REHOS thermodynamic cycle in a Nutshell

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Abstract:

This article put the Regenerative Heat of Solution (REHOS) thermodynamic cycle and its components into complete perspective. It highlights that the only novel aspect of this cycle is the combination of components and the regenerative coupling joining them together. The resultant thermodynamic cycle would be very disruptive for several industries, due to the high heat to power conversion efficiency which is (very nearly) independent of the temperature level of the waste heat used for heat recovery. The REHOS cycle can therefore also extract waste heat at temperatures lower than the ambient temperature and convert it to power....

The patent holders, REHOS Product Designs, license and partner with local manufacturers and interested entrepreneurs as facilitators to allow others to benefit from the revolutionary system so they can reach more potential suppliers quicker, as global demand is likely to require much more than what a few South African companies can produce......

Introduction

What you may know, is that some second generation ORC suppliers can now generate electricity economically from waste heat sources at a temperature as low as 80°C. Take Datacenter coolers as example. Datacenters are forced to use active coolers to dispose of all the heat generated by their servers and electronics packed into cubicles, as higher electronic computing speed and density heat up the chips and components to their maximum, currently limited to around 80°C. A typical Datacenter can pack servers and modules into a single cubicle with heat generating losses in excess of 16 kW, and if the Datacenter is very small, it may have 10 cubicles only, with the waste heat generated by these electronics already adding up to 160 kW of waste heat that need to be disposed.

A certain cooling system supplier from Germany of second generation state-of-the-art ORC technology, can now convert this waste heat, at the ultra-low grade temperature below 80°C to electricity amounting to 8 kWe, to be credited on the Datacenter's electricity bill. With the high prevailing electricity price, the payback time for such an ORC system incorporated in the cooling strategy and financed from the savings, would be conservatively 5.5 years, even though the heat-to-power conversion efficiency is only 5%, as reported by Ebrahimi et al [1] in 2017.

What you certainly do not know, is that the South African company, REHOS Product Designs, recently patented a novel thermodynamic cycle to totally disrupt these excellent German achievements. The REHOS cycle would, operating under similar circumstances, generate over 12 kWe realistically from this waste heat source of 160 kW at 80°C, rendering a revolutionary heat-to-power conversion efficiency nearly double the German ORC achievement !

Impossible? Read on......

What is this REHOS cycle ?

The Regenerative Heat of Solution (REHOS) thermodynamic cycle is formed by combining an Absorption Heat Transformer (AHT), fully regeneratively with an Organic Rankine Cycle (ORC) for the generation of power. The AHT operate as heat pump, utilizing waste heat to create a temperature gradient suitable for the ORC to use to generate power from. All the ORC rejection heat is routed to the input side of the AHT, that utilize it regeneratively for (partially) powering the heat pump. The balance of heat required by the AHT is extracted from the available waste heat source. The author previously published elaborate descriptions and explanations [2] in January 2019.

What is so special about the heat pump ?

The conventional Vapor Compression (VC) heat pump have an efficiency, or Coefficient of Performance (COP) depending on the temperature gradient that may be calculating to ~ 4 or 5 for the temperature upgrade < 100°C. The COP is defined as:

$$COP = \frac{Heat\_Pumped}{Pumping\_Energy}$$

and as the energy used for pumping is electrical power used by the vapor compressor, the electricity used amount to $\frac{1}{4}$ or $\frac{1}{5}$ of the heat pumped. In contrast, the AHT use heat to power the temperature upgrade instead of electricity. It use electricity only for liquid pumping, amounting to a factor of 50 to 100 times smaller than the electricity requirements of the vapor compression power. For the AHT, two distinctly separate Coefficient of Performance values are defined, namely for thermal energy used:

$$COP_{th} = \frac{Heat\_Pumped}{Heat\_used}$$

For electricity used the Coefficient of Performance is defined as:

$$COP_e = \frac{Heat\_Pumped}{Electricity\_used}$$

with COP_e values around 50 - 100. Actual electricity used calculates to values of $\frac{1}{50}$ to $\frac{1}{100}$ of the heat pumped, and therefore when the electricity requirement for the conventional VC heat pump is compared to that of the AHT, there is no comparison. For all practical purposes the AHT require no electricity for heat pumping! Thermal energy is sufficient to pump the heat to higher temperature grade.

