, is the desiccant of choice. As the process can operate as an open system exhausting air to the environment, efforts have been limited to desiccants that pose insignificant environmental risk. A liquid desiccant of choice has been lithium bromide.

The graph on the following page displays concentrations of lithium bromide solution as compared with water. The upper limits of its affinity for moisture absorption can be referred to as the equilibrium point between the vapor pressures between the vapor pressures of the gas and liquid. For instance, balance at a1.5 concentration is 260°F while at 1.8 balance exceeds 260°F.



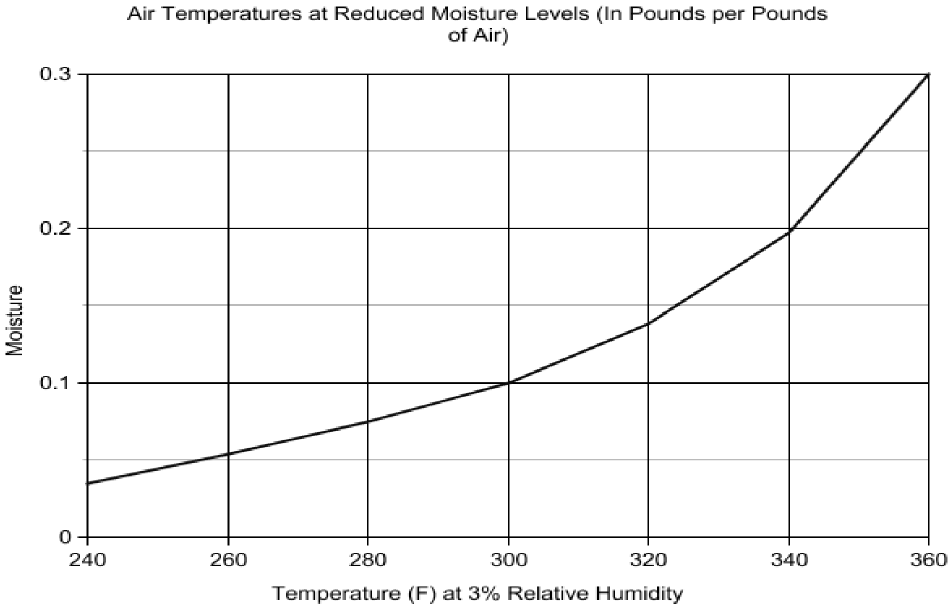
Mixtures of air and water vapor are the most common systems encountered in psychrometry, a study of their physical and thermodynamic properties. A psychrometric chart graphically expresses the ways various properties relate to each other. When following the calculated line for enthalpy, for example, a 80°F saturated air stream (100% relative humidity) contains the same energy were it 145°F and 5% relative humidity. Along with the increase in air temperature, the amount of moisture in the air has reduced from 0.022 pounds of water per pound of air to 0.008. As used herein, relative humidity is the amount of water vapor actually in the air divided by the amount of water vapor the air could hold. Relative humidity can be calculated by dividing actual vapor pressure by saturation vapor pressure.

As viewed in the following graph, temperatures generated by adiabatic dehumidification are dependent upon the initial moisture available. For example and as found in the first graph, saturated air at 140°F contains 0.15 pounds of water per pound of air.

Temperature of this air can be raised to 325°F when adiabatically dehumidified to three per cent relative humidity. Likewise, saturated air at 160°F holding 0.3 pounds of water per pound of air will increase in temperature to 360°F at three percent relative humidity.

Following adiabatic dehumidification, the heated air moves from the dehumidifier. In certain applications this heat may be used directly. Generally the useful heat is heat exchanged with a cooler liquid or gas in the heat exchanger. When cooling, the air saturates at a relatively high temperature with an exit per the above example at 170° with enthalpy content of 533 Btu. Heat transfer is the difference between 645 and 533

