Design of an 10MW OTEC Power Plant

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Summary

Ocean Thermal Energy Conversion (OTEC) is an advanced technology with a long history of developments, but up until now without a single commercial application. High technical risks, large scale development & engineering, substantial capital investments and significant environmental impact are a few of the challenges and difficulties which caused the OTEC system not to be of main interest. Today, research performed by students from Delft University of Technology shows that OTEC can be a feasible and cost competitive solution for sustainable energy in Curacao, one of the islands on the Netherlands Antilles.

Introduction

Ocean Thermal Energy Conversion (OTEC) is a method for generating electricity using the temperature difference between the hot surface water and the cold deep water in the ocean. The thermal potential drives a Rankine Cycle, which produces electricity, by what could be called a reversed refrigerator process. Interesting areas for OTEC applications are around the equator, where the temperature difference is highest.

Delft University of Technology challenged students to come up with innovative solutions for its corporate and governmental partners. A group of four students was assigned to design a technically feasible and cost competitive 10MW OTEC Power Plant for the island of Curacao. In order to meet the requirements of today's energy market, the team had to improve the key components and achieve radical innovation. The following research question has been defined and tested:

How can OTEC be turned into a feasible and cost competitive solution for the increasing demand in energy at Curacao?

OTEC developments

OTEC is an advanced technology with a long history of developments. Since 1800 there have been several attempts to develop and demonstrate OTEC systems [1]. Economic feasibility could however not yet be established.

The situation is changing now. Renewable energy is in the spotlight, offering opportunities for the OTEC technology. Developments such as the rise of the fossil fuel prices and an increasing knowledge in the offshore industry, have made the OTEC system economically more attractive and technologically more feasible.

Challenges

Although, the commercial interest in the OTEC system is rising, several challenges keep the industry from investing. In general these are:

- The environmental impact (biofouling, large seawater flows);
- Large required capital investment (5-11 million $ per installed MW);
- Technical risks (deployment, size).

Focusing on the key components of the OTEC system, the following main technological challenges can be identified:

1) Heat engine
   • Low thermal potential (around 20 - 25 degrees Celsius temperature difference);
   • Low Thermal efficiency of the heat engine (Rankine Cycle efficiency is only 3%);
2) Water ducting system
   • Large hot and cold water flows resulting in large diameter pipes (4 - 10m diameter);
   • High environmental loads and difficulties in deployment;
3) Pumping system
   • The relative large power required to pump the water from a large depth to the surface;
   • Environmental impact at the inlet and outlet.

Methods

Various OTEC concepts were analyzed in detail and optimized using simulation programs, whilst focusing on the key components (water ducting system, heat engine and the pumping system). At the same time various options to improve the system and its performance were checked, like preheating, dome shaped platforms and the 'airlift'. These options will be discussed in the coming sections.

Preheating
The heat engine has been modeled in the computer program Cycle Tempo [2]. The program allowed to optimize the system and perform a study on the possibilities of preheating, which means increasing the warm water intake temperature via solar energy absorption. Preheating potentially is an interesting option to increase efficiency and yield a higher power output. OTEC relies on the temperature gradient and the bigger this gradient becomes, the higher the plant efficiency will be.

The study focused on two concepts for preheating. The two concepts are:

(1) Open dome: continuous new water intake over the circumference of the dome which is heated before entering the heat engine;

(2) Closed dome: no new water intake during daytime, but water circulation within the dome to the heat engine and back. At nighttime the system has a standard open inflow.

The analysis and testing of both concepts showed that preheating of large volume flows of water (approx. 22m3/s) is simply not feasible, both from a technical and business perspective.

Water pumping
The heat engine takes in hot surface seawater and cold deep water from a depth of 1000m. In order to attain a sufficient cold water flow from these large depths to the surface, the system is equipped with a pumping system.

The cold water volume flow is approximately 22 m^3/s. The cold water will flow through a relatively large diameter pipe, which causes only a small pressure drop due to friction (wall shear) and small accelerations. The most significant physical effect left is the gravitational pressure gradient, which shall be overcome by the pumping system. Moreover, the 1000m water column inside the pipe will have a lower mean water temperature (5-6˚C) than the ambient mean water temperature (14-16˚C), which causes the negative pressure head to be a little higher.

The major energy consumer in the OTEC system are the water pumps. Making improvements there means an immediate gain in efficiency. Focusing on the cold water pump, there are a lot of conventional pumping methods available. These pumps all use moving parts and suffer from impure water, causing a high need for maintenance and a relative short operating lifetime of the pump. The team studied other opportunities to get the cold water up and came up with an innovative alternative for the pump: the ‘airlift’, as discussed in the following innovation section.

