Efficient Solar Cooling
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BACKGROUND

Solar cooling has long been a desired goal in utilizing the solar resource for the benefit of people. The reasons are intuitive; the resource is well-matched to the load (high cooling demand days are usually sunny days) and if deployed on a roof, solar radiation that would otherwise heat the building is instead diverted to cool the building. However, the technical barriers to implementation are well-known. Efficient absorption cooling machines (double effect) require relatively high temperatures ~ 180 °C which is well beyond the range of flat plate solar collectors, while tracking collectors are problematic for building applications. Moreover, absorption machines operate in a relatively narrow range of temperature and do not respond well to the natural variability of solar insolation. Recently the availability of fixed, high temperature non-imaging collectors, and absorption chillers that are gas/solar hybrids have created a new paradigm in effective solar cooling.

Solar Collectors

The collector configuration is an evacuated tube receiver matched to an external non-imaging reflector, typically referred to as an XCPC. The XCPC provides solar concentration without moving parts that can achieve operating temperatures up to 200 °C. The design principle maximizes the probability that radiation starting at the receiver would be directed to a specific band in the sky for the double effect chiller to operate independent of natural gas. Through all of our experiments it has been observed that once the solar collectors provide enough energy at temperature the chiller solely ran on solar energy for the remainder of the day. The chillers operated in a relatively narrow range of temperature and did not require relatively high temperatures ~ 180 °C, which begins at 34% and grows to 40%. The thermal efficiency becomes higher during operation due to the entire system tending towards thermal equilibrium and reducing the heat loss. There are two critical variables to the chiller: the coefficient of performance, COP, and the outlet temperature of the chilled water. The double effect absorption chiller is designed to produce 7 °C water at a rated COP of 1.1. The average COP that we measured was 0.9, and the average outlet temperature of the chilled water was 7 °C. The outlet temperature graph and the COP graphs below represent this data. This proved to us that the double effect absorption chiller functioned very well with having the solar collectors as the power input. The power vs. operational time shows that the non-tracking XCPC evacuated solar collector array at Castle Air Force Base provides enough energy for the double effect chiller to operate independent of natural gas. Through all of our experiments it has been observed that once the solar collectors provide enough energy at temperature the natural gas does not need to be turned on until evening. It has also been shown that despite fluctuations with solar insolation the COP of the chiller is fairly constant.

The Chiller

The cooling machine is a commercial 6.6 U.S. refrigeration ton double-effect lithium bromide chiller. It is a hybrid system that is powered by natural gas or solar thermal energy to operate on solar energy the chiller requires 21 kWth energy at 175 °C. The following description is how this machine works. When liquid evaporates, it absorbs heat from its surroundings. Water boils at 100 °C under normal atmospheric pressure (760 mmHg), but it can also boil at very low temperatures under partial vacuum conditions. By creating a vacuum (6 mmHg pressure) in an airtight vessel, water can boil at 4 °C. There is a Lithium Bromide, LiBr, solution as the absorbent, water as the refrigerant and natural gas or solar as the heating source. As the LiBr solution is deliquescent water absorbent, it can absorb surrounding vapor and maintain a low pressure condition in the evaporator. Chilled water at 14 °C enters the copper tubes inside the evaporator and the refrigerant water at 4 °C is sprayed on the outside of the tubes, under partial vacuum. The refrigerant water absorbs heat from the chilled water and evaporates, becomes vapor, thereby the chilled water temperature is reduced to 7 °C. Concentrated LiBr solution in the absorber absorbs the refrigerant vapor and then transfers the heat from the vapor to the cooling water. The cooling water heat is released to the ambient air via the cooling tower. The diluted LiBr solution is pumped to the high temperature generator where it is reheated and refrigerant vapor evaporates from the solution making the solution concentrated. The concentrated solution repeats the absorbing process and the refrigerant vapor goes to the condenser where it is condensed and returns to the evaporator to begin the cycle again.

The System

The power of the double effect chiller we built a 21 kWth XCPC array, in north south orientation. The collectors are elevated 20’ from the horizon to the favor summer operation and are orientated 14’ west of south to favor operation later in the afternoon. The figure below is a process flow diagram of the solar cooling system. There are three loops in this system: the solar loop, the cooling water loop and the glycol loop. The glycol loop was added to avoid potential contamination of the LiBr solution by oil. The instantaneous solar thermal collector output power was calculated by equation 1: \[ Q_{solar} = \eta_{cell} \times G \times A \] where \( \eta_{cell} \) is measured by the spectrally tilted photovoltaic array which measures the direct normal insolation, 
\( G \) is the global irradiance on the collector face, and \( A \) is the area of the collector face. 

The thermal efficiency of the collectors is \( \eta_{coll} = Q_{solar} \div W_{cell} \). The array performance is monitored by total insolation on the plane of the collector which is appropriate for conventional natural solar insolation. This is in contrast to individual collector testing where both direct and diffuse components are measured under stable, high insolation. Conventional a chiller’s effectiveness is characterized by its coefficient of performance, COP. The COP is calculated by the following equation:

\[ \text{COP} = \frac{\text{Solar Thermal Input to Chiller}}{Q_{solar}} \]

In our case the power input is the power provided directly by the collectors. This slightly de-rated the chiller performance by lumping in heat dissipation due to the glycol loop and heat exchanger. The power input to the chiller by solar energy is calculated by equation 1. In the natural gas mode the thermal input to the chiller is calculated by metering the natural gas consumption.

RESULTS

Thermal Efficiency of XCPC

CONCLUSIONS

On May 5th, 2011 the UC Merced solar cooling project was commissioned and by July 12th it became operational. The system starts on natural gas and once the solar reached operating temperature the chiller solely ran on solar energy for the remainder of the day. The chillers power output was consistent and actually attainted a higher COP when running on solar.

BIBLIOGRAPHY