The Hygroscopic cycle for CSP

FRANCISCO JAVIER Rubio discusses the Hygroscopic cycle – an evolution of the Rankine Cycle – and how it could be a competitive option for concentrated solar power (CSP) in desert or semi-desert areas.

A new twist on the traditional Rankine cycle could provide a major advantage for concentrated solar power (CSP) projects by increasing electrical output, considerably reducing water consumption and water treatment, and by cutting operational and capital costs.

In order to understand the hygroscopic cycle, it must be said the concept has been matured by specialists in refrigeration engines and absorption chillers. In these cycles, a refrigerant is vaporised and absorbed by a hygroscopic fluid, lowering its partial pressure, and allowing more liquid to evaporate.

In the case of energy systems like CSP, the fluid being absorbed is the steam leaving the steam turbine. The effect is the same, the hygroscopic fluid contacting the steam allows a low pressure of the exhaust steam, below 0.08 bar(a), or even up to 0.01 bar(a). This lower pressure improves the differential pressure through the steam turbine, increasing its electrical output, compared to the traditional Rankine cycle.

This absorption takes place in the absorber-condenser. Here the steam comes in contact with a highly concentrated solution of water and hygroscopic salts (salts which absorb moisture such as NaCl, CaCl2, NaOH, CuSO4, LiCl) coming from the boiler after having been cooled down. The molecules of steam are trapped by the hygroscopic salts where they are condensed. The steam condensation temperature is higher (between 1 and 30 ºC) than in a traditional Rankine cycle condenser. This can be seen by adding regular salt to water, which increases the boiling point, and decreases the freezing point.

Some salts show an endothermic effect when they are diluted (such as NaNO3). This means the condensation heat decreases in the absorber. The overall effect of this, in particular for CSP plants, is by using particular salts and dry cooling (through air coolers), the performance of the turbine could be kept high even in hot days (when market demand for energy is very high), and given the small size of the air-cooler needed, the overall power consumption of the plant would be lower. In this cycle the air is used to cool the concentrated solution (liquid phase) that goes towards the absorber.

After condensation, the mixture is pumped and split into two. The major part is recycled back to the absorber condenser, after being mixed with a concentrated hygroscopic flow and passed through the air-cooler. The lesser part goes through a heat recovery exchanger, where it is partly pre-heated, after which the fluid is degasified and pumped at high pressure into the boiler or source of heat.

The latter could be any conventional source of heat, although in the case of solar troughs or conventional fresnel systems, this would be hot mineral oil, or molten salts for solar towers, or the salts found in thermal storage devices in order to produce electricity for 24 hours.

As the fluid is heated in the boiler, it starts to vaporise, as in a traditional boiler, but at a higher temperature, due to the colligative effects of the salt explained earlier. As steam is being generated, the salts are being desorbed by the effect of heat, and concentrated at the bottom of the boiler. The droplets of the generated steam are eliminated by a demister, and the steam is superheated before passing through the steam turbine and generating electricity.

The hot concentrated hygroscopic mixture is recovered at the base of the boiler where it is cooled down partly in the aforementioned heat exchanger, and mixed with the return to the absorber (where it is further cooled down in the air-cooler mentioned earlier).

The benefits in action

The following is an example where the performance of a solar thermoelectric plant with cylindrical-parabolic collector technology located in the southwest of Spain, is compared to a similar plant using the Hygroscopic cycle technology instead of the Rankine cycle. We will maintain the same values of the steam conditions (pressure and temperature) at the inlet and outlet of the turbine.

The power of the plant is 50MWe using a conventional Rankine cycle and wet cooling (by means of cooling towers). Using a commercial Hygroscopic cycle the following results could be easily achieved:

- Saving an estimated 80% as a minimum in water consumption - 500,000m^3 of water per year.
- 500kWe more electrical power (around 1000MWh per year).
- An estimated reduction of €2mn in installation costs. and a 50% cut in operating and maintenance costs.
- Less environmental impact.

So the main advantages are an increase of electrical power output and less dependency on ambient conditions for cooling, even with dry cooling, allowing for good performance of the turbine. By using dry cooling there is a saving in operational cost (eg reduction in cooling water add-up, no need for chemical water treatment, lower water discharge in the Rankine section). The hygroscopic cycle could also be used in cogeneration plants, biomass plants, and so on.

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Further information: http://www.imasa.com.