A Closed Loop See Water Air Conditioning

Alessio Guarino and Bruno Garnier

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Alessio Guarino
University of the Reunion Island
ICARE Laboratory
Saint Denis, Reunion Island
alessio.guarino@univ-reunion.fr

Bruno Garnier
SCFP, DeProfundis
47, rue Guersant
Paris, France

Abstract— **The SWAC (Sea Water Air Conditioning) is now broadly well known and used. However, technical limitations imply that current SWAC system are inefficient for less than 1.5 MW cold power, which correspond to the need of about 300 rooms of 30 to 40 m². We propose a system allowing deep water-cooling systems to be suitable for much smaller structures (about 50 rooms).**

Keywords—SWAC, air conditioning, deep water, closed loop

I. INTRODUCTION (*HEADING 1*)

The SWAC (Sea Water Air Conditioning) has acquired fame thanks to its first commercial applications. However, physical limitations imply that the current SWAC system is inefficient for less than 1.5 MW cold power, which is roughly equivalent to an air conditioning system for 300 rooms of 30 to 40 m². Our system aims at allowing deep water cooling systems to be suitable for needs of much more modest structures (50 rooms) without a marginal price increase. In order to achieve simulations, we need to define a standard location. We based our assumptions on a Polynesian consumer of cold (like a hotel) located on a coral islet of French Polynesia. This location has the following characteristics:

- Intake depth: 800 m
- Intake Temperature: 5°C
- Rejection Temperature: 14 °C
- Rising pipe length: 2150 m
- Length of rejection tube for heated water: 700 m

The pipes are made of HDPE and have the following measures:

- External diameter: 150 mm
- Internal diameter: 123 mm

Concerning energy units, the international metric system is used inconsistently: even in official statistics (DGEMP, IEA, DOE), energy is measured in Kilowatt hours, tonne of oil equivalent, thermal kWh, or BTU, but the Joule is scarcely used. A crucial point of this paper is to study the impacts of modifying the water flow speed in different settings, which compel us to harmonize different units of measures [1]. We'll have to take some distance from the international system in order to privilege clarity.

Regarding the electrical power and energy, we shall use industry standards:

- For power, Watt and multiples (kW, MW, GW)
- For energy, the Watt hour (rather than the Joule) and multiples (kWh, MWh, GWh)

Regarding the thermal energy, the unit of measure used by the industry is the thermal Watt hour or the BTU (British Thermal Unit). In order to unify and clarify the units of measure, we will once again take some distance from the international system and also from industry standards. An important part of the present paper will compare for the same cooling performance the pumping power of the SWAC to a conventional compression system. In order to quantify the cooling power, we will thus use the Watt compression equivalent (Wce), that is to say the electric power which would be necessary to an efficient compression installation (COP=3) to produce the same coolness. We shall then use completely comparable units.

II. ENERGETIC ANALYSIS

The highest energetic cost of a SWAC system is the energy consumed by the pump. The pump is struggling against three different physics phenomena:

- the gauge pumping height (difference of level between sea level and the height of installations)
- the static height, because of the temperature and salinity difference between the water inside and outside the pipe
- the head loss.

We will see in the following pages that the first two phenomenons are negligible compared to charges losses. In order to estimate those charges losses, we chose to use the Colebrook formula [2], which, although complex to use, is the most accurate over a large conditions spectrum for turbulent flows. As a first approximation, we can consider that the energetic cost depends on the square of the speed.

