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Solar Cooling Technology

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I. INTRODUCTION

Althoughsolarcoolingtechnologies were introducedmuchearlier, it wasnot until the late 1990s that this technologybeganto emerge in the marketas a result ofincreasingoil, gas, andelectricityprices.

Accordingto the IEA, solarcooling will claim a marketshareofapproximately 17% by 2050. However, at this time, the markethasnot yet considerablygrown, with the predicted return on investment forsuch systems being measurable in 10–15 years—a time framealmostequalto their lifetime (United NationsEnvironmentProgramme 2014; BaldwinandCruickshank 2012).

At themoment, only a few manufacturersprovide a completesolarcooling unit. Such unitsconsistof the solarcollector, a hotwaterstoragetank, a pump set, a chiller, a control unit, and a heatrejection unit.

Solarcooling is anattractiveapplicationforsolarprocessheatandcurrently the majormarket segment for the applicationof CST heat systems. Utilities recognizethat summer peakingelectricitydemand in manycountries is increasinglydominated by airconditioningfromnoontolateafternoon. This isexactly the time with the highest solarirradiation, soanytechnologytransformingsolarradiationtocoldprofitsfrom the coincidenceof high demandandoptimumoperationconditions.

A varietyofsolarcoolingtechnologieshave been investigated in the past, rangingfrom PV-driven vapourcompressionto the manyoptionsforthermally-driven cyclesthatproducecoldanddehumidification. The racefor the mosteconomic, mostreliableormostpowerfultechnology is still open. However, it is clearthat due to different boundaryconditions there will not be the onesuperiortechnology, e.g., hotand humid conditions require a different solutionthan dry desert environments.

Solar energycan be convertedintocooling using twomainprinciples:

- Electricitygenerated with photovoltaicmodulescan be convertedintocoolingusing well-knownrefrigerationandair-conditioningtechnologiesthataremainlybasedonvaporcompressioncycles.
- Heatgenerated with solarthermalcollectorscan be convertedintocoolingusing thermally driven refrigerationorair-conditioningtechnologies.

Mostofthese systemsemploy the physicalphenomenaofsorption in either anopenorclosedthermodynamiccycle. Othertechnologies, suchassteam jet cyclesorothercycles using a conversionofheattomechanical energy andofmechanical energytocoolingare less significant.

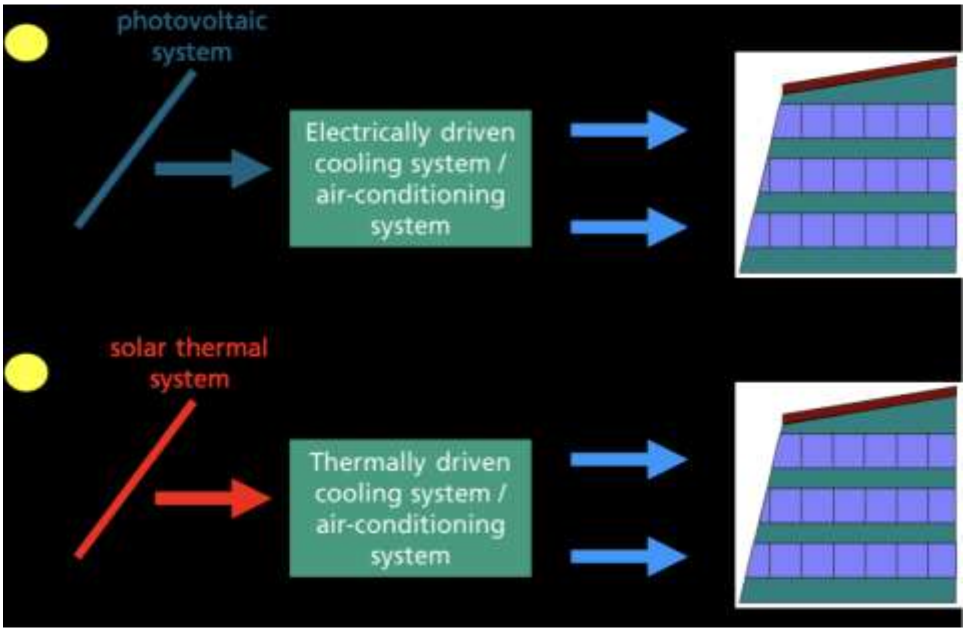
The mainargumentsforsolarassistedcooling (SAC) originatefromboth energysavingandelectricityinfrastructurecostsaving perspectives:

