

Theoretic Research of Generating Electricity from Alternate Sources on a Natural Temperature Difference

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Abstract: It has put forward a concept of generating electricity from alternate sources on a natural temperature difference in this paper. There is an introduction of the utilization of energy as well as its developing tendency. It elaborates the principle of generating electricity with the analysis of the alternate sources and the working substance. On the supposed condition, it has made a thermodynamic analysis of the circulation. It has also calculated the thermal efficiency of the system on given parameters. Finally we can obtain the influencing factors of the thermal efficiency, which is valuable for the optimized design of the system.

Keywords: alternate sources, natural temperature difference, thermodynamic circulation, thermal efficiency.

NOMENCLATURE

m	mass flow rate [kg/s]
v	specific volume [m^3/kg]
V	volume [m^3]
s'	specific entropy of saturated liquid [kJ/(kg·K)]
s''	specific entropy of saturated steam [kJ/(kg·K)]
h	specific enthalpy [kJ/kg]
q	specific heat transferred [kJ/kg]
w_T	work done by the turbine [kJ/kg]
w_p	work done by the pump [kJ/kg]
η_t	thermal efficiency
P	power[kW]
Subscripts of s	isentropic
Subscripts of 1, 2, 3	states in system

1. INTRODUCTION

Energy and environment are two of the most concerning issues in the current world. Today we have consumed too many fossil fuels such as coal, oil and natural gas. Not only do fossil fuels have a limited life but also their combustion emissions have serious negative impacts on our environment such as adding to the greenhouse effect and causing acid rain. Reducing the amount of the fossil fuels consumed while supplying the sufficient power to meet the increasing demand is a tough task.

As a clean, free and non-depleting source, geothermal energy have been utilized mainly in two aspects: the high-temperature geothermal resources are used to generate electricity, the hot water exhausted by which system may carry on multilevel

uses; the medium-temperature and low-temperature geothermal resources are primarily used directly.

Since the distribution of geothermal resources is extremely unequal, it has become a hot spot to develop the low-potential thermal energy of the earth's surface. Being another form of the geothermal energy, it includes energy which contains in ground water, soil, river, seawater and so on. It has steady parameters. And it is not restricted by district or influenced by environment climates.

In the view of thermodynamics, it is possible to produce power where there is a difference in temperature. People in various countries are paying much attention to the technologies of generating electricity on temperature difference. One practical research is the technology of ocean thermal energy conversion as an electric generation. It has a broad prospect although there is a series of technical problems.

The research of this paper is to make use of the natural temperature difference between the soil and the surroundings. The authors have proposed a Rankine cycle system which can convert energy in the temperature difference into the mechanical energy, then convert it through the electric power facility into the electrical energy. It assures the system work continuously the whole year with alternate sources in winter and summer.

2. THE PRINCIPLE OF GENERATING ELECTRICITY FROM ALTERNATE SOURCES ON A NATURAL TEMPERATURE DIFFERENCE

2.1 Principle Description

As is shown in Fig.1, E represents evaporator, S is superheater, T is turbine, G is generator, C is condenser and P is the feed pump.

The system is a closed cycle using the low boiling point working fluid. In winter, the working fluid absorbs heat from the high temperature source which is the energy contained in the soil six meters below the ground. Then it becomes a high pressure steam, the temperature of which increases after passing through the superheater. This steam enters the steam turbine, expanding and working in it. The turbine drives the generator to work. The steam leaves the turbine at a low pressure. It is condensed to the form of liquid at a low temperature and low pressure in the air cooling condenser. The working fluid is then pumped into the evaporator. This is a Rankine Cycle.

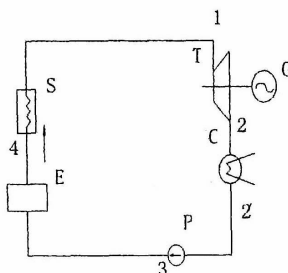


Figure 1: The system of generating electricity from alternate sources on a temperature difference

In summer, when ambient temperature increases to an extent that it can not condense the steam, it starts up the assistant facility on the ground to heat up the working fluid. The working steam passes through the superheater and turbine and enters the high temperature source in winter which has turned its role into the low temperature source.

