Applied Thermal Engineering 103 (2016) 695–704

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Feasibility of a novel de-foulant hydrocyclone with reflux for flushing away foulant continuously

Long Ni *, Jinyi Tian, Jianing Zhao

School of Municipal and Environmental Engineering, Harbin Institute of Technology, Harbin 150090, PR China

HIGHLIGHTS

- A novel anti-blockage device named novel de-foulant hydrocyclone was proposed.
- The novel de-foulant hydrocyclone has high separation efficiency for foulant.
- The energy consumption of the novel de-foulant hydrocyclone was small.

ARTICLE INFO

Article history:
Received 8 February 2016
Revised 18 March 2016
Accepted 3 April 2016
Available online 19 April 2016

Keywords:
Sewage source heat pump
Hydrocyclone
Feasibility
Separation efficiency
Foulant

ABSTRACT

In this paper, the possibility of using a novel de-foulant hydrocyclone with reflux function to separate foulant (<4 mm) from sewage and flush away the foulant continuously was studied. This de-foulant hydrocyclone can be used in prior to the sewage heat exchanger of a sewage source heat pump for pre-treatment of sewage to avoid or relieve blockage and fouling in the sewage heat exchanger. A de-foulant hydrocyclone prototype with 165 mm internal diameter and reflux function was designed and created for foulant separation. Different separation experiments of sand–water, high-concentration sewage and low-concentration sewage were investigated. The results showed the novel de-foulant hydrocyclone had an effective performance to separate the foulant from the sand–water and the domestic sewage. Maintaining low split ratio, the separation efficiency for sand–water was close to 100%, and that for high-concentration domestic sewage was 93–97%, and 57–72% for low-concentration domestic sewage. The separation efficiency was proportional to the feed foulant density while the feed pressure had no significant effect on the separation efficiency. The total static pressure losses of the novel de-foulant hydrocyclone were all within 10–20 kPa.

1. Introduction

Sewage source heat pump systems, using sewage (such as untreated urban sewage, wastewater or sewage treatment plant effluent) as the heat source of heat pump, are developing quickly in the world [1], especially in China in recent years [2]. There are more than 78 practical projects which have been widely applied in Beijing, Heilongjiang, Liaoning, Hebei, Shandong, Tianjin, Shanxi, Henan, Chongqing, Jiangsu, Hubei, Inner Mongolia, Xinjiang, etc. The scale of a single sewage source heat pump system has increased from hundreds m^2 to millions of m^2 and more than 12 projects were with the scale of $>2 \times 10^5\ m^2$. In addition, as a renewable heat source, the urban sewage has three critical advantages: (1) sewage contains approximately 40% of the waste heat energy discharged in cities [3]; (2) the amount of urban sewage discharged every year is very large, almost 85% of water consumed; (3) the urban sewage temperature is higher than outdoor air temperature in winter and lower in summer, and relatively stable in the whole heating and cooling seasons [4]. Accordingly, a number of sewage heat energy recovery systems have been developed, such as the heat pump water heater assisted with shower drain water [5], snow-melting system using the waste heat of urban sewage [6], sewage source heat pump for heating the wastewater treatment plants and neighborhood buildings [4]. However, the development of sewage source heat pump is challenged by the blockage and fouling problems of sewage heat exchangers due to the foulant in the sewage. Therefore, before the sewage flowing into the sewage heat exchanger, the separation of the foulant has far-reaching significance for recovering the waste heat energy in sewage/wastewater.

* Corresponding author.
E-mail address: nilonggn@163.com (L. Ni).

http://dx.doi.org/10.1016/j.applthermaleng.2016.04.017
1359-4311/

Nomenclature

E	separation efficiency (%)
E'	reduced separation efficiency (%)
m_i	feed foulant flow rate (kg/h)
m_o	foulant flow rate in the overflow (kg/h)
m_u	foulant flow rate in the underflow (kg/h)
c_i	feed foulant concentration (kg/m^3)
c_o	foulant concentration in the overflow (kg/m^3)
Q_i	feed sewage flow rate (m^3/h)
Q_o	sewage flow rate in the overflow (m^3/h)
Q_u	sewage flow rate in the underflow (m^3/h)
F	split ratio (%)
E_h	separation efficiency of the heavy foulant (%)
E_l	separation efficiency of the light foulant (%)
E'_h	reduced separation efficiency of the heavy foulant (%)
E'_l	reduced separation efficiency of the light foulant (%)
$c_{o,h}$	heavy foulant concentration in the overflow (kg/m^3)
$c_{o,l}$	light foulant concentration in the overflow (kg/m^3)
$c_{i,h}$	feed heavy foulant concentration (kg/m^3)
$c_{i,l}$	feed light foulant concentration (kg/m^3)
ΔP	total static pressure loss (kPa)
ΔP_1	pressure drop between the feed pressure and the vortex finder outlet pressure (kPa)
ΔP_2	pressure drop between the feed pressure and the underflow orifice pressure (kPa)