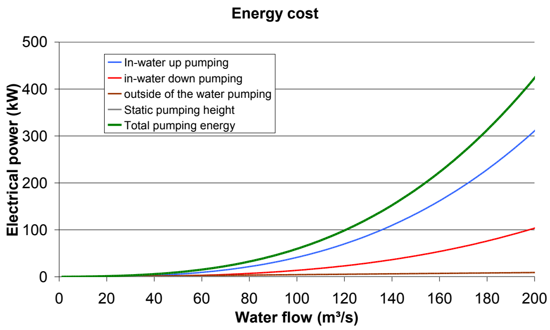

Figure 1: energy cost

The energetic gain of the SWAC systems are expressed as :

$$G=(T_s-T_e)*Q*Cte \quad (1)$$

Where Ts represent the temperature of water going out of the system (constant, decided by the cooling usage), Te is the temperature of the water entering the system and Q is the quantity of water pumped to the surface. Cte is a constant to harmonize units. The heating of water in the pipe, in a given configuration, depends uniquely on the time spent in hot environment and thus on water's linear speed. The energetic gain curve is therefore asymptotic to the line of equation:

$$Y=(T_i-T_o)*F*Cte \quad (2)$$

Where Ti is the temperature of the incoming water (K), To is the temperature of the outgoing water (K) and F is the flow (m³/s)

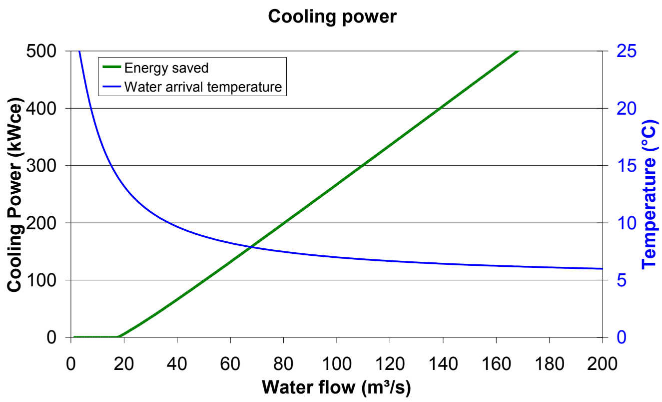

Figure 2: cooling power

Deep water suction lowers the pressure inside the pipe. The water phase diagram tells us that whatever the temperature, under a certain pressure, liquid water will vaporize, causing a phenomenon called cavitation.

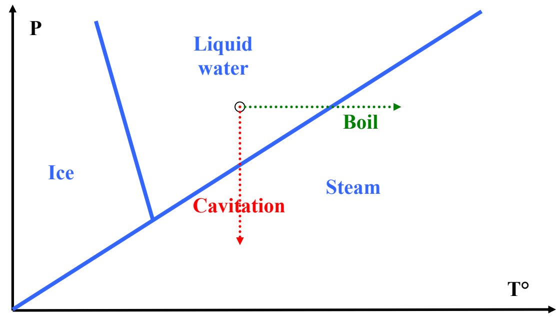

Figure 3: phase diagram of water

Cavitation has two nefarious consequences for the system:

- it changes the behaviour of the liquid, and prevent the pump from functioning correctly.
- it is extremely destructive when the steam bubbles condensate back.

Figure 4: Centrifuge pump destroyed by cavitation

The consequence of this phenomenon is that it is imperative to limit suction power in order to avoid cavitation [3].
This suction limitation dramatically limits the speed of the incoming water :

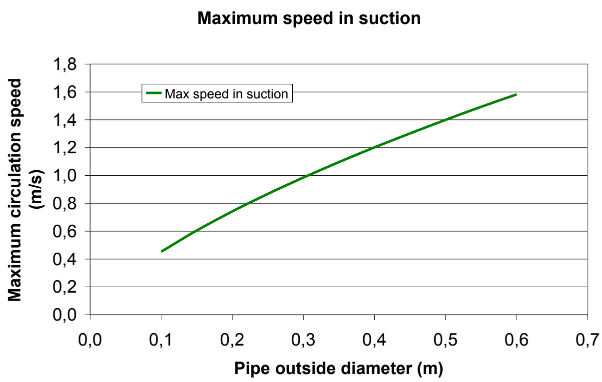

Figure 5: Maximum water speed in suction

This water speed limit causes two problems:

- Water flow is the main component of cold power formula
- As water is slowed down, it stays longer in the pipe, and therefore gets more heated by the environing sea water

The energetic results (BE) are defined by the difference between the energetic costs and the energetic gains of the system, and will thus present the energetic balance of the system.

