Elevating Geothermal Temperatures

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ABSTRACT

A method utilizing low temperature geothermal resources (170°F) to produce improved temperatures for electricity generation (345°F) is described. Liquid desiccant is employed adiabatically to raise the temperature of moisture-saturated air by its dehumidification. This air exchanges its heat with turbine loop fluids. Moisture removal from the desiccant by elevated temperature ambient air is discussed. The overall purpose of this method is to geographically expand geothermal resources available for power generation as well as improve their efficiency when using lower grade energy.

Geographic Limitation of Geothermal Resources for Electricity Generation

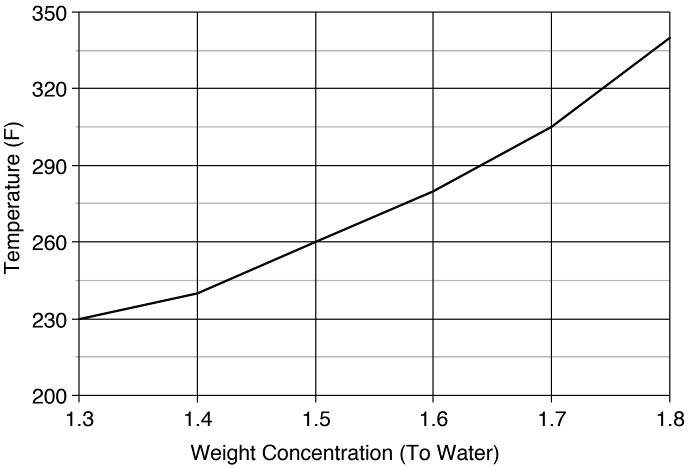
Minimum temperature of a commercial geothermal plant in the United States is reported by the Geo-Heat Center to be 220°F. (1) Steam plants are most cost effective when the resource temperature is above 347°F. (2) Furthermore, net plant efficiency increases from under seven percent to 12 percent as the resource temperature increases from 200°F to 350°F. (3) This temperature increase is projected to almost double efficiency for Kalina Cycle based installations. (4) A listing compiled by NREL showed 22 geothermal electric power sites located in four states; California, Hawaii, Nevada, and Utah. (5)

Expansion of Geothermal Resource Utilization

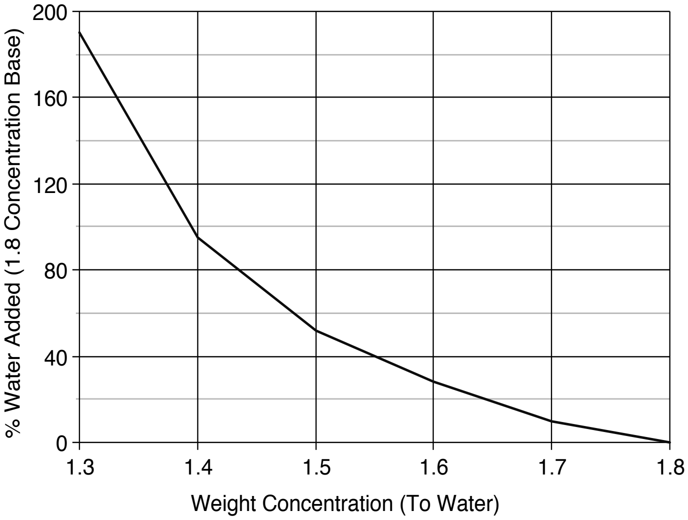
The process described herein allows utilization of geothermal resources as low as 170°F for electric power generation. Utilization would increase the number of sites as well as broaden the geographic areas available. Details of sites in lower temperature ranges are sketchy. The Thermal Springs list by the U.S. National Geophysical Center gave adequate temperatures in nearly 200 of the 1,661 hot springs listed with their locations found in 15 states (6) By intention, this list is limited as the entered hot water sources were restricted to be within piping range of populated areas for space heating purposes.