The evaporator is the type of cooling liquid in winter while cooling air in summer. The condenser is the type of cooling air when in summer the type of cooling water. The roles of the evaporator and condenser are alternated by the valves which are not included in Figure 1.

The thermal energy from burning down the garbage is considered as assistant heating source.

2.2 Analysis of Alternate Sources

High temperature source: in winter, we choose the soil six meters below the ground. In summer, we may choose the surroundings which have received the heat from air convection and the solar radiation. After the heat extracting in winter the temperature of the original high temperature source will be the boiling temperature of the working fluid. It can certainly take the part of low temperature source in summer. After the heat absorption its temperature will increase to the original number, therefore it can be the high temperature source in winter again.

Low temperature source: in winter we choose the surroundings of northern area which have enough period of cold. In summer we choose the original high temperature source.

Local conditions: the temperature can reach to -10 °C for nearly four months in North and other plateau areas) in winter when the temperature of the soil six meters

below the ground maintains at 15 °C. The temperature difference is 25 °C, which has a great ability to generate electricity.

2.3 Analysis of working Fluid

The properties of the working fluid to the low enthalpy difference Rankine cycle is not easy to satisfy completely. According to the present system of ocean electric generation on temperature difference, ammonia and R22 are widely used as the working fluid. The comparisons of ammonia and R22 are as Table 1 depicts, which are based on the following data: the temperature of saturated steam is 23°C, the condensation temperature is 9°C, the relative inner efficiency is 40%, the power generation is 0.2 kW and the efficiency of the generator is 0.75.

The ammonia has better thermodynamic properties than R22, as we can see from Table 1, and the mass needed of R22 is six times than that of ammonia. Other aspects should be taken into consideration. To ammonia, the ozone depletion potential ODP=0 and the global warming potential GWP=0. Although poisonous it has easy leak detection due to the special smell. It has been utilized safely for over 100 years. Besides, it is easy to purchase because of the low cost.

Table 1: Comparisons of thermodynamic properties between ammonia and R22

items	ammonia	R22
Absolute pressure of inlet [kPa]	944.65	988.67
Enthalpy of saturated Steam [kJ/kg]	1394.38	412.756
Specific volume of saturated steam [m³/kg]	0.1347	0.0239
Absolute pressure of outlet [kPa]	595.34	660.62
Ideal enthalpy of outlet [kJ/kg]	1337.64	403.34
The drying extent of outlet	0.96	0.974
Ideal enthalpy fall of turbine [kJ/kg]	56.74	9.416
Effective enthalpy fall of turbine [kJ/kg]	22.70	3.77
Output power [kW]	0.200	0.200
Mass of working fluid [kg]	45.52	272.83
Pressure fall in the turbine [kpa]	349.31	328.25

3. THERMODYNAMIC ANALYSIS OF THE CYCLE

3.1 Presumptive Conditions

In winter as the system absorbs heat continually from the high temperature source the temperature near the evaporator changes. This paper is to discuss the system thermal efficiency on Rankine cycle only considering the constant heat source. That is to work out the mass of the working fluid when generating 1 kilowatt electricity namely the capacity of generating electricity when the mass of the working fluid is 1

kilogram. Besides, the performance of heat-exchanger which absorbs or emits heat to the soil will be influenced by many factors as thermal capacity of the soil, the way of heat transfer and the coefficient of heat transfer. That goes beyond the field of this paper.

3.2 Thermodynamic Cycle

The process of thermodynamic cycle is shown as Figure 1.

The working fluid absorbs heat at a constant pressure in the evaporator and becomes saturated steam. It has become the superheated steam after further heat absorption in the superheater. The steam expands and works in the turbine. The steam exhausted from the steam turbine emits heat to the cooling water and condenses to the state of liquid. Heightening the pressure by the pump the liquid enters the evaporator. And a cycle is completed.