- Applicationof SAC saveselectricityand thus conventionalprimary energy sources.
- SAC alsoleadsto a reductionofpeakelectricitydemand, which is a benefitfor theelectricitynetworkandcouldleadtoadditionalcostsavingsof the most expensivepeakelectricity when appliedon a broadscale.
- SAC technologies use environmentallysoundmaterialsthathavenoozonedepletionandno (or very small) globalwarmingpotential.

Otherargumentsoriginatefrom a moretechnicalperspective:• Solar energy is availablealmostat the same time as when cooling is needed,reducing the need forstorage.

- Solarthermal systems used forproductionofsanitaryhotwaterandheating(solarcombi-systems) havelargecollectorareasthatarenot fully used duringsummer. They can be used for SAC and thereby reduce risk ofstagnationsituationsof the solarcollector system.

•Comparativelylownoiseandvibration- freeoperationofthermallydrivenchillers.



CarnotCycleforRefrigeration

the processfollows a reverse Carnot, whichconsistsoftwoisothermalprocesses between twoadiabaticprocesses. the reverseCarnotcycleconsistsoffourphases:

- 1–2: Work isprovided in the cycletoadiabaticallycompress the refrigerantandraise its temperaturefrom the lowtemperature TC to the high temperatureof the cycle TH.
- 2–3: The refrigerantisothermallyrejectsheat QH at a temperature TH. The heat is rejected reversibly from the system by being in contact with a high temperatureheat sink, with a temperatureequaltoorlowerthan TH.
- 3–4: The refrigerant is adiabaticallyexpandedto the lowtemperature TC of the cycle.
- 4–1: The refrigerantevaporates, reversibly absorbingheat QC, at a constanttem- perature TC from a coldreservoir. This heat, transferredfrom the coldreservoirto the system, is the coolingloadof the cycle, which results in the decreaseof the coldreservoir'stemperature.

After thecompletionofprocess 4–1, the refrigerant is led to the compressorfor the restartof the cycle.

Classificationofsolarcoolingtechnologies

Solarcooling systems can be classifiedintotwomaincategoriesaccordingto the energy used to drive them: solarthermalcooling systems andsolarelectriccooling systems.

In solarthermalcooling systems, the coolingprocess is driven by solarcollectorscollectingsolar energy andconverting it intothermal energy, and uses this energy to drive thermalcooling systems suchasabsorption, adsorption, anddesiccantcycles; whereas in solarelectriccooling systems, electrical energy that is provided by solarphotovoltaic (PV) panels is used to drive a conventionalelectricvaporcompressorair-conditioning system. Bothtypesofsolarcoolingcan be used in industrialanddomesticrefrigerationandair-conditioningprocesses, with upto 95% saving in electricity.

AbsorptionCooling

Absorptioncycle is oneof the promisingmethodsto utilize the solarheatforspacecooling in domesticandindustrialapplications.