Adiabatic Alteration of Air Temperature

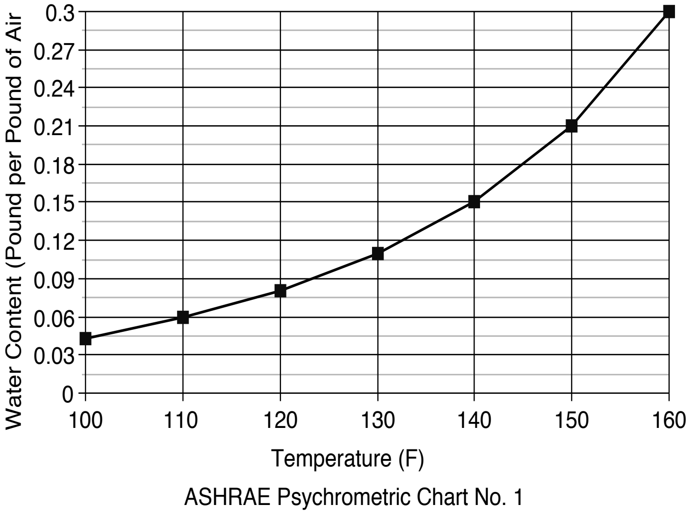
Evaporative-type coolers have been used in the West for nearly 100 years and for millennia in the Middle East using wet toweling hung in breezeways. While the energy contained in the air remains unchanged, an "adiabatic" switch occurs in these coolers between the moisture energy in the air and the heat energy in the air. For instance, a hot June day in Phoenix may show 105°F and 10% relative humidity. Were this air saturated with moisture, the delivery condition would be 64°F and 100% relative humidity. The same situation exists if water is removed from air. Assuming a spring rain with an air temperature of 50°F and 85% relative humidity, a strong liquid desiccant would adiabatically alter the condition to 77°F and 4% relative humidity.



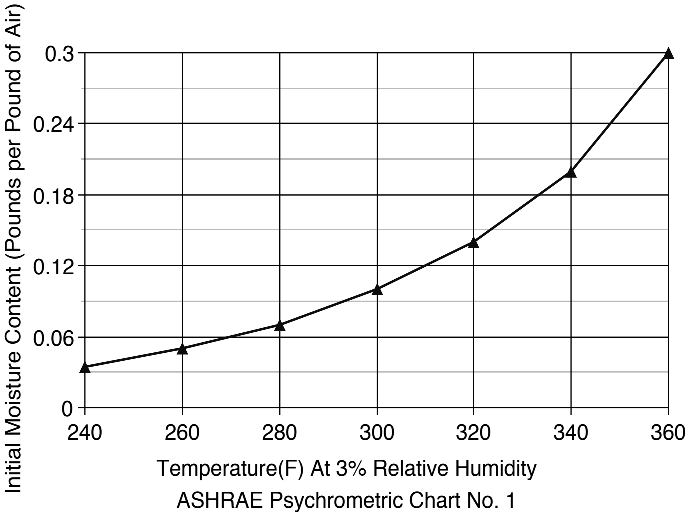
Graph 1. Lithium Bromide boiling temperature.



Graph 2. Lithium Bromide dilution.



Graph 3. Moisture content of saturated air.



Graph 4. Air termperatures at reduced moisture levels.

Liquid Desiccants

Schlumberger's oil industry liquid desiccant definition is as good as any: "A hygroscopic liquid used to remove water and water vapor from a gas stream". (7) Our group has been working with liquid desiccants since the mid 1980's. Many patents have been granted and certain products have been commercialized outside the United States. (8) As these products are "open" systems, efforts have been limited to desiccants that pose insignificant environmental risk. The liquid desiccant of choice has been lithium bromide. Over the years efforts have been made to expand the envelope of liquid desiccant knowledge. Increasing temperatures of air streams has been a primary interest. Graph 1 displays the concentration of lithium bromide solution compared with water with the highest concentration being 1.8. The concentration of the desiccant controls the point at which the desiccant no longer has an affinity for absorbing water and hence becomes stable. For instance, the balance at the 1.5 concentration is 260°F while at 1.7 the balance is over 300°F.

A 1.7 concentration will be 1.3 or less before it must be reconstituted. The amount of water absorbed greatly increases as the desiccant dilutes. As seen in Graph 2, 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.

Concentrated desiccant requires an adequate moisture supply in the air stream to allow sufficient moisture content to heat the air to elevated temperatures. Looking at Graph 3, moisture contained in saturated air steam is shown over temperature range from 100°F to 160°F. At 110°F, for example, air has a moisture content of 0.06 pounds water per pound of air. To construct perspective around a "pound" of air, at 100°F and 100% relative humidity for example, its volume is 15 cubic feet or a cube slightly under 2.5 feet per side. As viewed in Graph 4, temperatures generated by adiabatic dehumidification are dependent upon the initial moisture available. For example, saturated air 140°F containing 0.15 pounds of water per pound of air (Graph 3) can be raised in temperature to 325°F when adiabatically dehumidified to three percent relative humidity.