In the process of Rankine cycle the condensation of exhaust steam from the turbine is complete on reaching to 2'. The complete condensation adds a heat up process 3-4 to the cycle. Consequently the average temperature difference decreases which is unfriendly to the thermal efficiency whereas favorable to simplify the facility. It is much easier to compress the liquid state of the working fluid of which the specific volume is v_2 than the wet steam. Hence it is a heating process isobaric other than isothermal which has made advantages over increasing the average temperature difference of the cycle and dry extent of the exhausted steam.

3.3 Thermal Efficiency Analysis

The four processes of a Rankine cycle, as shown in Figure 2, can be described as follows:

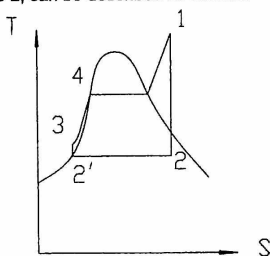


Figure 2: the processes of Rankine cycle

1-2: This is the stage that the turbine converts heat into work. Ideally, this is an isentropic process. The working fluid is in the state of low-pressure wet steam indicated by point 2 at the exit of the turbine.

2-2': This is the isobaric condensation stage also an isothermal stage. The steam exhausted from the turbine emits heat to the cooling water and condenses to the state of saturated liquid.

2'-3: This is the isentropic process that the condensed working fluid is compressed by the feed pump. At an increased pressure it enters the evaporator again. It is a process that needs external work.

3-1: This is the isobaric heating stage that the high pressure liquid state of working fluid converts from the unsaturated liquid to superheated steam.

Thus a Rankine cycle completed. The following discussions are based on conditions that the mass of working fluid is one kilogram.

The work done by the turbine is

$$w_T = h_1 - h_2$$

The work done by the pump is

$$w_p = h_3 - h_{2'}$$

The heat transferred from the evaporator to the working fluid is

$$q_1 = h_1 - h_3$$

The heat transferred from the condenser to the cooling water is

$$q_2 = h_2 - h_{2'}$$

The net work of the cycle is

$$w_0 = w_T - w_p = (h_1 - h_2) - (h_3 - h_{2'})$$

The net heat of the cycle is

$$q_0 = q_1 - q_2 = (h_1 - h_3) - (h_2 - h_{2'}) = (h_1 - h_2) - (h_3 - h_{2'})$$

It is obvious that $q_0 = w_0$

The thermal efficiency of the cycle is

$$\eta_t = \frac{w_0}{q_1} = \frac{q_1 - q_2}{q_1} = \frac{(h_1 - h_2) - (h_3 - h_{2'})}{h_1 - h_3} = \frac{w_T - w_p}{q_1}$$

We can obtained that

$$\eta_t = \frac{(h_1 - h_2) - (h_3 - h_{2'})}{(h_1 - h_{2'}) - (h_3 - h_{2'})} = \frac{(h_1 - h_2) - w_p}{(h_1 - h_{2'}) - w_p}$$

When simplifying the formula the work done by the pump can be omitted as w_p is much smaller than

$(h_1 - h_2)$ and $(h_1 - h_{2'})$. It has little influence on the accuracy of the calculation and it is convenient to analyze the influential factors of the thermal efficiency. Therefore the approximate expression of thermal efficiency is

$$\eta_t = \frac{h_1 - h_2}{h_1 - h_{2'}}$$

3.4 Calculations of Thermal Efficiency

The relevant parameters are obtained by the thermal property chart of the ammonia and p-h chart on given properties. Calculations of Thermal Efficiency in winter and summer are as follows:

In winter: assume that the temperature of the condenser $t_c = -20^\circ\text{C}$ ($p_c = 190.15\text{kPa}$) and $p_1 = 730.07\text{kPa}$ ($t_h = 15^\circ\text{C}$), $t_1 = 25^\circ\text{C}$.

Parameters of point 1:

$$h_1 = 1417.59\text{ kJ/kg}, s_1 = 3.064\text{ kJ/(kg} \cdot \text{K)},$$

$$v_1 = 0.1819\text{ m}^3/\text{kg}.$$

Parameters of point 2: $p_2=190.15\text{ kPa}$,

($t_s=20^\circ\text{C}$), $s'=-1.79237\text{ kJ}/(\text{kg}\cdot\text{K})$, $s''=3.45736\text{ kJ}/(\text{kg}\cdot\text{K})$.