Innovation
Research on increasing cost-competitiveness of OTEC through technological innovation led us to the final design ‘dOmeTEC’ with two major achievements:

- The Airlift

The “dOmeTEC” design incorporates an innovative pump system, which is called the ‘airlift’. The airlift is designed to inject air via an external/internal air tube. Injected air aerates the fluid and reduces its density. The result is an increase in pressure difference over the inlet of the pipe and the liquid starts to flow upwards. Compared to conventional pumps, the airlift has the following advantages:

- Up to 20% - 30% more efficient
- More system robustness
- Impure water does not influence performance

Extensive research and prototype testing on the airlift led to great expertise within the Department of Multi-Scale Physics at Delft University of Technology. This department studies multiphase flows in great detail with the use of both experimental and numerical techniques.

- The floating Dome

The floating dome is the cheapest way to protect the system from the harsh environmental conditions and simultaneously acts as the foundation for the heat engine. The dome, based on the award winning design of Water architect Bart van Bueren, is made of low cost, corrosion resistant and light-weight plastics while retaining the structural stiffness.

The roof of the Dome is constructed using ETFE foil, which is sealed around its perimeter and inflated to a large cushion. The resulting cushion acts like a thermal blanket to the structure. The foil material ETFE is chosen because of its low weight properties and very good insulation. Furthermore, the construction will be simple to install, to operate and maintain. With a life span of 20 years, this is an interesting design concept for OTEC.

The foundation material is made of foam and concrete. The foam creates enough buoyancy to carry the structure, while the concrete reinforcements ensure the foundation to be strong enough to resist environmental loads.

The foundation layout is a sandwich construction, providing a strong & lightweight structure with use of relatively cheap materials.

Furthermore, the design incorporates an oval shaped warm water reservoir for minimizing the environmental impact.

Economics

A significant profit can be made per year with the build of a 10MW (Net Power) plant.

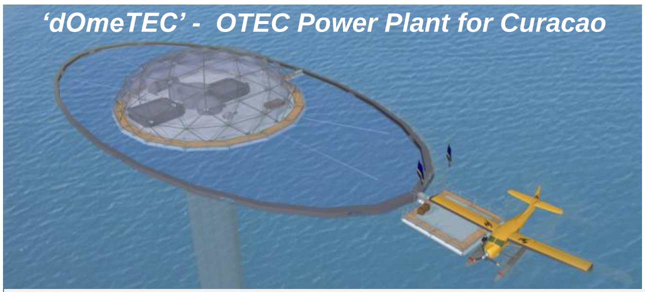
The dOmeTEC 10MW power plant would account for around 9% of the total energy demand on Curacao. Theoretically, a 108MW plant would be able to produce all the energy the island needs.

The reason for the high profit potential is Curacao's high dependency on fossil fuels and its soaring prices, as well as water production cost. Curacao has one of the highest energy costs per kWh in the world ($0.25-$0.40/kWh US dollars 2008). The water is also very expensive ($6.10-$10.25/m^3 US dollars 2008), which creates potential for added revenues from OTEC, if a desalination unit is installed.

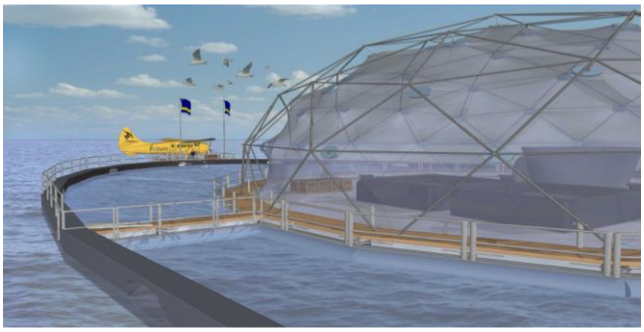
Currently only 5% of the total production comes from sustainable energy, mostly wind and a negligible part by solar. This can be increased but only up to a maximum of about 10-20%, due to its high variations over time.

Cost and revenues estimation and analysis reveal potential for an attractive profit. The cost for the realization of the 10 MW plant is estimated at 77 ± 30 million USD, including 5% of operational expenditure per year. Assuming these costs, a gross profit of 7 to 15 million USD can be realized per year. This profit emerges from production costs of around 0.203 USD/kWh and current energy prices of 0.37 USD/kWh. Additionally, based on the local prices, selling the water would provide an extra 3 million USD per year.

According to this estimation, the initial investment will be written-off in 5 years on average with a plus/minus of 2 years. This means that the plant will start realizing profit in less than a decade which significantly increases its business potential.



System performance			
Net power	10 MW	Gross power	11.16 MW
Efficiency	3.4%	Water flows	22m^3/s



Conclusion

The dOmeTEC design can be the solution for an innovative and low cost 10MW OTEC Power Plant. Integrating the innovations as mentioned above will optimize the operating performance, resulting in a relative high system efficiency of 3.4% and with a gross power of 11.16 MW. Thereby, the significant reduction of the OTEC capital investment shows OTEC to be an economical viable and technical feasible solution.

Future

The results are so promising that the OTEC Team from Delft University of Technology will continue developing the dOmeTEC design and is enthusiastic to contribute to the future of OTEC.

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References

[1] L. A. Vega, Ph.D., Hawaii, Ocean Thermal Energy Conversion (OTEC), USA 1999

[2] Cycle Tempo Simulations, Design software Delft University of Technology