The AHT use a vapor absorption process to generate the temperature upgrade. Vapor, even at very low temperatures and pressures, carry a lot of energy in the form of latent heat of condensation, as well as the heat of solution. When dissimilar media dissolve into each other forming a solution eg. NH3 and H2O, the process may be exothermic, generating heat of solution like this example. A binary mixture like NH3 and H2O is said to be zeotropic, as the two media boil at different temperatures. NH3 is much more volatile than water, boiling off first when the mixture is heated.

In the AHT, vapor is generated by boiling off the binary mixture at low temperature, absorbing a lot of thermal energy from the evaporator, powered by the waste heat source and transferred in the form of latent heat & Heat of Solution (HOS) as the vapor is generated in the cold evaporator. This energy is then carried in the vapor form and released where the vapor is injected into the hot absorber, heating the absorber further in the vapor absorption process. The actual temperature of the absorber depend on how much of this generated heat is removed via a heat exchanger (H/E), but may easily be 80°C - 90°C.

In another section of the AHT, the absorbed NH3 is distilled, concentrating the binary mixture to feed a high concentration NH3 liquid via the liquid pump back to the cold

vapor generator, being kept at a pressure slightly higher than the hot absorber, to guarantee vapor flow spontaneously from the evaporator to the absorber.
AHT technology is not new, and has been around since the 1960's and have been developed at the same time as absorption refrigeration. More recently, from about the 90's the high electricity prices globally made scientists have a serious re-look at commercialization of more AHT applications.

What about the ORC ?

The organic rankine cycle developed hand-in-hand with steam power in the mid 19th century. Already by 1850 some rankine cycles that needed to run at low temperatures had the steam replaced with organic refrigerants in order to increase the pressures at the low temperatures. It is a mature technology commercially used since the beginning of the 21 century, for power generation where the temperatures are relatively low, eg. in the geothermal power generation sector.

Although the ORC technology is very matured, it is understandable that low temperature gradients will only be able to deliver conversion efficiencies limited to the Ideal maximum, or Carnot efficiency, which is a function of the absolute temperature levels in the gradient. It is defined as:

$$\eta_{carnot} = \frac{Temperature\_gradient}{High\_temperature} = \frac{(T_{hot} - T_{cold})}{T_{hot}}$$

and only very large systems come close to efficiencies of > 80%Carnot. Smaller ORC systems of a few kilowatt very often do not even achieve 65%Carnot, and therefore it is not surprising to note the heat-to-power conversion efficiency of the state-of-the-art ORC system incorporated into the Datacenter cooling plant is 5%. The balance of 95% of the input heat to this turbine is rejected as low pressure, low temperature vapor.....

With both AHT and ORC both mature technologies, how about regeneration?

Over the 21 century, the regeneration cycle have mostly been used for steam power plants used by electricity utilities all over the world. It drastically increase the standard rankine cycle efficiency if steam is extracted at multiple points along the turbine expansion line, and used for the stepwise regenerative heating of the feed water in multiple feed heaters. Should the number of feed heating steps be infinite, the thermodynamic efficiency of the regenerative cycle would approach Carnot efficiency!

The value of regeneration is therefore very well known now for over a century among power generation practitioners.

What is then the novel part of the REHOS cycle ?

As explained above, the AHT is powered by an organic refrigerant vapor mixed with a solvent, in our example this media is ammonia (NH3) dissolved in water (H20). This vapor drives the temperature upgrade via the absorption process in the AHT absorber. The regenerative coupling of the ORC to the AHT simply involve the sharing of the AHT evaporator pressure level with the ORC turbine exhaust. In this way the massive ORC heat rejection vapor from the turbine exhaust is used directly, and parallel to the vapor generated by the evaporator as heating vapor in the AHT absorber, so the 95% ORC rejection loss is fully regeneratively recovered and used for (partially) powering the AHT! This have the result that the only external heat required by the REHOS cycle would be the balance of 5% heat the turbine require, as well as a small amount of heat lost as radiant loss from the system hot components. Power generated must obviously also power both the ORC-Pump delivering liquid NH_3 at an elevated pressure eg. 20 Bar, and the AHT Recovery liquid pump before netto power can be calculated.

