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Electricity generation from hydrothermal vents

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Electricity generation from hydrothermal vents

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Abstract. Hydrothermal vent is a kind of manifestation of geothermal energy on seabed. It produces high temperature fluid through a hole which has a diameter in various range between several inches to tens of meters. Hydrothermal vent is mostly found over ocean ridges. There are some 67000 km of ocean ridges, 13000 of them have been already studied discovering more than 280 sites with geothermal vents. Some of them have a thermal power of up to 60 MWt. These big potential resources of energy, which are located over subsea, have a constraint related to environmental impact to the biotas live around when it becomes an object of exploitation. Organic Rankine Cycle (ORC) is a method of exploiting heat energy to become electricity using organic fluid. This paper presents a model of exploitation technology of hydrothermal vent using ORC method. With conservative calculation, it can give result of 15 MWe by exploiting a middle range diameter of hydrothermal vent in deep of 2000 meters below sea level. The technology provided here really has small impact to the environment. With an output energy as huge as mentioned before, the price of constructing this technology is low considering the empty of cost for drilling as what it should be in conventional exploitation. This paper also presents the comparison in several equipment which is more suitable to be installed over subsea.

1. Introduction

Energy plays an important role in the history of human development. Firewood, coal, oil, natural gas and so on are considered as the energy resources for warmth, coking, automobile and other human activities until now. However, environmental problems associated with the use of the energy also began to appear, and tended to be more serious. One of the ways to solve the contradiction between environmental problems and energy demand is searching for new and clean energy resource.

Geothermal is a kind of sustainable energy and even when it is developed well, it can become a renewable energy. Geothermal come from subsurface which sometimes the manifestation of the energy can emerge to the earth surface. On land, the type of manifestation can be in kind of fumarole, geyser, hot spring, hot lake, steaming ground, or many others. These types of manifestation can also be found on seabed and one type of them is hydrothermal vent.

Thermal energy from geothermal manifestation can be exploited using various technologies depend on the characteristics of the manifestation itself. Organic Rankine Cycle (ORC) is a method for exploiting heat energy by using organic fluid instead of steam directly from evaporated water. In this paper, this ORC method, then, is used in model of electricity generation form thermal energy supplied by hot water flowed through hydrothermal vent.

2. Hydrothermal Vents

Hydrothermal vent is the result of seawater percolating down through fissures in the ocean crust in the vicinity of spreading centers or subduction zone (places on Earth where two tectonic plates move away or towards one another). The cold seawater is heated by hot magma and reemerges to form the vents. Seawater in hydrothermal vents may reach temperatures of over 340 ^{0}C. Hot seawater in hydrothermal vents often does not boil because of the extreme pressure at the depths where the vents are formed.

There are some 67 000 km of ocean ridges, 13 000 of them have been already studied discovering more than 280 sites with geothermal vents. Some of them with a thermal power of up to 60 MWt [2] but there are some of them really gigantic as the one in Rainbow with an output of 5 GWt [2].

Scientist first discovered hydrothermal vents in 1977 while exploring an oceanic spreading ridge near the Galapagos Islands. To their amazement, the scientists also found that the hydrothermal vents were surrounded by large numbers of organisms that had never been seen before. These biological communities depend upon chemical processes that result from the interaction of seawater and hot magma associated with underwater volcanoes [1].

3. Organic Rankine Cycle

Organic Rankine Cycle is conceptually similar to Steam Rankine Cycle in that it is based on the vaporization of a high pressure liquid which is in turn expanded to a lower pressure thus releasing mechanical work. The cycle is closed by condensing the low pressure vapour and pumping it back to the high pressure. Therefore, the ORC cycle involves the same components as a conventional steam power plant (a boiler, a work-producing expansion device, a condenser and a pump). However, the working fluid is an organic compound characterized by a lower ebullition temperature than water and allowing power generation from low heat source temperatures.

Low-temperature geothermal ORC plants are also characterized by relatively high auxiliary consumption: the pumps consume from 30% up to more than 50% of the gross output power. In conventional development of ORC, the main consumer of power is the brine pump that has to circulate the brine over large distance and with a significantly high flow rate. The working fluid pump consumption is also higher than in higher temperature cycles, because the ratio between pump consumption and turbine output power (“back work ratio”) increases with decreasing evaporation temperature.

