Applied Thermal Engineering 105 (2016) 577–593

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Energetic and economic feasibility analysis of utilizing waste heat from incineration facility and power plant for large-scale horticulture facilities

Keum Ho Lee [a], Jae Ho Lee [a], Kwang Ho Lee [a,*], Doosam Song [b]

[a] Department of Architectural Engineering, Hanbat National University, San 16-1, Dukmyung-Dong, Yuseong-Gu, Daejeon 305-719, South Korea
[b] Department of Architectural Engineering, Sungkyunkwan University, 2066 Seoburo, Suwon, Gyeonggi 440-746, South Korea

HIGHLIGHTS

- Difference in pipe material had insignificant effect on annual energy cost.
- Greenhouse crop growing under high temperature showed less payback period.
- HDPE pipe showed 56% reduction of payback period for power plant waste heat.
- For incineration heat, HDPE pipe with high temp. set-point was the most economical.

ARTICLE INFO

Article history:
Received 18 November 2015
Accepted 9 March 2016
Available online 21 March 2016

Keywords:
Heat sources
Power plant waste heat
Incineration waste heat
Large-scale horticulture facility
Life cycle cost
EnergyPlus

ABSTRACT

The Korean government plans to establish large-scale horticultural facilities using reclaimed land to improve the competitiveness of the national agricultural sector at the government level. One of the most significant corresponding problems is the ongoing dependence of these facilities on fossil fuel, whereby constant heating is necessary during the winter season to provide the necessary breeding conditions for greenhouse crops. This study investigated the potential applicability of waste heat from incineration facility and power plant for use in large-scale horticultural facilities by evaluating the hot-water temperature, heat loss and life cycle cost as functions of the pipe material and distance between the heat source and the greenhouse. In case of utilizing waste heat from incineration facility, providing heating for greenhouse crop under high temperature set-point with HDPE pipe turned out to be the most economical method, which showed the equipment cost of approximately $4,300,000, annual energy saving cost of approximately $600,000 during winter season and the payback period of approximately 7.16 years based on 16 km distance.

1. Introduction

1.1. Background

Rapid industrial developments in the recent years are causing the increase in global energy demands. In particular, the issue of climate change threatens the existence of humans by creating meteorological disasters and changing the order of ecological system. There is a prospect that in case the excessive energy consumption continues, the economic loss for the whole world due to climate changes will reach 5–30% of global GDP every year [1]. The reckless use of fossil fuel will accelerate the energy exhaustion as well as global warming due to excessive amount of greenhouse gas consequently. Also, when fossil fuels that are mainly used for heating in facility horticulture which is an agricultural sector are burnt, a large amount of CO_2 is emitted, having a negative effect on the global warming along with other gases such as CH_4 (methane) or N_2O (nitrogen dioxide). Therefore, it is urgent to provide safe and eco-friendly alternative energy, and the Korean government presented "Low carbon green growth" as new national vision in order to make preparations for changes in the trend on use of primary energy which has become a global issue [2]. The government has invested the budget of 27.3 billion KRW (23,329,345$) in 2011 for the community energy service for the purpose of reducing CO_2 and developing source technologies in environmental field through 'Development and Distribution of New Renewable Energy in 2012' which is coming to the fore among the low carbon green growth plans of the government, and the contents of 'The 3rd Master Plan of Community Energy Supply' [3] include that utilizing community energy service using the incineration facility waste heat from the resource recovery

* Corresponding author. Tel.: +82 42 821 1126; fax: +82 42 821 1590.
E-mail address: kwhlee@hanbat.ac.kr (K.H. Lee).

