Capital Regional District
Core Area Wastewater Management Program

Integrated Resource Management Strategy

Discussion Paper – Heat Recovery
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1 Objective

This Discussion Paper provides an overview of technology that can be used to recover heat from wastewater and effluent. In addition, the paper also examines the regional potential of heat energy extracted from wastewater/effluent generated within the Capital Regional District in the context of the Core Area Wastewater Management Program.

2 Topic Area Overview

2.1 Heat Recovery Technology

Heat recovery from wastewater can be conducted using raw wastewater and effluent. The heat available in raw wastewater and effluent is described as low-grade heat. The low-grade heat extracted from wastewater can be used for space heating and water heating through the application of heat pump technology. Heat pump technology uses a reverse refrigeration cycle to factor low temperatures to useable heating levels.

Heat recovery from raw wastewater and effluent occurs via heat exchangers. Heat exchangers are devices designed to transfer heat between two liquids without crossover. Heat transfer occurs between two fluids of different starting temperatures, such as the wastewater and the refrigerant. Heat exchanger technologies that are typically used include pumped heat exchangers, in-tank heat exchangers, and in-pipe or in-trench heat exchangers. In the following discussion, the relative heat transfer rates for in-tank heat exchangers and in-pipe and in-trench heat exchangers were based on a comparison with typical pumped tubular heat exchangers.

Pumped Heat Exchangers
Common pumped heat exchangers that may be used for wastewater heat recovery applications are the shell and tube heat exchanger and the plate and frame heat exchanger.

A shell and tube heat exchanger consists of a shell or pressure vessel with bundles of tubes inside. Heat transfer coefficients for pumped heat exchangers, such as the shell and tube heat exchanger, range between 150 and 1200 W/m^2·K (average value of 700 W/m^2·K) (Engineering ToolBox, 2005), depending on the temperature of the fluids and the design of the heat exchanger. Examples of heat pumps equipped with shell and tube heat exchangers for raw wastewater heat recovery applications are presented in Figure 1 and Figure 2.

Figure 1
Installation of Heat Pump (18.4 MW) Equipped With Shell and Tube Heat Exchangers for Heat Recovery From Raw Wastewater
(Source: Friotherm, 2006)

Figure 2
Installation of Two (6.5 MW) Heat Pumps with Shell and Tube Heat Exchangers for Heat Recovery From Raw Wastewater
(Note: raw wastewater is subject to mechanical screening and sedimentation prior to use)
(Source: Friotherm, 2005)

A plate and frame heat exchanger consists of a series of thin metal plates fastened into a rigid frame. The use of multiple thin plates results in a large surface area and facilitates more efficient to heat transfer between two fluids. Heat transfer coefficients for plate and frame heat exchangers are relatively high compared to tubular heat exchangers. The heat transfer coefficients for a typical plate and frame heat exchanger range between 1000 and 4000 $W/m^2 \cdot K$ (Engineering ToolBox, 2005). Using an average value (2500 $W/m^2 \cdot K$), the heat transfer coefficient for a plate and frame heat exchanger is approximately 357% greater than the heat transfer coefficient for a typical tubular heat exchanger, such as a shell and tube heat exchanger. An example of a plate and frame heat exchanger installed in a potable water treatment facility, which uses lake water for heating and cooling, is presented in Figure 3.

Figure 3
Example of Pumped Plate and Frame Heat Exchanger Installed in a Water Treatment Facility that Uses Lake Water for Heating and Cooling
(Source: Associated Engineering)

Pumped heat exchangers may be used for raw wastewater or effluent. However, for use of pumped heat exchangers with raw wastewater, the likelihood of fouling of the heat exchanger is more significant compared to effluent. Fouling of the heat exchanger will reduce the effectiveness of heat transfer between the two liquids. In order to minimize fouling and clogging of pumped heat exchangers when using raw wastewater, the wastewater must be screened or settled prior to use.

In-Tank Heat Exchangers

In-tank heat exchangers are typically used for in-pond and in-lake heat recovery applications. Such heat exchangers can be put into a tank of raw wastewater or effluent for heat recovery applications.

