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Seabed sediment – a natural seasonal heat storage feasibility study

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Abstract. The new discovery among renewable energy resources, seabed sediment, has been utilised as a heat source for 42 houses in Vaasa since 2008. Sediment heat is annually loaded by the Sun. In this study the amount of annually charged energy is estimated. The difference of sediment temperatures between the coldest and the warmest month during the year is a key value in the approximation of the loaded energy. Sediment temperatures are measured once per month via optical cable by distributed temperature sensing (DTS) method. The monitoring period is three years, 2014–2016. The estimation of incoming energy (575 MWh) versus known exploited energy (560 MWh) is reasonable. Despite of the extraction this seasonal heat storage in the seabed of the Baltic Sea seems to reload well annually.

Key words: renewable energy, sediment heat, distributed temperature sensing, heat storage.

INTRODUCTION

Renewable, Sun-based energies are often available when the need of energies is low. Especially in the Northern countries, the demand of heat is greater in wintertime but a lot of renewable heat is available in summertime. Due to the seasonal nature of the solar energy, its utilisation requires storing. Water tanks, bedrock batteries and aquifers are the most used applications as heat storages. Old flooded mines have also been studied as potential heat storages (Watzlaf et al., 2006; Martinkauppi & Hiltunen, 2015). There are also natural seasonal heat storages like seabed sediment. The natural seasonal storing guarantees that the heat is available in winter time when the heating season is going on. The advantages of natural storage are also automatical annual function, fewer infrastructure constructions and thus less CO_2 emissions.The aim of this study is to estimate the amount of reloaded energy. This will help to estimate how much energy is exploited without detrimental effects.

Local renewable energy sources are available almost everywhere on Earth. The seabed sediment heat is one geothermal heat energy source which has been utilized in Vaasa, Finland since 2008. Actually the heat of this source is mainly coming from the Sun which is a common feature of natural heat sources in the upper crust. In Finland, the seasonal variation in air temperatures is observed to correlate even to the depth of 10–15 meters from the soil surface (Mäkiranta et al., 2016a).

Geological Survey of Finland made a geological analysis of the sediment in Suvilahti area in 2006. They also measured the sediment temperatures in house fair area in 2008–2009 (Martinkauppi, 2013). Valpola (2007) discovered that the annual air temperature variation is observed only to the depth of 3 m in the seabed sediment in Vaasa area. Instead in the ground that variation is observed even to the depth of 10–15 m. The Research group of Renewable Energies from University of Vaasa continued temperature measurements in 2013 in the same site, Suvilahti suburb.

Hiltunen et al. (2015) and Mäkiranta et al. (2016b) have investigated the dependency between the air temperature, the sediment heat collection fluid (water ethanol mixture) temperature and the sediment temperature on the residential area which is utilizing the seabed sediment as a heat source. They observed that there is a clear correlation between the heat carrier liquid temperature and the sediment temperature of the next month and the temperatures of the same month as well. The conclusions of that study were that there is heat energy sufficiently available for all the houses included in the low energy network, the collection pipeline is sized correctly.

In this study, the annual recovery of the sediment heat is examined. The annually loaded energy is estimated by means of the seasonal temperature variation in sediment when the composition of sediment is known to be wet clay.

MATERIALS AND METHODS

Seabed sediment has been utilised since 2008 as a heat source in the residential area in Vaasa next to the Gulf of Bothnia in the Baltic Sea. This low energy network is used for heating and cooling houses throughout the year. The main heating season starts on October continuing to May. During the summer season cooling is used occasionally. Instead the loading occurs from April to October. The sediment temperature measurements have been executed there starting from the year 2013 by the Renewable Energy Research group of University of Vaasa. The used measurement method is distributed temperature sensing (DTS) method and the device is a product of Sensornet, Oryx DTS. The method and more detailed description of measurements are presented by Mäkiranta et al. (2016c).

Figure 1. The measurement site is located in Ketunkatu street. A box including optical fibers with connectors is placed in the distribution well.