http://dx.doi.org/10.1016/j.applthermaleng.2016.03.049
1359-4311/

facilities actively, advantage will be provided in the selection of community energy provider. Therefore, the expanded supply of community energy using the incineration facility waste heat from the resource recovery facilities has become inevitable. Currently, incineration facility waste heat produced from resource recovery facilities is received through heat pipes and cooling and heating are provided to apartment houses, officetels, sales facilities, business facilities and educational facilities in connection with regional heating facilities for regional cooling and heating in community energy supply zone in order to take part in national energy saving and promote community energy supply efficiently in the country. Meanwhile, the government is carrying out reclamation projects on the western sea and southern sea, and according to the Ministry of Agriculture, Food and Rural Affairs, a detailed plan regarding agricultural utilization of reclaimed land such as advanced horticulture complex for export, general horticulture complex and eco-friendly stock-breeding complex on reclaimed lands has been presented as the basic utilization plan of large-scale reclaimed lands [4]. Among them, the total land assigned for horticulture facilities accounts for over 70%, showing that there is a high interest in the agricultural plan regarding large-scale horticulture facility complex. Also, the total area of horticulture facilities in the country is 93,511 ha in 2014, showing high utilization rate in comparison with total land area and 7.74% increase in comparison with 86,765 ha in the previous year so that there is a high potential for development. Therefore, the Rural Development Administration has invested the budget of 8.1 billion KRW (approximately 6,921,893$), promoting projects for the goal of developing heating technologies using geothermal heat, waste heat from power plant and incineration facility since 2011. Among them, heat at 25–34 °C can be supplied stably from waste heat from power plants so that it is classified as very useful resource, and studies regarding this heat source are being carried out actively [1]. With regard to this, Lee et al. [5] selected air and seawater heat, river water heat source, thermal effluent from power plant and geothermal heat for applicable heat sources to large-scale horticulture facility and analyzed changes in reaching temperature of heat source at the horticulture facility and changes in the electricity consumption at the horticulture facility according to the distance and pipe material through the simulation and pipe heat loss calculation equation. It was confirmed that there was approximately 3.3–17.9 W/m^2 difference in electricity consumption based on 15 km when comparing thermal effluent from power plant with geothermal heat, and as the distance became longer, the electricity consumption increased gradually and it became similar with geothermal heat. Also, Chin [6] analyzed the present status of incineration facilities in the country and community energy service using waste heat and carried out studies for energy saving promoted by the central and local governments, and the oil substitution effect according to the waste heat recovery projects from incineration facilities was approximately 75.8 billion KRW (approximately 64,775,252$) in economic aspect. Also, the electricity supply of 156 GW h/year and heating supply of 487,663 GW h/year could be achieved from the waste heat recovery projects from incineration facilities due to the living energy conversion effect of oil substitution, showing the importance of waste heat recovery from incineration facilities. However, only studies regarding the present status have been carried out so that studies in direct connection with facilities or buildings are insufficient [7].

In addition, Culha et al. performed comprehensive review of wastewater heat exchangers in wastewater source heat pump applications and the potential of wastewater, types of wastewater source heat pumps, and their applications are briefly discussed [25]. Narita and Maekawa investigated the potential of utilizing waste heat of cities using heat pump technology, since waterworks and sewer systems in cities can be used for this purpose with slight modifications. It is stated in the study that a heat distribution network using heat pumps also has advantages over conventional district heating systems: little heat loss, economical district piping, easy expandability, and the ability to make use of a variety of waste heat sources, emphasizing that energy recycling systems should be introduced as part of our social system from the viewpoint of urban planning, energy policy and environmental protection [26]. Torio and Schmidt performed case study of a small district heating system in Kassel, Germany. Results from preliminary steady-state and dynamic energy and exergy analyses of the system showed that lowering supply temperatures from 95 to 57.7 °C increased the final exergy efficiency of the systems from 32% to 39.3%. Similarly, reducing return temperatures to the district heating network from 40.8 to 37.7 °C increases the exergy performance in 3.7%. In turn, the energy performance of all systems studied is nearly the same. This paper shows clearly the added value of exergy analysis for characterizing and improving the performance of district heating systems [27]. Cipolla and Maglionico investigated the possibility to use sewer water as alternative source of heat in residential building and the sewer system in Bologna, Italy, is taken as case study. Results of a monitoring period have showed the variability of wastewater flow rate and temperature and their correlation, which could be useful for mapping the potential thermal energy of sewage systems and for designing of heat recovery system [28]. Li et al. investigated the potential of utilizing the district heating and cooling (DHC) system of a seawater-source heat pump. This study developed a least-annualized-cost global optimal mathematic model that comprises all constrict conditions and considered the variety of heating load and cooling load, the operational adjustment in different periods of the year. Genetic algorithm (GA) is used to obtain the optimal combinations of discrete diameters, which, in turn, is used for the design of the DHC network of Xinghai Bay commercial district. It is turned out that the design optimization can avoid the matter of the hydraulic unbalance of the system, enhance the running efficiency and greatly reduce the annualized-cost comparing with the traditional design method [29]. Woodruffa et al. introduced the concept of environmentally opportunistic computing (EOC), which conceptualizes the data center as a series of distributed heat providers (nodes) for other-purposed buildings that use the waste heat from the data center nodes to offset their own heating costs. A general framework for evaluating the deployment of EOC is developed in their study and select model cases are analyzed. The results show that by redefining a centralized data center as distributed nodes across multiple buildings, the overall energy consumption of an organization decreases significantly. The advantages of applying EOC to buildings that require constant water heat as opposed to seasonal space heat are explained, and the method of distributing the computational load among data center nodes is evaluated [30].

Sadohara and Ojima experimentally looked into seven kinds of exhausted heat sources in Tokyo city which are power plants, sewerage plants, incinerators, refrigerating storages, electricity converters, subways and underground cables. Comparative analysis concluded that power plants, sewerage plants and incinerators have enough exhausted heat to supply heat to the surroundings. The total exhausted heat was 18,295 Tcal/a, corresponding to 47.3% of total demand [31]. Wang et al. addressed municipal solid waste (MSW) generation and characteristics for the city of Chongqing, China. This study examined the emission reduction potential for MSW incineration power plant in urban Chongqing. Results of the case study showed that with the power displacement potential at 235,060 MW h, Chongqing was expected to generate emission reductions as much as 815,862,827,969 tCO_2 and net profit US $7.72 million annually [32]. Kalincia et al. dealt with determination of optimum pipe diameters based on economic analysis and the performance analysis of geothermal district heating systems along