Heat exchanger technology suitable for this application is plate heat exchangers typically used for lake and pond geo-exchange applications. This technology could potentially be applied for both raw wastewater and effluent. However, there are disadvantages of this approach including potential fouling of the surface of the plate heat exchangers, which can significantly decrease heat transfer rates. Since these heat exchangers are submerged directly into a tank of raw wastewater or effluent, operations and maintenance procedures must be in place that include regular cleaning of the heat exchanger plates to minimize reductions in heat transfer rates. An example of submersible plate heat exchangers is presented in Figure 4. Based on manufacturer information, the heat transfer coefficient for a submersible plate heat exchanger is approximately 568 $W/m^2{\cdot}K$ (AWEB Supply, 2008b). The heat transfer coefficient for plate heat exchangers is approximately 81% of a typical pumped tubular heat exchanger.

Figure 4
Example of Plate Heat Exchangers Typically Used for Lake and Pond Geo-exchange Applications ***(Source: AWEB Supply, 2008a)***

In-Pipe or In-Trench Heat Exchangers

In-pipe or in-trench heat recovery are two alternate approaches that may be used for heat recovery from raw wastewater or effluent. In-pipe heat recovery involves the use of heat exchangers installed directly within the sewer pipe, whereas in-trench heat recovery involves the use of heat exchangers installed parallel to the exterior of the sewer pipe (Cobalt Engineering, 2005), i.e., directly in the trench of the sewer pipe.

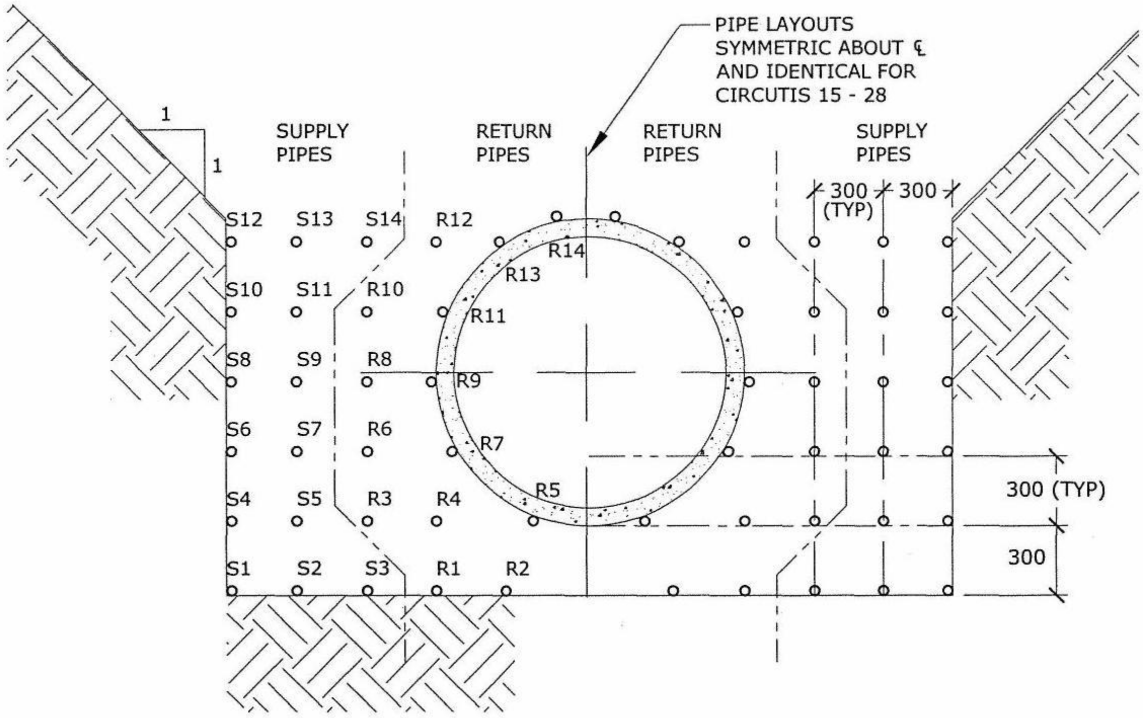
In-pipe heat exchangers for raw wastewater are constructed of stainless steel plates that transfer heat to supply and return lines, which transport heat to a heat pump. An in-pipe heat exchanger in a concrete sewer pipe is presented in Figure 5.