$h'=27.891\text{ kJ}/\text{kg}$, $h''=1356.861\text{ kJ}/\text{kg}$

$$x_{2s} = \frac{3.064 - (-1.79237)}{3.45736 - (-1.79237)} = 0.925.$$

$$h_{2s} = 27.891 + 0.925 \times (1356.861 - 27.891) = 1257.$$

3 kJ/kg

$$h_2 = h_1 - \eta_c(h_1 - h_{2s}) = 1417.59 - 0.8 \times (1417.59 - 1257.3) = 1289.36\text{ kJ/kg}$$

$$w_T = h_1 - h_2 = 1417.59 - 1289.36 = 128.23\text{ kJ/kg}$$

$$x_2 = \frac{1289.36 - 27.897}{1356.861 - 27.897} = 0.95$$

If the output power is $P_1=1\text{ kW}$, the mass of the working fluid is $m = \frac{1}{128.23} \times 3600 = 28.07\text{ kg/h}$

The temperature is -20°C , $v=1.50347 \times 10^{-3}\text{ m}^3/\text{kg}$

$$V = 28.07 \times 1.50347 \times 10^{-3} = 42.15 \times 10^{-3}\text{ m}^3/\text{h},$$

The work done by the pump is

$$P_2 = \frac{V(p_1 - p_2)}{3600\eta_c} = \frac{42.15 \times 10^{-3} (730.07 - 190.15)}{3600 \times 0.6} = 0.01\text{ kW}$$

η_c is the pump efficiency. We can omit the power of the pump since it is quite small compared to the output power of the system.

$$q_1 = 1417.59 - 27.891 = 1389.699\text{ kJ/kg},$$

the thermal efficiency is:

$$\eta_t = \frac{w_T}{q_1} = \frac{128.23}{1389.699} = 9.2\%$$

In summer:

1. Assume that $p_1=859.22\text{ kPa}$, ($t_s=20^\circ\text{C}$),

$$t_1=55^\circ\text{C}, p_2=516.79\text{ kPa}, (t_s=5^\circ\text{C}).$$

The working fluid is converted from saturated steam of 20°C to superheated steam of 55°C in the superheater.