There is assembled an optical cable along one heat collection pipe in Ketunkatu street (Fig.1). In measurement session the laser pulse travels along the optical glass fiber inside the cable. So the cable functions as a thermal profile sensor transferring temperature data with spatial resolution of 1 meter. The cable is 300 meters long and it is diagonally drilled to the depth of 3–4 meters, see Fig. 2. During the drilling action there was noticed some rocks and the direction of drilling had to be changed. Because of this variety in the composition of sediment layer the depth position of cable may vary from the supposed one.

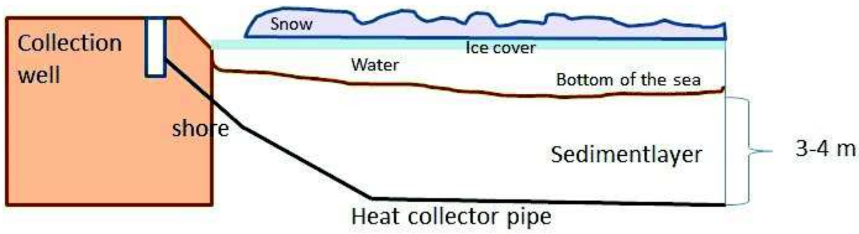

Figure 2. The conjectural position of the collection pipe and measurement cable along it in the seabed sediment is visualized in this graphical presentation. (not in scale).

The measurements were made once per month throughout the years. To discover the annual reloading of sediment heat the temperature difference between the warmest and the coldest month of the year were calculated. Year 2013 was measured only partly, thus the first year for observing the reloading of the seabed sediment heat was 2014. The highest sediment temperatures were observed in October 2014, 2015 and 2016. Instead the time of the coldest month varied being February in 2014 and March in 2015 and 2016. The temperature difference curves are shown in Fig. 3. The *x*-axis shows the length and the distance of the cable from the shore. The zero point is on the shore in the well and the sediment layer occurs after about 5 meters distance from the well. The first hundred meter is partly covered by reeds and there is located a pedestrian route with a bridge, too. They may have an effect on temperatures. Therefore, the starting point for calculating the differences was decided to be at 100 meter distance from the shore. The sediment temperature differences are presented 100–300 meters distance from the shore in years 2014–2016 in Fig. 3.

According to the Finnish Meteorological Institute (2017) the annual average air temperature in Finland during the year 2016 was the warmest compared to the long term average in 1981–2010. Sediment temperatures in 2016 were indicating the warming too. Based on the previous research by Mäkiranta et al. (2016b) the sediment temperature correlates strongly with the air temperature of two previous months.

The amount of annually loaded energy in the sediment layer is estimated with help of the facts that how much energy is bound to close range around the collection pipe while the annual temperature variation in sediment is known. The calculated energy is compared to the experimental extraction of energy which is known to be 560 MWh per year in the low energy network (Energy Vaasa, 2016).