Process Schematic and Energy Flows

A simple schematic is shown as Figure 1. Entering saturated air (A) passes through a counter-current flow heat exchanger (B) receiving heat from air exiting the heating device. This heated and saturated air then enters heat exchanger (C) where it receives heat from the geothermal source (D) before flowing upward through media (E) and adiabatically exchanging moisture for heat with the gravity flow of desiccant (F). This heated passes through heat exchanger (G) giving up energy to turbine loop flow (H). Prior to exiting the system, the discharge air passes through heat exchanger (B). The desiccant regenerator (I), discussed later, removes absorbed water from the desiccant and accepts ambient air (AA) that is then heated

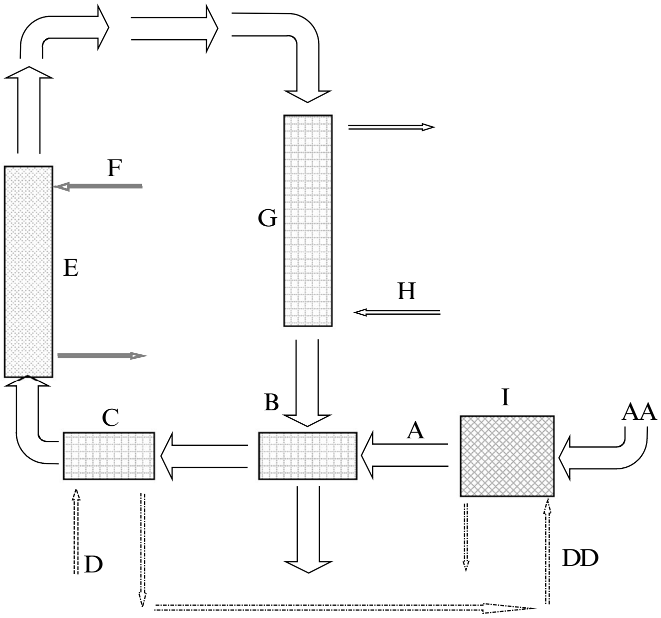


Figure 1. Process schematic.

by geothermal source (DD), a continuation of the flow exiting heat exchanger (C).

By way of example, 100°F saturated air (A) increases to 143°F saturated (0.169 pounds of water per pound of air and 225 Btu's) by heat exchange (B) with the exiting air stream. Gaining heat from 170°F geothermal water (D) air enters the desiccant column (E) at 155°F saturated containing 0.252 pounds of water and 322 Btu's. Air exiting this column contains the same enthalpy level but is reduced in moisture content to 0.197 pounds while gaining heat to 345°F. Heat exchange occurs with turbine loop (G) and the air begins to condense at 148°F and exits heat exchanger (B) at 105°F containing only 0.051 pounds of water and 81 Btu's per pound of air.

Per the example, gain in air temperature is from 100°F to 345°F; a level that is twice the temperature of the supplied geothermal resource. Geothermal heat requirement is the difference between the energy of the air entering and exiting or 322 less 225 or 97 Btu's per pound. Other thermal uses are relatively insignificant. An example includes heating the desiccant supply to 345°F. The moisture absorption by the desiccant is 0.055 pounds of water per pound of air (the difference between air entering and leaving the desiccant column). Allowing a 100% increase in desiccant volume, the beginning 1.8 desiccant concentration (Graph 2) would decrease to slightly less than 1.4. Returning to Graph 1, this desiccant could continue to absorb water until reaching a temperature 240°F, a level greatly in excess of process requirements. Concentrated lithium bromide has a heat capacity equal to one-half that of water (0.5 Btu's per pound of water per degree change). Assuming a temperature rise of 200°F, the heat requirement would be less than 6 Btu's.

Omitting unspecified thermal losses the energy requirements are 103 Btu's. Water energy is one Btu per pound of water per degree F. The entering geothermal water would have a 10°F temperature differential (170°F to160°F) which is maintained throughout the heat exchange indicating an exit temperature of 153°F. Water utilization is 103 Btu's divided by 17 degrees temperature change thus requiring six pounds or 0.7 US gallons to service the example requirements.

Moisture Removal from the Desiccant

Water to be removed from desiccant in the above example is 0.055 pounds per pound of air. Heat required to disassociate one pound of water from a lithium bromide solution is approximately 1,100 Btu's and varies with desiccant concentration. Experience with desiccant regenerators indicates an efficiency of approximately 60% (on a thermal basis) when sources are below 150°F. Thus gross energy requirements are 0.055 times 1,140 divided by 0.6 or 105 Btu's. The same six pounds of water is employed for desiccant regeneration. Assuming a 10 degree differential between the geothermal liquid and the desiccant within counter-current liquid-to liquid heat exchangers, the maximum temperature to an air stream used for regeneration would be 143°F and the exiting temperature would be 126°F. The humidity level selected is the one percent summer design point for Reno, Nevada holding 0.0052 pounds of water per pound of air at 92°F and 14% relative humidity. (9) This condition is similar to much of the western United States. (The one percent design point means that the climate design condition is only exceeded one percent of the time.) Air would exit the regenerator holding 0.040 pounds of water per pound of air. The difference of 0.035 indicates an air flow requirement of 1.6 pounds of air.