Figure 5
Example of Concrete Pipe with Built-in Heat Exchanger
(Source: BauLinks, 2003)

Based on information provided by the manufacturer, heat transfer coefficients for in-pipe heat exchangers range between 750 and 1250 $W/m^2{\cdot}K$ (R. Schober, Pers. Comm., May 21, 2008). Using an average value (1,000 $W/m^2{\cdot}K$), the heat transfer coefficient for an in-pipe heat exchanger is approximately 143% greater than the heat transfer coefficient for a typical tubular heat exchanger, such as a shell and tube heat exchanger. However, a significant limitation of the in-pipe heat recovery approach is that there is currently only one manufacturer of this technology. There is also only limited time-tested experience for installations using this technology. Further, in-pipe heat recovery from raw wastewater is likely most economically feasible for new sewers or replacement of existing sewers, rather than for retrofits of existing sewers (Compass Resource Management Ltd. & MK Jaccard and Associates, 2005). Similarly, since these in-pipe heat exchangers are in direct contact with raw wastewater, fouling and corrosion of the heat exchangers may be of concern.

In-trench heat recovery technology involves the use of heat recovery pipes installed parallel to the sewer pipe within the trench itself. This approach uses the surrounding soil and groundwater to assist with heat transfer between the sewer pipe and the heat recovery pipes (Cobalt Engineering, 2005). Sewer pipes are typically constructed of concrete or PVC piping, while geo-exchange ground- and lake-loop systems use high-density polyethylene (HDPE) piping for heat exchangers. Although no examples of in-trench heat recovery applications were located in our literature review, in-trench heat recovery from sewer pipes was proposed for use in a sewer system in New Westminster, BC; however, the in-trench sewer heat recovery approach was not implemented. A proposed layout for in-trench heat recovery from sewer pipes is presented in Figure 6.

Figure 6
Example Layout of In-trench Sewer Heat Recovery Application
(Source: Cobalt Engineering, 2005)



Heat transfer coefficients for concrete and PVC piping are typically higher than for HDPE pipes for pipes of similar thickness. As a result, the heat transfer coefficients for concrete and PVC are approximately 18% and 3%, respectively, of pumped heat exchangers. Similarly, the heat transfer coefficients for HDPE are approximately 7% of pumped heat exchangers. Overall, it appears that in-trench heat recovery transfer rates are generally poor compared to heat recovery transfer rates for pumped heat exchangers.

2.2 Raw Wastewater Application

Heat recovery from raw wastewater is possible. However, heat recovery from raw wastewater poses significantly more challenges than heat recovery from effluent. Since raw wastewater contains solids and other constituents in concentrations much higher than those for effluent, there are significant concerns for fouling and clogging of heat exchangers. Therefore, raw wastewater should undergo some form of pre-treatment, such as screening or settling, prior to use for heat recovery applications. The following case studies discuss some raw wastewater applications.

Southeast False Creek – Vancouver, British Columbia

A local example of the implementation of heat recovery from raw wastewater is the Southeast False Creek Community Energy Centre Project in Vancouver (Sandwell 2003, Compass Resource Management Ltd. & MK Jaccard and Associates 2005). Prior to recovery of heat from the wastewater, the raw wastewater will be screened using 2 mm traveling screens, with screened solids returned to the effluent downstream of the heat exchanger (C. Baber, Pers. Comm., 2008). Although the in-pipe heat recovery technology was recommended for use at this site, a pumped heat exchanger will be used to extract heat from raw wastewater. The district heating system (DHS) for the new development will use heat recovered from raw wastewater using a shell and tube heat exchanger. Measures to reduce fouling of the heat exchanger include the addition of brushes to clean the tubes and periodic wastewater flow reversals through the heat exchanger (C. Baber, Pers. Comm., May 12, 2008; Anonymous, 2007). A heat pump (2.7 MW) (C. Baber, Pers. Comm., May 12, 2008) will supply high-grade heat energy to residential users for space heating and domestic hot water heating. Peak energy loads for the DHS that cannot be met by the raw wastewater will be supplemented by high efficiency natural gas boilers.

Basel, Switzerland (Wärmeversorgung Binningen AG)

A heat pump system operating in the community of Binningen in Basel, Switzerland extracts heat from raw wastewater using heat exchangers installed directly in sewer collection pipes. Using approximately 140 m of heat exchanger elements in the sewer pipes, the heat pump system, which is operated by Wärmeversorgung Binningen AG, supplies approximately 2.4 GWh to the DHS of 300 apartments (WasteWaterHeat, 2007a).