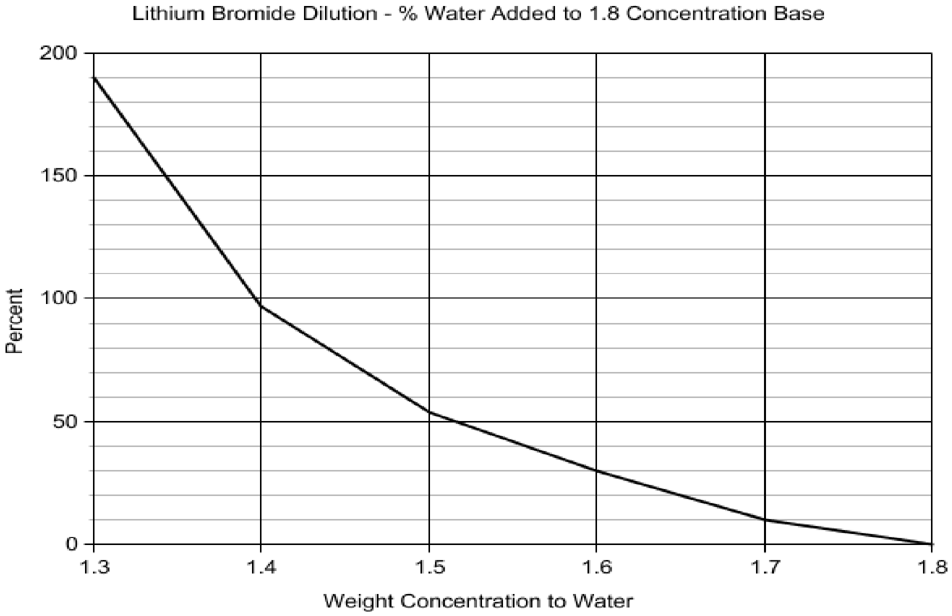
Btu giving 112 Btu per pound of air. As the adiabatic changes to the air tend to cancel, on a theoretical basis energy transferred to the saturated air stream from the thermal source approximates that removed by heat transfer to the cooler liquid or gas.



The air may be continually dehumidified in a continuous or staged manner, again working with relative humidity equilibriums. In this mode of operation, the air temperature may be heat exchanged with the cool liquid or gas to a much reduced temperature. Looking to the above example, the five percent relative humidity of the 345°F air becomes 10% at an air temperature of 295°F allowing further moisture removal by the desiccant. Were this procedure continued to an air temperature of 120°F and 90% relative humidity, the enthalpy content would reduce to 110 Btu per pound of air. Heat transfer to the cooler fluid would now be calculated as 645 less 110 or 545 Btu per pound of air. Concurrently, moisture removal from the air has increased from 0.07 to 0.39 pounds per pound of air. Following heat exchange the gas passes through an air movement blower and then returning to the heater / saturator.

In certain instances, dehumidification performed of the saturated air can be combined with the heat exchanger so that the saturated air stream from the heater / saturator can be dehumidified and raised in temperature while concurrently exchanging heat with the turbine loop fluid.

The employment of desiccants is largely throughout their absorption range. Saturated air exiting contact with the thermal resource may be contacted with a desiccant capable of reducing the air saturation level from 100% to 90%. Again suggesting the counter-current arrangement of the air and the desiccant, an air stream relative humidity may range from approximately five percent to 90%. This range provides for considerable change of desiccant concentrations. When looking at lithium bromide, the amount of water absorbed greatly increases as the desiccant dilutes. Seen in the graph following,



movement from the 1.8 concentration (utilized as the measurement base) to a concentration of 1.7 causes the addition of only 11% more water whereas the dilution from 1.4 to 1.3 requires a dilution of 90%. Overall there is absorption of 190% when compared with an initial 1.8 concentration.

Partial removal of absorbed water from a dilute liquid desiccant may be accomplished by contacting the desiccant with a ambient air stream, especially in dryer climatic conditions. Supplemental heating of an ambient air stream significantly reduces the relative humidity levels. Using an earlier example, the harsh conditions of 95°F, 40% relative humidity would deliver a satisfactorily concentrated desiccant when heated to 180°F. Further moisture removal of moisture from the desiccant requires utilization of the heat source A device to remove moisture from the desiccant is generally referred to as a “regenerator”. Dilute liquid desiccant flows counter-currently to an air stream that has received heat from the low grade source. This temperature increase reduces the relative humidity of the air stream thereby allowing evaporation of moisture from the desiccant into the air.

All of the modules described above have a horizontal configuration with air flow parallel to their base and distribution of liquids from the top of the media and the liquid collected in basis below. A migratory flow of liquids between basins allows development of a distinct temperature and concentration profile. The media is similar to that found in evaporative coolers except modified for higher temperatures. The heater/saturator module allows direct contact between the low temperature resource and the air stream providing its temperature elevation and continual saturation. In the dehumidification module the air stream is directly contacted counter-currently by the desiccant. The module transferring heat to the turbine loop is more complicated as the high temperature and dry air is continually dehydrated as its temperature falls while giving up heat to the pressurized fluid within the turbine loop. The regenerator follows the same format. Size of modules is primarily dictated by air velocity through the media. The largest modules, the saturator and regenerator, would have an active face area 10 feet wide and 8 feet high with a media depth of 4 feet. These sizes would be for a system capable of transferring heat needed for generating 250 kW.

Footnotes

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