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Renewable, carbon-free heat production from urban and rural water areas

E. Hiltunen [a], B. Martinkauppi [a, *], L. Zhu [a], A. Mäkiranta [a], M. Lieskoski [b], J. Rinta-Luoma [a]

[a] University of Vaasa, Wolffintie 34, 65200 Vaasa, Finland
[b] Geo-Pipe GP Oy, Konsterinkuja 5, 65280 Vaasa, Finland

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ABSTRACT

A new renewable and carbon-free heat energy collection system is introduced in this paper for both urban and rural water areas. Its operation principle rests on the annual renewal of heat energy at the sediment layer under a water body. Thus it is called as sediment heat energy collection system. It has some resemblance with other heat collection systems, and the most important points of these resemblances and differences are discussed in this paper. Several other aspects of sediment and water-area-related energy production are suggested by earlier studies and four of them are reviewed and compared to the suggested system. The sediment heat energy collection system has been installed 2008 for a small district to provide heating/cooling and hot service water as well. The performance analysis of the installed system includes a measure for sediment temperature and consumption of electricity, and user experiences prove the validity of the method.

1. Introduction

Urban energy is the energy which already exists in urban, built and constructed areas. People often think that energy is always imported to the cities or at least it is coming from energy production plants at the countryside. On the contrary, there is a lot of renewable energy in the urban areas where it can be collected even with small distributed systems. The main limitations of adapting to the use of renewable energy are lack of knowledge and shortage of suitable methods for energy harvest. Since the cities have wires and tubes in the ground as well as in the air, it is challengeable and restrictive to build an energy harvest system in those areas. The convenience and approval of the people living in towns is essential to take into account when wind turbines, larger solar collectors or geothermal energy is planned to be built.

In this paper it is described a new approach suitable for urban and rural renewable energy production. It is expected to overcome urban energy limitations and challenges which has been mentioned above. In this approach, the heat energy is collected from solid layers at bottoms of water bodies. These layers consist of sediments and thus the approach is called “sediment energy”. The sediment energy is truly renewable energy – it is renewed annually. The main part of its heat energy is from the Sun and a very minor part is from the Earth's geothermal energy. Sediments and water bodies have also been subjected to other studies related to energy production. A review of four other sediment-related approaches has been presented in Chapter 2. The sediment energy system itself is described in detail in Chapter 3.

The sediment energy system is installed for supplying heat and service water for a very small district with 42 houses. The usability of the system has been demonstrated by measuring the sediment temperatures as well as showing the energy consumption. The results indicate that the sediment heat energy is a worthy candidate to heat houses and to produce the hot service water. Since the sediment heat energy is related to other ground source heat systems like borehole heat collection systems and pond- and lake-based ground heat systems, a discussion is provided to show their similarities and differences.

2. A review of some previous studies on sediment related energy production issues

The word “sediment” refers here to the soil existing under ooze layers located at the bottom of water bodies. Sediments are found

* Corresponding author.
E-mail addresses: birmar@uva.fi, jbirgittamartinkauppi@luukku.com (B. Martinkauppi).

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in lakes, rivers, reservoirs, bays and shallow sea, and they are in this area rich in organic matters usually derived from aquatic phytoplankton and vascular plants, including land plants and macrophytes (Woszczyk et al., 2011). The formation of sediment deposits is promoted by a high level of primary productivity, low influent rate of inorganic matters, high sedimentation rate, low water dynamics, and oxygen depletion.

Sediment compositions vary greatly among water bodies and are affected strongly by land-plant productivity, algal productivity, transport processes and climate conditions (Yang et al., 2011). Fang et al. (2014) found that the total organic carbon (TOC) concentrations of sedimentary sludge in the Lake Dianchi (China) ranged from 0.8 to 1.9%, while Woszczyk et al. (2011) discovered that the surface sediment in the Lake Sarbsko (Poland) was characterized by a TOC content between 0.3 and 18.5%, with most samples rich in TOC (>5%). The ranges of TOC and total nitrogen (TN) at 0.36–0.76% and 0.04–0.09%, respectively, were obtained during the analysis of sea bay sediments (Wang et al., 2013). The average concentrations of TOC and TN in the Yangtze River were found to be 0.79% and 0.10%, respectively (Yang et al., 2011). This variability in compositions enables different applications for sediment usage.

Brine and fresh water sediment-related energy production is a promising avenue due to their abundance. A short review is provided with four previous approaches and their aspects: sediment-based power collection using anodes and cathodes, sediment collection for burning or biogas production, gas hydrate collection from sediment and algae collection for biofuel applications.