Oslo, Norway – Skøyen Heat Pump Plant (Hafslund Fjernvarme AS formerly Viken Fjernvarme AS)

The Skøyen Heat Pump Plant in Oslo, Norway uses a 20 MW shell and tube heat exchanger to extract heat from raw sewage (Anonymous, 2007). Prior to entering the heat exchanger, the raw sewage is screened; these screened solids are returned to the raw sewage flow downstream of the heat pump. Hourly changes in the flow direction of the raw sewage through the evaporator are also used to prevent fouling and clogging of the heat exchanger. The heat pump plant, which is owned and operated by Hafslund Fjernvarme AS, supplies approximately 85 GWh to the DHS for heating of 9,000 apartments (Anonymous, 2007; WasteWaterHeat, 2007a). Peak energy loads for the DHS that cannot be met by the raw wastewater are supplemented by equipment using fuel oil, electricity, and natural gas. At the time of the heat pump plant commissioning, this facility was the largest of its kind in the world (Anonymous, 2007).

2.3 Effluent Application

Heat recovery from effluent is advantageous in that the effluent quality is better than for raw wastewater. As a result, potential fouling and clogging of heat exchangers, which are associated with the use of raw effluent for heat recovery, are reduced. However, a significant limitation of effluent applications is that wastewater treatment plants are not often located near the potential users of the heat, such as DHS applications. The following case studies examine effluent heat recovery applications.

Whistler Olympic and Paralympic Athlete's Village – Whistler, British Columbia
A local example of the implementation of heat recovery from effluent is the Whistler Olympic and Paralympic Athlete's Village for the 2010 Olympic Winter Games. The DHS for the new development will use heat recovered from effluent produced by the Whistler wastewater treatment facility. The DHS will extract low-grade heat from effluent using parallel flow plate heat exchangers. This low-grade heat will be supplied via a closed-loop DHS system to residential users where it is upgraded to high-grade heat via heat pumps to meet an 11,000 MWh annual demand. The system is a dual-pipe, closed-loop, ambient temperature system, with a minimum loop temperature of 10°C extracted from the effluent and a minimum return temperature of 5°C once heat energy has been extracted at the individual buildings connected to the loop. Heat pumps will supply high-grade heat energy to residential users for space heating and domestic hot water heating. Peak energy loads for the DHS that cannot be met by the effluent will be supplemented by high efficiency natural gas boilers.

Göteborg, Sweden – Göteborg Rya AB Wastewater Treatment Plant and Rya Heat Pump Works (Göteborg Energi)
The Göteborg Rya AB (Gryab) wastewater treatment plant in Göteborg, Sweden is a 350 ML/d facility that uses heat recovery from effluent (Gryaab AB, 2008). Treated effluent from the Gryab wastewater treatment plant is pumped to the nearby Rya Heat Pump Works operated by Göteborg Energi. At the heat plant, heat is extracted from the effluent using heat pumps and the effluent is returned to the outfall for discharge. The Rya Heat Pump Works supplies the Göteborg DHS with approximately 150 GWh/yr of energy (Gryaab AB, 2008), which is approximately 5% of the annual heating requirements of the DHS. The majority of the Göteborg area is served by the DHS.

Stockholm, Sweden – Henriksdal Reningsverk and Hammerby Heat Pump Facility (Fortum Energi)
The Henriksdal Reningsverk is a 240 ML/d facility that uses heat recovery from treated effluent in Stockholm, Sweden. Treated effluent from the Henriksdal Reningsverk is pumped to the nearby Hammerby Heat Pump Facility operated by Fortum Energi. The Hammerby Heat Pump Facility produces approximately 250 MWh via treated effluent and heat exchangers. On a recent site visit to the facility by the CRD project team (Associated Engineering, 2008), it was noted that the facility provides heating for 95,000 two bedroom apartments; however, wastewater treatment plant effluent flows and heat requirements for the district heating system were often "out of sync" by a few hours.

To address this issue, large storage tanks were installed for overnight storage of treated wastewater for heat recovery use in the mornings.

3 Heat Energy Potential

3.1 Unit Basis

The maximum theoretical unit potential heat energy from raw wastewater and effluent is 4,187 kJ/m^3/°C. However, the heat energy that can actually be recovered from raw wastewater and effluent is lower than this value and will depend on the temperature conditions and system utilized. Section 3.3 provides an example of actual heat recovered, for a specifically defined situation.