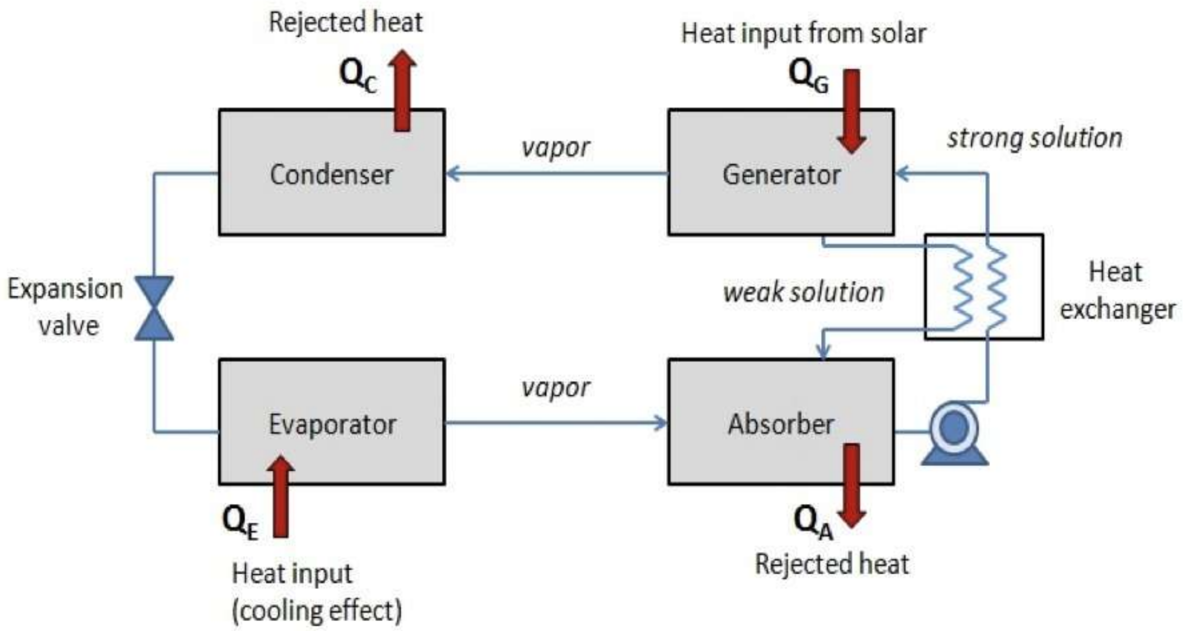
There aretwobasictypesofabsortpioncoolingcycles:
(1) Lithium Bromide (LiBr)-Water
(2) Ammonia-Water. The LiBr-H2O appearsto be moresuitableforsmall-scaleandlow-costsolarapplications due toloweroperatingtemperatureof this cycle .

In comparison with the conventionalrefrigerationcycle , the absorptioncyclehas a different kind ofpressurization. Insteadof using a mechanicalcompressor (usuallypower-expensive), it completespressurization by dissolving the refrigerant in the absorbent. In caseof LiBr-H2O system, LiBractsasanabsorbent, and H2O actsasrefrigerant. LiBr is a salt, so we can guess that if the LiBr-H2O solutionboils, water will go, andsalt will stay. The solubility limit ofLiBr in water is quite high, so the solution used in the absorptioncycle is very concentrated (~60% LiBr by mass).

There arefourmaincomponentsof the absorptioncoolingcycle: generator, absorber, condenser, andevaporator (where the coolingeffect is achieved). The simplifiedschematicdiagramof the absorptioncycle is shownbelow:-

The solar (orotherexternal) heatinputto the system is denoted QG. The heatthat is absorbed by the system from the cooledspace due toevaporationprocess is denoted QE. The heatrejectedfromcondenserandabsorberareshownrespectivelyas QC and QA. The overall energy balanceof the system
is therefore:

QC + QA = QG + QE



solaradsorptioncooling system

Conventionalcoolingtechnologiesaregenerallybasedon the electrically driven refrigeration system. These systemshaveseveraldisadvantages: they require high levels ofprimary energy consumption, causingelectricitypeakloadsandemployrefrigerants with negativeenvironmentalimpacts. Solaradsorptionrefrigeration is anoptiontoovertake the drawbacksof the conventionalcooling system.

The idealadsorptionrefrigerationcyclecan be explained by fourthermodynamicprocesses with helpofClapeyrondiagram, asshown in Figure. The cycle begins ata point A, where the adsorbent is atlowtemperature TA andatlowevaporationpressure PE. The process A–B represents the heatingofadsorbent-adsorbatematerial. The adsorbentcollector is connectedto the condenserand the progressiveheatingof the adsorbentfrom B to D causesadsorbateto be desorbedand its vaporto be condensed (atpoint C). The desorptionprocessceases when the adsorbentreaches its maximumtemperature TD. Then the liquid adsorbate is allowedinto the evaporatorfrom C to E and the collector is closedandcooleddown. The decrease in temperaturefrom D to F induces the decrease in pressurefrom PC to PE: Then the adsorption bed is connectedto the evaporatorandevaporationoccurs while the adsorbent is cooleddownfrom F to A. In thiscoolingperiod, heat is withdrawntodecrease the temperatureof the adsorbent.