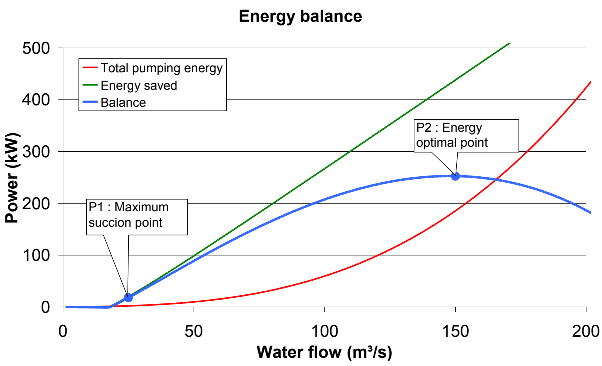

Figure 6: energy balance

On this graphic, we will focus on two points:

- P1 is the optimum of the curve if we care of the suction limitation.
- P2 is the theoretical maximum of the curve, without taking care of the suction limitation:

	P1	P2
Head loss	0.7 bar	21 bar
Flow	25 m³/h	155 m³/h
Energy balance	18 kW	252 kW
Cold power	20 kW	455 kW
Number of standard rooms air conditioners (20 000 BTU)	4	93

Table 1: the two points of interest

This comparison shows that with small pipes, the circumvention of the suction limit is the key point for enabling middle-sized SWAC systems to be economically interesting. The only way to avoid a suction limit is to push the water instead of aspirating it. The first obvious solution is to put an immersed pump on the lower part of the cold pipe. However, this is not viable for three reasons:

- Pumps resisting to a 80 bar pressure are difficult to find and are very expensive.
- The electrical wire necessary for the electrical alimentation of the pump will need to be so thick that it would cost twice the price of the pipe.
- Maintenance operations 800 meters under the water surface will be too complex.

CLOSED LOOP SWAC

In order to avoid suction limit, while having the pumps above the surface, we have patented a new process:

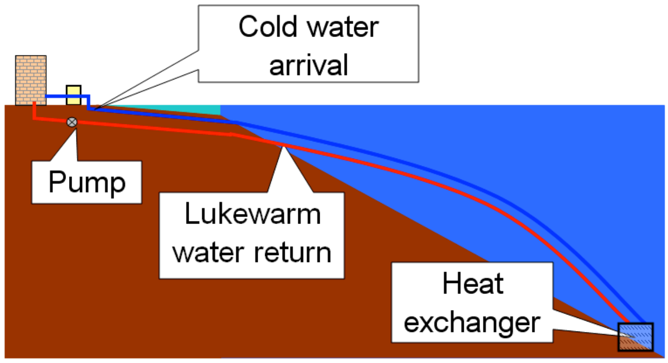

Figure 7: scheme of a closed loop

In our scheme, we have a closed loop of fresh water that gets cooled by a heat exchanger located on the lower part of the loop. Three parameters will therefore change from the initial scheme:

- The pipe is 50% longer to finish the loop, so the head loss will increase.
- Efficiency of the heat exchanger will increase the heat of the cold water by 1°C.
- We will use fresh water instead of salted water as coolant liquid, which has a better specific heat capacity (≈4200 J kg−1 K−1 for fresh water, ≈4000 J kg−1 K−1 for sea water), but smaller density [1].

Moreover, even if we are not subject to a suction limit, the pressure in the pipe will have to be limited to 16 bar, which is the mechanical resistance of the pipe [5,6].
With these new parameters, we are able to compare the energy balance of our system to the points we have formerly studied.