4. Heat Exchanger

When installed over submarine, we need to do some modifications to the system of ORC. For the boiler, it is modelled here to use the external part of one extreme of the submarine that is the mouth of the vent itself. A heat exchanger in the form of a conic coil, then, is installed exactly at the top of the vent in a way that the hot water flows naturally through the coil, touching as much surface of the tubes as possible. This is the evaporator of the cycle. In the other extreme of the submarine, another heat exchanger is installed in the cold water of the surrounding sea, also in the shape of a conic coil.

Key characteristics regarding heat transfers are the efficiency (or pinch point) and pressure drops. Each heat exchanger in the cycle is sized according to these two parameters. Different type of heat exchangers can be used. In conventional use, the most common used heat exchangers are shell and tube (mainly in larger-scale systems) and plate heat exchangers (mainly in small-scale systems, due to their compactness).

Related to submarine geothermal exploitation, the design of heat exchanger should be modified to match with the site where it will be installed. The efficiency of the heat exchanger (boiler and condenser) is directly proportional to the touching area of geothermal fluid from the earth and the heat exchanger itself. Relation between the amounts of heat transferred in conduction is shown in the following equation:

$$\frac{Q}{t} = \frac{\mathrm{KA}(T_{hot} - T_{cold})}{d} \qquad (1)$$

where (K) is conductivity of the barrier, (A) area, (T) temperature, and (d) the thickness of barrier.

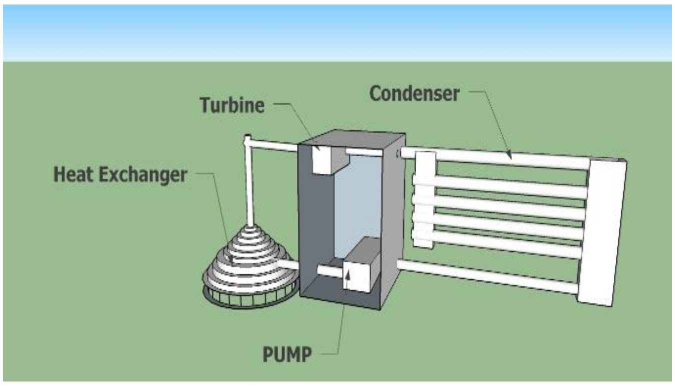

Figure 1. Schematic design of submarine geothermal exploitation machinery

5. Pump

The low pressure organic fluid come out from the condenser, then need to be pumped to become high pressure liquid before it goes through the boiler. A pump as the tools for pumping the fluid has big consumption of energy when used in ORC system compared to Stem Rankine Cycle system. The ratio between pump electrical consumption and expander output power is called Back Work Ratio (BWR):

$$BWR = \frac{\dot{W}_{pp}}{\dot{W}_{exp}} \qquad (2)$$

The pump efficiency is a crucial parameter in low temperature cycles and in trans critical cycles. Figure 2 give us a description about relation between fluid type and BWR value. From that figure, it can be concluded:

1. The higher the critical temperature of the working fluid, the lower the BWR.
2. BWR increases with T_{ev}, and gets significantly high when operating the cycle close to the critical point.

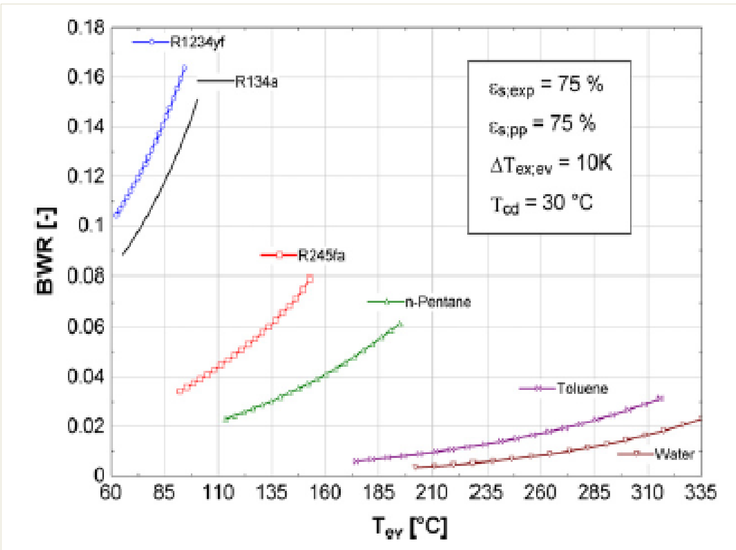

Figure 2.BWR as a function of evaporation temperature for different fluids [3].