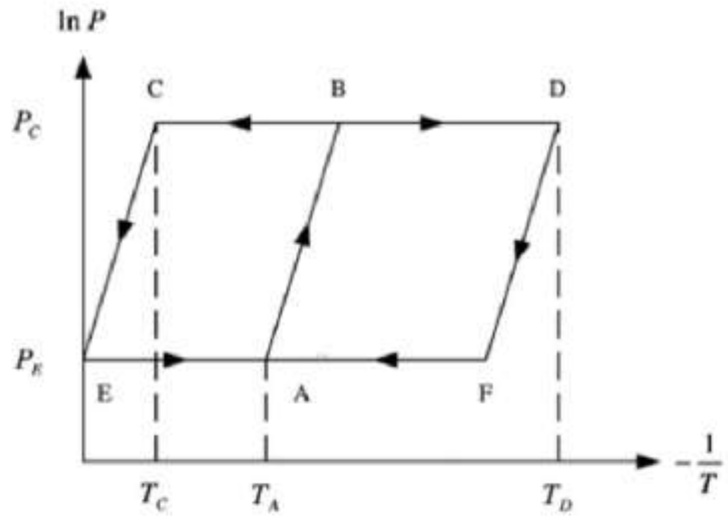
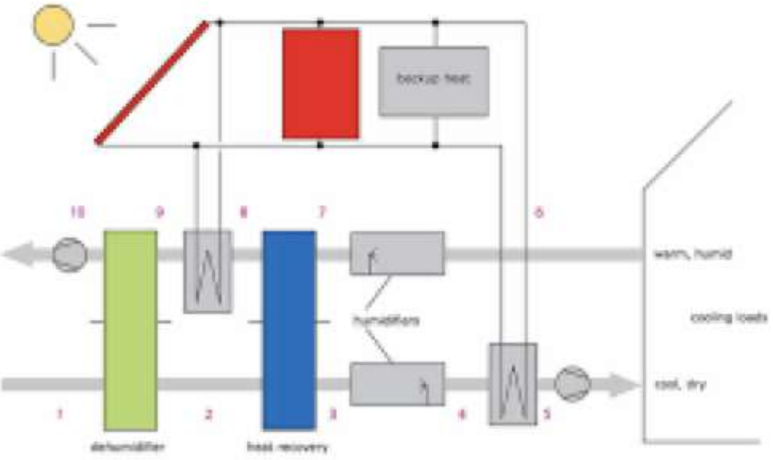


Fig.1:Clapeyron diagram of ideal adsorption cycle

DESSICANT SYSTEM

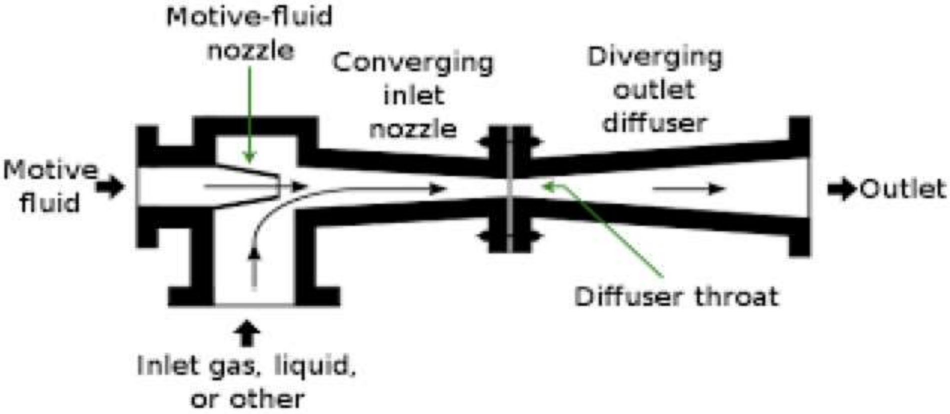
Desiccantcooling systems areheat-driven cooling units and they can be used asanalternativeto the conventionalvaporcompressionandabsorptioncooling systems. The operationof a desiccantcooling system is basedon the use of a rotary dehumidifier (desiccant wheel) in whichair is dehumidified. The resulting dry air is somewhatcooled in a sensible heatexchanger (rotaryregenerator), and then further cooled by anevaporativecooler. The resultingcoolair is directedinto a room. The systemmay be operated in a closedcycleormorecommonly in anopencycle in ventilationorrecirculationmodes. A heatsupply is needed toregenerate the desiccant. Low-gradeheatat a temperatureofabout 60–95°C is sufficientforregeneration, sorenewable energies suchassolarandgeothermalheatas well aswasteheatfromconventionalfossil-fuel systems may be used. The system is simpleandthermalcoefficientofperformance (COP) is usuallysatisfactory.