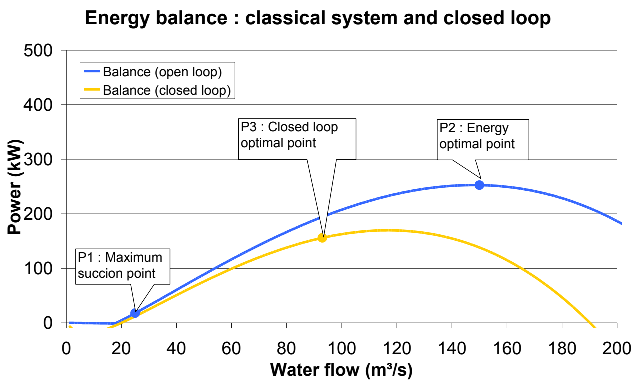

Figure 8: Energy balance: closed and open loop

With this new P3 point, we now have three points of interest for the closed-loop system.

	P1	P2	P3
Head loss (rising	0.7 bar	21 bar	8 bar

pipe)			
Flow	25 m³/h	155 m³/h	93 m³/h
Energy balance	18 kW	252 kW	156 kW
Cold power	20 kW	455 kW	223 kW
Number of standard room air conditioners (20 000 BTU)	4	93	45

Table 2 : the three points of interest

We see from above that point P3 keeps 62% of the theoretical energy optimal point (instead of only 7% for the P1 point).

The main innovation in the proposed system, is the immersed heat exchanger, and it is also the most challenging part in the system. It is a natural convective heat transfer exchanger and therefore, it has to be much bigger than advective heat transfer used in classical open-loop SWAC systems. Our technical studies show that, in order to cool down water 1°C over the temperature of the ambient water, we need 4 000 m of 20 mm metal pipe. The design of this exchanger is modulary and massively parallel. We will therefore have 6 cubical modules (3m x 3m x 3m) containing each 15 rows of 15 pipes, linked by metal chains and hydraulically connected by flexible pipes. The weight of each of these modules will be 400 Kg (200 Kg for the pipes, and 200 Kg for the structure) and will thus be handled by a team of workers.

III. COMPARAISON BETWEEN OPEN LOOP AND CLOSED LOOP

Because of the suction limit, classical is dedicated to large cooling needs, while closed loop is efficient only for small cooling needs :

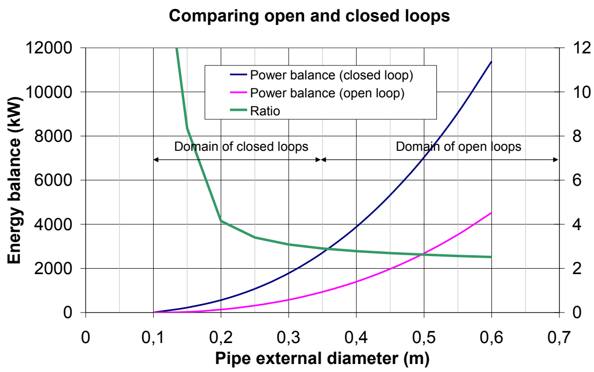

Figure 9: Energy balance

The limit, in cooling needs would therefore be :
closed loop < 1.5 MWc < open loop. We thus see that open loop is complementary to traditional SWAC systems, allowing remote middle sized cooling consumers to access SWAC technology.

IV. 5. CONCLUSION

The closed loop system is therefore the only known system that allows making SWAC systems with thin pipes, giving the following advantages on middle sized remote locations:

- Pipes can be delivered in 100 m rolls and therefore are easier to deploy
- They can be handled by workers, and do not need expensive machinery
- The maritime deployment needs boats that can be found on every island (barges, fishing boats), when thick pipes need large specialized materials which are not usually available in remote locations.

Moreover, the loop system by itself gives some more advantages:

- Control on the quality of the circulating water
- No need for an end-pipe filter that requires regular maintenance
- No risk of aspirating sea water material or animals that could damage the system

The economic study is not within the scope of this conference, but, in Tahiti, the return on investment has been calculated to be between 5 to 10 years, depending of the geography of the site.

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