Parameters of point 1: $h_1=1488.09\text{ kJ/kg}$,

$$s_1=3.215\text{ kJ}/(\text{kg}\cdot\text{K})$$

Parameters of point 2: $s''=3.0995\text{ kJ}/(\text{kg}\cdot\text{K})$,

$$s_2=s_1=3.215\text{ kJ}/(\text{kg}\cdot\text{K}),$$

Thus it is superheated steam. $h_{2s}=1416.54\text{ kJ/kg}$,

$$h_2=1488.09 - 0.8 \times (1488.09 - 1416.54) = 1430.85$$

$$w_T = h_1 - h_2 = 1488.09 - 1430.85 = 57.24\text{ kJ/kg},$$

$$m = \frac{1}{57.24} \times 3600 = 63\text{ kg/h}$$

$$q_1 = 1488.09 - 418.09 = 1070\text{ kJ/kg}$$

$$\eta_t = \frac{w_T}{q_1} = \frac{57.24}{1070} = 5.3\%$$

2. Assume that $p_1=1005.1\text{ kPa}$, $t_s=28^\circ\text{C}$,

$$t_1=55^\circ\text{C} (t_s=5^\circ\text{C}), p_2=516.79\text{ kPa},$$

Parameters of point 1: $h_1=1479.73\text{ kJ/kg}$,

$$s_1=3.119\text{ kJ}/(\text{kg}\cdot\text{K})$$

Parameters of point 2: $s''=3.0995\text{ kJ}/(\text{kg}\cdot\text{K})$

$$h_{2s}=1389.03\text{ kJ/kg}$$

$$h_2=1479.73 - 0.8 \times (1479.73 - 1389.03) = 1407.17$$

kJ/kg

$$w_T = 1479.73 - 1407.17 = 72.56\text{ kJ/kg}.$$

$$q_1 = 1479.73 - 350.01 = 1129.72\text{ kJ/kg}$$

$$\eta_t = \frac{w_T}{q_1} = \frac{72.56}{1129.72} = 8.9\%$$

3. Assume that $p_1=859.22\text{ kPa}$, ($t_s=20^\circ\text{C}$),

$$t_1=50^\circ\text{C}, p_2=430.17\text{ kPa}, (t_s=0^\circ\text{C}).$$

Parameters of point 1: $h_1=1474.99\text{ kJ/kg}$,

$$s_1=3.175\text{ kJ}/(\text{kg}\cdot\text{K}),$$

Parameters of point 2: $p_2=430.17\text{ kPa}$, $s''=3.167$

kJ/(kg·K),

$$h_{2s}=1381.4\text{ kJ/kg}$$

$$h_2=1474.99 - 0.8 \times (1474.99 - 1381.4) = 1400.12$$

kJ/kg

$$w_T = h_1 - h_2 = 1474.99 - 1400.12 = 74.87\text{ kJ/kg},$$

$$q_1 = 1474.99 - 373.23 = 1101.76\text{ kJ/kg}$$

$$\eta_t = \frac{w_T}{q_1} = \frac{74.87}{1101.76} = 6.8\%$$

4. ANALYSIS OF INFLUENTIAL FACTORS

4.1 The Influence to Thermal Efficiency of Initial Temperatures t_1

Under the same initial and back pressure, it is able to improve the thermal efficiency by increasing the temperature of inlet steam. This is because increasing t_1 to t_{1a} , as Fig.3 depicts, has added a heat state of high temperature, which increases the temperature difference of the cycle. However, increasing the temperature of inlet steam is limited by the material thermal durability.

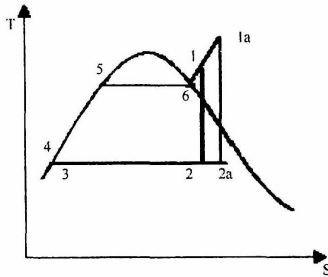


Figure3: the influence to η_i of t_1

4.2 The influence to Thermal Efficiency of Initial pressure p_1

Under the same initial temperature and the back pressure, it is also able to improve the thermal efficiency by increasing the pressure of inlet steam. This is because the temperature difference increases when increasing initial pressure p_1 , as is shown in Fig.4. Increasing p_1 might bring a possibility of corrosion to blades in turbine which can be counteracted by increasing t_1 simultaneously.

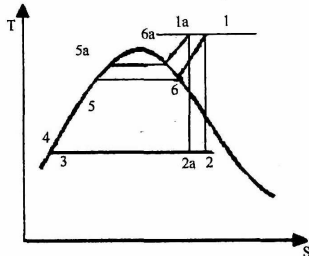


Figure 4: the influence to η_i of p_1

4.3 The influence to Thermal Efficiency of back pressure p_2

Under the same p_1 and t_1 reducing the back pressure p_2 can also improve the thermal efficiency because of the increase in temperature difference, as is shown in Fig.5. Reducing p_2 means decrease of the saturated temperature t_2 whereas it must be higher than that of the surroundings, therefore it is limited. In addition, reducing p_2 must be along with increasing t_1 otherwise there is the same consequence as increasing p_1 alone.

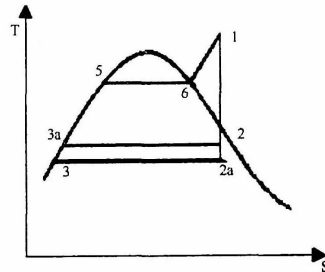


Figure 5: the influence of η_i of p_2

5. CONCLUSIONS

The concept of generating electricity from alternate sources on a natural temperature difference is put forward in this paper. It has analyzed the alternate sources and the working fluid. From the studies above we can conclude that the soil six meters below the ground takes the role of alternate source perfectly and ammonia satisfies the properties of working fluid. Finally the influential factors to thermal efficiency are analyzed on the calculation of thermal efficiency and knowledge of Rankine cycle.

This is a significant research because the energy contained in the soil is not restricted by district and it is easy to actualize in technology. Especially in cold district the value of it is considerable.

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