Multi-stage regenerators have been developed for use in liquid desiccant based air conditioners (10). These hot water regenerators contain four stages, with each connected to a plate heat exchanger, liquid distributor, heat exchange media and solution sump. Dilute desiccant enters the first stage of the regenerator where it is pumped through the heat exchanger for heat gain and distributed over the media. In contact with an air stream, moisture from the now high temperature dilute desiccant evaporates and removed together with latent heat by the air flow. The stronger desiccant collects in the solution sump and migrates to the next stage. The process is repeated in each stage providing for an ever-increasing desiccant concentration. Process flow, omitting air-to air exchangers to recover heat

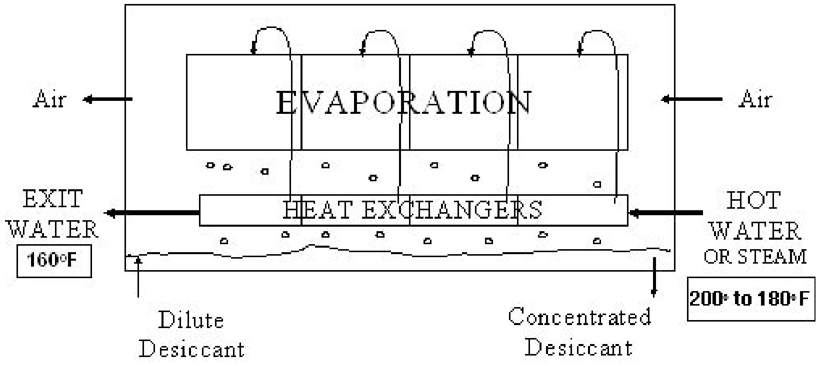


Figure 2. Desiccant Regenerator.

imparted to the air, is shown in Figure 2 with temperatures established for an air conditioning installation. A photograph of a commercial-sized desiccant regenerator constructed in China is shown following.

Hot Water Driven Regenerators

Air exiting the regenerator contains a moisture level centered about 0.040 pounds of water per pound of air. When saturated with water this air temperature ranges from 96°F to 100°F and serving as the supply to the heating device.

At design winter conditions for Reno, Nevada for instance, the relative humidity is 50% with a 1% design temperature is 13°F having an enthalpy content of four Btu's per pound of air. Water content is only 0.00076 pounds per pound of air. Desiccant regeneration requirements are met by increasing this air temperature to 85°F with energy content of only 21 Btu's per pound. This dry ambient air also allows the regeneration air flow to reduce to 1.4 pounds. Energy increase from this temperature to 100°F having energy content of 72 Btu's is by direct water saturation at elevating temperatures. Energy requirements can continue to be satisfied with the geothermal source exiting the heating device.

Electrical Requirements

Based on past experience, air pressure resistance through the heating device is approximately 0.3 inch water column for the desiccant media and 0.2.5 inches through each of the three heat exchangers or a total of one inch water column. The pressure resistance through known desiccant regenerators is 0.7 inch water column. In combination, when based upon a cubic foot per minute (CFM) basis, commercially available blowers give power requirements of 0.0055 horsepower. (12)

Further Development

The example presented is one of many higher or lower temperature sets that are available. Use of heat released by condensation within the turbine loop will be investigated. Alternate liquid desiccants providing higher absorption temperatures are to be examined.

Conclusion

The process provides elevation in temperatures above that available by directly using low grade geothermal sources. In operation, this geothermal energy is utilized to develop a moisture saturated air stream. A liquid desiccant is then employed to adiabatically to raise the temperature of this air by its dehumidification. The air then exchanges its heat with turbine loop fluids. Water is removed from the desiccant by warming ambient air with remaining heat from the geothermal source. An example is given wherein a 170°F geothermal source is utilized to produce 345°F heat. The rationale for developing this process is to geographically expand geothermal resources available for power generation as well as improve their efficiency when using lower grade energy.

Acknowledgement

Verification of desiccant behavior at high temperatures was accomplished by Gerald W. Niebur, an associated engineer with a physics background.

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