6. Turbine

The performance of an ORC system strongly correlates with that of the expander. The choice of the technology depends on the operating conditions and on the size of the system. Three main types of machines can be distinguished: the turbo and positive displacement types [3].

The main feature of a turbine designed for the expansion of an organic Rankine fluid, typically rated less than 15 MW, is the overhung configuration, meaning an expander wheel, composed of maximum 3 stages supported by bearings on a single side. The main reason for this technological choice rather than a double-support (horizontally split or barrel casing) machine is the necessity to limit costs and ease maintenance, favouring at the same time the operation of the plat: the double support design implies two end shaft seal, doubling seals maintenance and eventual troubles. This technology currently represents the most common turbine technology for this application [4].

A second technology, with a minor share of the market, is the radial inflow expander: typically a high-speed integrally geared machine derived from gas expansion application and applied on some medium power geothermal binary plants.

A new type of turbine, developed by Exergy, defined the radial outflow turbine, combines the simplicity of the axial turbine with the efficiency of a radial inflow turbine (figure 3.).

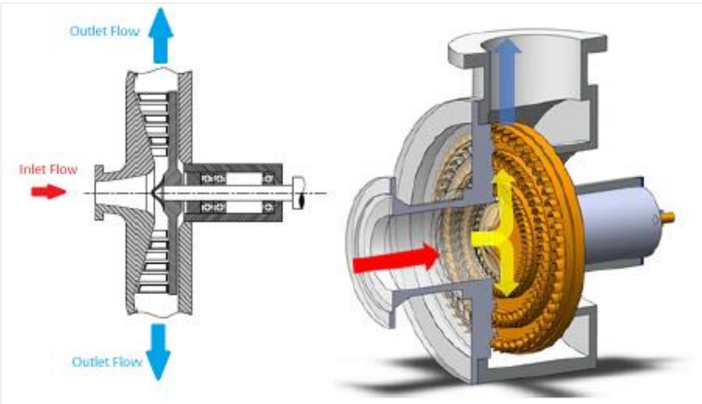

Figure 3. Cross sections of a typical radial outflow turbine [4].

This radial outflow turbine is composed of a series of radial stages, alternating one stator and one rotor blade ring per stage, fitted on one disk side all contained in a casing together with the discharge volute. The mechanical coupling between turbine disk and generator is completed by a system of seals and bearings supporting the overhung shaft [4].

Related to the utilization of this turbine in submarine geothermal manifestation, there are several advantages which make this type of turbine is more suitable, those are as follows:

- it has low vibration profile,
- it is the most efficient stages develop more enthalpy head, at the same pressure ratio,
- pressure difference favours expansion without major 3D effects,
- It has relatively low rotating speed, meaning direct coupling with the generator,
- It has limited overhung mechanical structure.

7. Energy Output Calculation

In calculation of energy output from hydrothermal vent, we use the assumption that the fluid discharged from the vent is at its saturation temperature. This is inferred to the maximum temperature of the fluid. Figure 4 show the maximum temperature that the water can attend in a hydrothermal vent and the maximum efficiency that can be achieved. In thermal cycle, the maximum efficiency which can be achieved is the Carnot Efficiency, that is$(1-\frac{T_1}{T_2})$. With T is the temperature of the cold and hot water respectively, in Kelvin. The Carnot efficiency presented in figure 4 is using the saturation temperature of the fluid from hydrothermal vent as (T_2) and the low temperature of sea water surrounding the vent as (T_1).