Subscripts

i	inlet
o	vortex finder outlet
u	underflow orifice
h	heavy foulant
l	light foulant

Definitions

Sewage source heat pump heat pump using sewage as the heat source and consisting of sewage heat exchanger, compressor, throttle mechanism and user-side heat exchanger

Currently, almost all the separation methods of foulant used in sewage source heat pump in China are mechanical filtration and backwashing in nature, such as the filth block device [7], modified filth block device [8], semi-submerged rotary orifice plate sewage-source heat pump intake machine [9] and rotating oval-tube sewage filter [10]. However, some unavoidable problems arose in their applications. For example, the decrease of the mesh size of filter increased the pressure required by backwashing and the static pressure loss, which means the mesh size of the filter is inversely proportional to the difficulty and the energy consumption to wash the filter. Moreover, it is difficult to clear up the filtering foulant since the amount of foulant is huge. For instance, to a untreated urban sewage source heat pump system for a building with 10,000 m^2 area, the amount of filtering foulant was such high to reach 76 kg/h in heating condition and 115 kg/h in cooling condition [8].

At present, one of the most popular filters used in untreated urban sewage source heat pump system is the filth block device [7] and the modified filth block device [8]. The applications showed some common issues. It could only remove the foulant (>3 mm) due to its mesh size was set at 3 mm [8]. However, in urban sewage, approximately 90% of the total foulant is the foulant with size of <3 mm [11]. What is worse, the small-size foulant (<4 mm) is the main source of the fouling on the sewage heat exchanger [12] and the foulant is the main source of fouling deposition on the tube surfaces [13]. There is a short circuit with large amount of sewage for the inlet and outlet sewage cannot be completely sealed. The experiment demonstrated that there was 21.5% of return flow bypass and 41.9% of spur track bypass [7]. The bypass making part of warm sewage mix with cold sewage would lead to waste heat energy. Moreover, the energy consumption caused by the rotating filter and the static pressure loss was huge.

Accordingly, such a device that can separate most of the foulant with size of <4 mm and almost all of the foulant with size of >4 mm with additional advantages to solve the problems existed in current de-foulant devices, will be a significant innovation of de-foulant devices. The hydrocyclone has the potential to remove the foulant from domestic sewage because of its merits such as the high separation efficiency and no moving parts [14]. It was reported that a hydrocyclone was utilized to separate the components of municipal solid waste incinerator fly ash, and the experimental results indicated that the chloride salts and the fly ash particles could be separated from the fly ash [15]. It was found that the hydrocyclone using for removing the individual polymers including HIPS, ABS, PVC and PE has the capability to separate HIPS from ABS [16]. A hydrocyclone was also applied to separate waste plastics (PET and PVC particles) based on their difference in density. At the same time these tests demonstrated that the purity of PVC and PET could reach 93.2% and 94.5% respectively [17]. A hydrocylone was used to treat storm water runoff from bridge [18]. A multihydrocyclone water pretreatment system was applied to reduce suspended solids and the chemical oxygen demand [19]. An electromagnetic hydrocyclone was employed to remove impurities of 50 μm and less (organic contaminants, dust, etc.) which result in reducing the turbidity of contaminated process water significantly [20]. As being an effective method, the hydrocyclone that is able to guarantee continuous cleaning process was used for separation of anaerobic sludge digesters [21]. A mini-hydrocyclone was applied for removing fine catalyst particles suspended in wastewater, leading the separation efficiency of particles (>3 mm) to reach ⩾85% and the cut size d_{50} was 1.70 μm [22]. A hydrocyclone was employed for the removal of micron-sized particles suspended in water, and the results illustrated that it had potential to remove micron particles effectively [23]. Furthermore, a 10 mm hydrocyclone was used for sub-micron particle dewatering [24], etc.

However, the feasibility of the removal of foulant from domestic sewage with a hydrocyclone was not tested directly and the hydrocyclones mentioned above all discharged the foulant intermittently, not continuously. For sewage source heat pump, the sewage is only the heat carrier. What the system need is to exchange heat with sewage without foulant. Therefore, only the sewage flowing into the heat exchanger need to be kept clean, and the separated foulant should be taken out when the sewage flow out from the heat exchanger. Following this idea, a novel de-foulant hydrocyclone with reflux was proposed. The de-foulant hydrocyclone with reflux function can flush away foulant continuously. In order to test the feasibility of the de-foulant hydrocyclone with reflux function directly, a de-foulant hydrocyclone prototype with 165 mm internal diameter and reflux function was designed and created for foulant separation. The experiments based on the sand–water, high-concentration domestic sewage and low-concentration domestic sewage were conducted and the separation performance was investigated in this paper.