The **unique regenerative coupling of an ORC with an AHT therefore represent the only novelty in the REHOS concept**, yet the cycle so formed is able to totally disrupt the heat recovery landscape with heat-to-power conversion efficiency much higher than where previously thought possible! The high REHOS cycle conversion efficiency is also not limited by temperature gradient values, and may therefore also be utilized for **recovering waste heat even at temperatures below ambient**, as the heat pump create the operational gradient for the ORC operation. The large regenerative component used in the **REHOS cycle also mean no bulky cooling system**, even at high power ratings. In a referenced publication [4] the cycle is described from first principles, and [3] put an economical perspective to it, highlighting equipment costs.

For not only power generation in the very small to several megawatt utility range, but also the transport aero, overland and marine mobile power, not to mention refrigeration and air conditioning operations an extremely high disruption potential exist, also with global interest in the REHOS Technology. The IP owners, REHOS Product Designs, opted to commercialize this technology as facilitators and partners to manufacturers. We are in the ideal position to license REHOS technology, after 12 years of R&D, to South African entrepreneurs, manufacturers and other interested parties and to guide our licensees for proper transfer of the valuable, yet fairly simple REHOS technology, **so you can put up your factory** and supply not only South- and Southern Africa, but the global community with your own REHOS prime mover powered products.

Are you interested in manufacturing water pumps powered by the sensible heat in the water it is pumping? Or would you rather adapt your factory for supplying small modular low cost power units to power your household from the solar thermal input incident on a swimming pool? Maybe you like the bigger challenges and plan to provide Eskom with cooling water heat recovery systems to facilitate phased decarbonization of their coal fleet? If, on the other hand, you have a love for the marine environment, you may want to supply marine transport with sea-water thermal powered propulsars? Or replace the fossil combustion IC with mobile power packs extracting heat from the air for powering the bus or truck electrically? Even aero-mobility is not outside your reach, as lightweight fiberglass heat exchangers, coupled with the high efficiency power packs would extract heat from the air to use electrical propulsion on planes and helicopters....

Possibilities are endless, only limited by our imagination......

References Cited:

1. The Viability of Ultra Low Temperature Waste Heat Recovery using Organic Rankine Cycle in Dual Loop Data Centre Applications, by Khosrow Ebrahimi, Gerard F. Jones and Amy S. Fleischer and published in Applied Thermal Engineering 126 (2017) 393 - 406, made available by Elsevier.

A Selection of Previous Publications by J. Enslin:

2. The document "Key Principles of the REHOS Cycle" was written by Johan Enslin in November 2018 and published in the Open Access Bioenergetics Journal at https://www.omicsonline.org/open-access/key-principles-of-the-rehos-cycle-2167-7662-19-154.pdf in January 2019, as well as on my own website http://www.heatrecovery.co.za/.cm4all/iproc.php/Key Principles of the REHOS Cycle.pdf

3. The document titled "Economic Aspects of Utilizing Heat Transformer Technology.pdf" was written by Johan Enslin in February 2019 and published on my website http://www.heatrecovery.co.za/.cm4all/iproc.php/Economic Aspects of Utilizing Heat Transformer Technology.pdf

4. The document titled "The Versatility of a Vortex Bubble Distillation Reactor.pdf" was written by Johan Enslin in April 2020 and published on my website http://www.heatrecovery.co.za/.cm4all/iproc.php/The Versatility of a Vortex Bubble Distillation Reactor.pdf

5. Website for REHOS Product Designs, formerly traded as Heat Recovery Micro Systems cc, where the above publications are listed from: www.heatrecovery.co.za