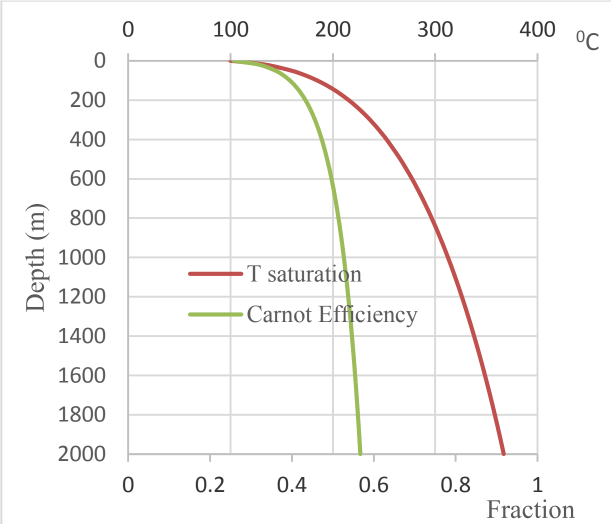

Figure 4. Saturation temperature and maximum efficiency (Carnot) as a function of depth.

Using the value given in figure 4, we can calculate an approximate electrical output of a given vent flowing at the highest temperature that it can have at certain depth. Assuming machine total efficiency is equal to 80%, thermal recovery efficiency 10%, and fluid velocity 1 m/s, the sensitivity analysis of energy output from several vent diameters and depths is described in figure 5.

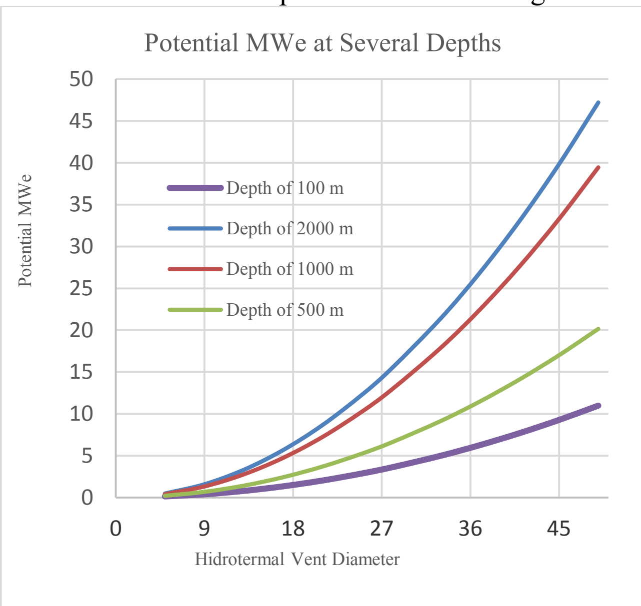

Figure 5. Potential MWe from hydrothermal vent at several depths at any given vent diameter.

The basic calculation of the diagram above is that by calculating the discharged mass of fluid which contains thermal energy. Multiplying the area of the vent with assumed fluid velocity will result the volumetric flowrate of the fluid. Then, when it multiplied again with the density and the enthalpy calculated from steam table, the resulting value is the total thermal energy output of the vent. Finally, the total electricity potential of the vent is achieved by multiplying the thermal energy with machinery efficiency and thermal recovery efficiency.

Hydrothermal vent is mostly found in depth of 2000 m. With a diameter ranging from several inches to tens of meters [1], choosing a middle value that is 27 inches will result a potential electricity from hydrothermal vent over 15 MWe.

This value of energy is big enough compared to the energy achieved from conventional development. In conventional development, the utilization of geothermal energy need of drilling several wells which is costly and not natural friendly.

8. Conclusion

Many surveys carried out around the world has given a description about the existence of hydrothermal vent over World Ocean. It is found that there are over 280 sites of hydrothermal vent exist from 13000 km studied of 67000 km oceanic ridges. With a big thermal produced from those vents, they become an object to be developed as future energy resources.

Detailed calculation of energy output using conservative value of overall efficiency give 15 MWe for one exploited hydrothermal vent.

With several constraints related to the environment, the technology is needed to be developed well for more appropriate environmentally. ORC system is best method to be used in this case. With well operated system, it will not discharge any material to the environment. So, the biota surrounding the exploited vent will not get any disturbance.

More research and development are needed to be done further. The challenge related to the utilization of energy from deep sea should be faced. But, considering the energy output that can be generated, this becomes more interesting compared with conventional development of geothermal energy onshore which need to drill several wells.

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