2.1. Power collection using sediments from marine or fresh water environment

Many research instruments and vehicles need to be operated long time on sea or lakes without any outer supply current, which would make on-the-spot energy collection very useful (e.g. Wilcock and Kauffman, 1997). One solution would be the use of sediment – especially marine sediment – as a part of this kind of power collection system. For example, a collection system called sediment microbial fuel cell has been suggested and its operation is based on the oxidization of organic matter of sediment by bacteria, causing electricity formation.

As early as 2001, Reimers et al. suggested a collection of energy from marine sediment–water interface (Reimers et al., 2001). The researchers placed one electrode in marine sediment and another one in seawater in the experiments (Fig. 1). This anode–cathode system is the basic structure for the fuel cell. Reimers et al. demonstrated in their laboratory aquaria that the system was able to collect a low level power caused by microbe-based voltage gradients at marine sediments. The power obtained was on the order of 0.01 W/m^2 per geometric area of the electrode.

Tender et al. stated that the power generation is at least from two anode reactions (Tender et al., 2002). The first reaction is caused by micro-organisms close to the anode to oxidize the sedimentary organic carbon. This oxidation produces a by-product, sediment sulfide, which is then again oxidized during the second reaction. Anode materials and their processes were studied further by Lowy et al. (2006). In that study, the anodic current was demonstrated to be notable due to oxidation process of the organic matter of sediment. Micro-organisms on the anode were catalyzing the oxidation. Later Nielsen et al. suggested a chamber-based fuel cell (Nielsen et al., 2007).

Available power density is limited by the quantity of organic sediment ingredient which causes the voltage gradient via oxidation process. One inherent property of most marine sediments is, however, relatively low level content of organic ingredient. Rezaei et al. suggested increasing chitins or cellulose to the anode side to increase the power generation (Rezaei et al., 2007). The tests with substrates showed a significant improvement in the maximum power density.

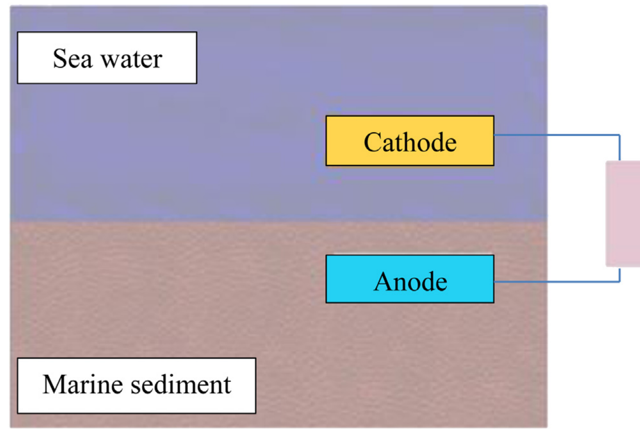

Fig. 1. Microbial fuel cell with an anode in marine sediment and a cathode in sea water.

The power collection from micro-organism is not limited to brine water environments. For example, Hong et al. made the studies in fresh water environment: physico-chemical properties of sediment organic matter were changed during electrical current production from fresh water sediments in the microbial fuel cell (Hong et al., 2010). Micro-organisms, which cause the oxidation of organic maters, are studied and analyzed e.g. in Holmes et al. (2004a,b). The study of Holmes et al. encompassed microbes from marine, salt-marsh and freshwater sediments (Holmes et al., 2004b). The sediment microbial fuel cell is still a promising and quite new approach. So far, the cell has not achieved wider usage probably due to early state of its development as well as limited available energy in sediments.

2.2. Sediment for burning or biogas production

Energy production capabilities of sediments have been tested by burning them, by using them in biogas formation, and by evaluating their content. The first phase in all cases is the collection of sediment from the bottom of a water body, for example, via a floating excavator or a suction dredger or some other means. The collection methods affect on the yield of sediment, so its selection is an important parameter by itself: the floating excavator method provides a high yield of sediment with approximately 80% water content while the suction dredger provides a small amount of dry matter (Saarela, 2012).

The sediment collection itself may cause disturbances and murky in water but its duration might be only few days (Saarela, 2012). The collection might not be suitable for some areas, for example, if it releases dangerous elements or substances from the bottom or causes inconvenience for local people. If sediments are used for burning or biogas production, more than two weeks should be allocated for drying process of the collected sediment (Saarela, 2012) as well as a suitable space for the process. Sediment quality or suitability can be evaluated in advance by measuring its total organic carbon/total nitrogen (TOC/TN) ratio, analyzing its heavy metal content or determining its available energy capacity.

The TOC/TN ratio is also an important indicator for the feasibility of sediment burning or biogas production. The ratio varies with different organic matter sources. For example, bacteria have usually approximately 2.6–4.3 for the TOC/TN ratio, phytoplankton ranges from 6.7 to 10.1 and high terrestrial plants are generally greater