Ejector systems

A solar-driven ejectorcooling system consistsofanejectorcoolingcycleand a collectorcircuit. The maincomponentsof the system arecollectorarray, generator, ejector, condenser, expansionvalve, evaporator, andcyclepump.

In thegenerator, the refrigerant is vaporizedas a primarysteam by utilizing the solar energy comingfrom the solarcollector. This primarysteamleaves the generatorat a relatively high pressureand enters the supersonicnozzleof the ejectortoaccelerate it atsupersonicvelocityandcreatinglowpressureat the nozzle exit section. This lowpressuredraws the secondaryflowcomingfrom the evaporatorinto the chamber. The primaryandsecondarystreamsare mixed in the mixing chamber. These mixingsteams enter into diffuses where increases its pressureto the condensingpressure. The mixingstreamdischargesfrom the ejectorto the condenser, where the stream is convertedinto liquid refrigerant by rejectionheatto the surrounding. Somepartof the liquid refrigerantpumpsto the generatorand the remaining liquid partleaves the condenserand enters the evaporatorthroughexpansionvalue.

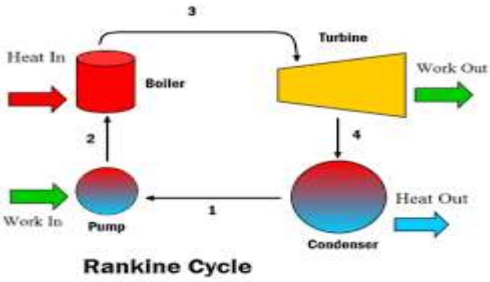


Rankine systems

Oneof the promisingmethodsthat utilize solarheattoproducemechanicalworkand then use it to drive a conventionalvaporcompressioncycle is solarRankinecooling systems. Two differentconfigurationsofsolarRankinecooling systems were suggested by different scholars . Onearrangement is using separatepowerandcooling system where the compressorof the vaporcompressioncycle is mechanicallycoupled with the expanderoforganicRankinecycle.

Anotherarrangement is anintegrated system by the use ofonejointcondenserforbothcyclecoupled with the expander-compressor.

The mainadvantagesof a secondconfigurationare the use of a sameworking fluid in bothloopstoremove a leakageand mixing problems. Moreover, theintegrated design is simpler but on the other side reduces the system flexibility.



II. CONCLUSION

The executedinvestigationson the field ofsolarthermal-driven cooling systems and the gained results can be concludedasfollows:

The investigationsonsolarthermal-driven systems showthatsolarthermalrefrigeration systems arepromisedtechnologies, especially in the smalland middle coolingcapacityranges.

The worktemperatureshave a big impacton the refrigerationcapacityof the chiller.

The higher is the required chilledwatertemperature, the higher are the refrigerationcapacityand the coefficientofperformance (COP) of the absorptionrefrigerationmachine.

The lower is the coolingwatertemperature; the higher are the refrigerationcapacityand the COP of the absorptionrefrigerationmachine.

There are a big potentialfor further researchat this field tooptimize the system operationandtoreduce the specificcosts (€/kW coolingcapacity).