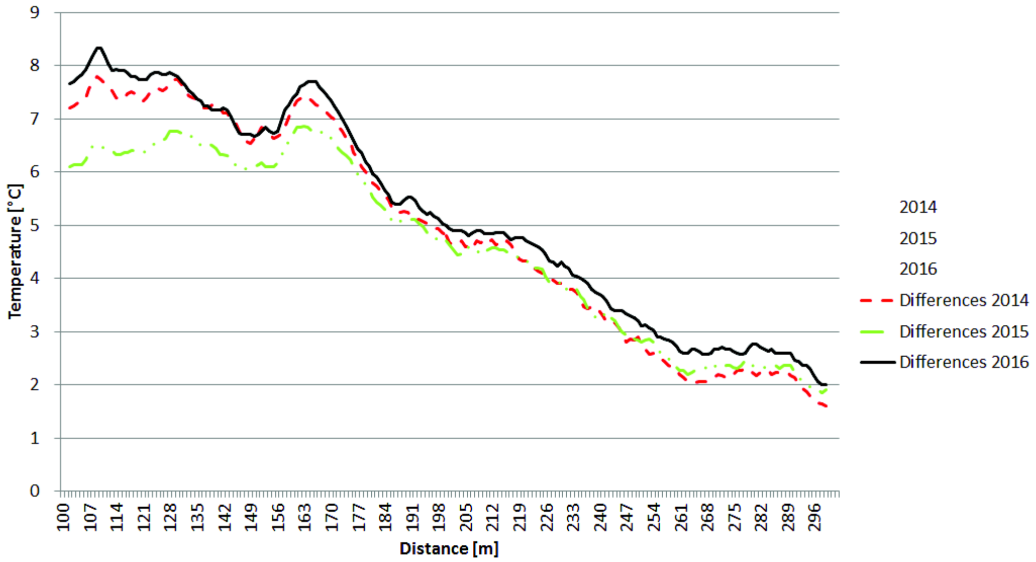

Figure 3. Temperature differences between the warmest and the coldest months during three annual loading periods in 2014, 2015 and 2016 as a function of length and distance of the cable from the shore. (Note: data is smoothed in Excel with the following option: moving averages with period 3, as the original data is very noisy).

The estimation of loaded and later extracted energy by the Sun is calculated as follows. First, the volume

$$V = \pi r^2 h \tag{1}$$

The volume of heat collection pipeline (26 pipes, h = 300 m, Ø = 84 mm) in the sediment is 43 m³ calculated with Eq. 1. The volume of seabed sediment around the pipeline with a radius of 2 m is 98.0 10^3 m³. The mass of the volume is calculated using the basic formula (Eq. 2):

$$m = \rho \cdot V \tag{2}$$

The calculation gives the value of mass as 172 10^6 kg when density of wet clay ρ = 1,760 kg m^{-3} is used. The heat energy is:

$$Q = cm\Delta T \tag{3}$$

The quantity of heat energy Q in the seabed sediment for heat collection is calculated with help of Eq. (3), when the average variation of annual sediment temperature (ΔT) is 5 °C and specific heat capacity of wet clay c =2.4 kJ kg^{-1} °C. By using these consumptions the quantity of heat energy is counted to be 2,070 10^6 kJ which is equal to 575 MWh.

RESULTS AND DISCUSSION

The absolute temperatures at the distances of 100–170 m are variating from 3–14 °C. This reveals that the depth of the heat collection pipe is not more than 3 m. The annual air temperature variation is clearly affecting to the sediment temperatures. Instead the effect of air temperature is not noticed in winter months measured sediment temperatures. The ice cover and snow form an isolating layer against the effect of the air temperature.

The absolute temperatures at the distances of 180–230 m variate from 5–12 °C and at the distances 240–300 m about 6–10 °C throughout the year. According to these last values (h = 300 m - 240 m = 60 m and ΔT = 10 °C – 6 °C = 4 °C), the heat energy Q = 92 MWh is available in the sediment layer.

The temperature difference (ΔT) between the warmest and the coolest month remain almost at the same level year after year. The variation is only between 0–2 °C and the difference curve follows the same shape every year. After 180 m distance the variation in the temperature differences is about 0.5 °C. This may indicate the fact that the sediment heat collection pipe is located deeper in the sediment layer at the distance of 180–300 m than closer to the shore. Thus the air temperature has not such a great impact on the sediment temperature.

The annual variation of the sediment temperature indicates the fact that the heat energy is truly naturally loaded to the seabed sediment despite of the usage for heating houses in the residential area.

The estimation of incoming energy compared to known exploited energy is reasonable when the estimated influence area`s radius is 1°m around the heat collection pipe and ΔT = 5 °C. The annual extraction of energy is 560°MWh and the calculated value for annually loaded heat energy is 575°MWh. Despite of the extraction the sediment heat seems to reload well annually.

CONCLUSIONS

Sediment temperature measurements were made once per month for three years period by using distributed temperature sensing (DTS) method. With help of the temperature differences of coldest and warmest month the annual reloading of heat was calculated and verified. The stage of annual charging may vary due to the average air temperature level of the year but still the variation is only 0–2 °C. Regardless of the heat extraction the annual reloading of sediment heat seems to be complete and even in the long run no cooling is expected.

This study shows that nature formulates seasonal storages to the watercourse sediment layers. The renewable heat will stay there waiting for the utilization.

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