3.2 Temperature Boundaries

Besides the thermodynamic limitations in the amount of heat that can practically be recovered from wastewater or effluent, two other issues must be considered. First, low wastewater temperatures can impact collection system operations and treatment facility performance. In the former situation, low wastewater temperatures increase the potential for congealing of fats, oils, and greases in the sewer lines. Of greater concern is the impact of low wastewater temperatures on treatment systems, particularly those using biological processes.

As a result, for heat recovery from raw wastewater, minimum temperature requirements have been established for some utilities/municipalities, such as in Switzerland and Germany. In these instances, the minimum temperature for raw wastewater entering a treatment facility cannot be lower than 10°C (Schmid, 2008; WasteWaterHeat, 2007). Minimum wastewater temperatures of 10°C are experienced in colder climates (i.e. without heat recovery) in Canada and industry experience with treatment operations at such temperatures indicates satisfactory performance can be obtained. Therefore, for planning purposes at this time, we suggest the CRD assume that the minimum temperature of wastewater entering a CRD treatment facility should be limited to 10°C.

The second issue that requires consideration is effluent discharged to the aquatic receiving environment. Effluent temperature affects plume density, which in turn impacts the initial dilution and secondary dispersion of the effluent plume and effluent constituent concentrations in the water column. Further, changes in ambient water temperatures may pose potential thermal impacts on aquatic life within the vicinity of the outfall.

For heat recovery from effluent, our literature review did not reveal minimum temperature requirements for effluent instituted by a regulatory agency. However, for planning purposes, we suggest that the minimum temperature of effluent discharged to the ocean, following heat recovery, remain in the range of 6 to 8°C. This range is consistent with ambient temperatures at depth in the vicinity of the existing Macaulay and Clover Point outfalls (University of Victoria, 1972; Goyette et al, 1979). While it may be possible to reduce the effluent temperature further without an adverse environmental impact, detailed analysis would be required to support a reduction in values.

Some of the CRD treatment facilities may discharge effluent to freshwater watercourses, some of which may be effluent-dominated during dry-weather periods. In this situation, thermal impacts to aquatic life, rather than effects on effluent plume dilution/dispersion, is the key issue. Available historic water temperature information for urban creeks within the CRD, collected by the CRD and British Columbia Ministry of Environment, indicate winter temperatures (i.e. February) can be as low as 5 to 6℃. Maximum summer temperatures varied significantly amongst the creeks, ranging from 14 to 28℃. In comparison, urban creeks in the Lower Mainland (Beecher Creek – Burnaby, North Creek – Surrey), with characteristics similar to those within the CRD, have winter temperatures of around 3 to 6℃ in December and January (Kerr Wood Leidal, 2008). Maximum summer temperatures during the warmest periods range from 18 to 21℃.

Based on this information, and recognizing that there are site-specific physical and biological characteristics of any watercourse, for the planning purposes we recommend the CRD set the following boundaries for effluent temperature in the context of urban watercourses and in consideration of fisheries requirements (British Columba 1998):

- 6℃ in the winter during the peak heating demand period. In this situation the effluent would have a similar temperature as the ambient water.

- 12℃ in the summer, where some heat may be recovered from effluent for hot water tank heating, which is a minor heating demand. In this case the cooler-than-ambient effluent temperature will reduce the temperature of the watercourse, the extent of which will depend on the effluent flow rate relative to the stream flow rate, to a level better suited to aquatic life.

- No use of effluent for cooling in the summer, since discharging warmer-than-ambient effluent to the environment will further heat the watercourse and exaggerate an already problematic situation.

3.3 Regional Potential

The total amount of heat energy that could potentially be recovered from wastewater/effluent generated within the CRD, in the context of the Core Area Wastewater Management Program, is a function of the transfer efficiency of the heat exchanger technology, wastewater/effluent flow rates, initial temperature of the wastewater/effluent, minimum temperature requirements for the wastewater/effluent, and efficiency of the heat pumps.

For illustration purposes, consider the scenario where heat is recovered from all effluent produced within the CRD, where effluent (i.e. same as wastewater) average dry weather flow rates are 95 ML/d and 160 ML/d, now and in Year 2065, respectively. Assume a winter effluent temperature of 13℃, based on historical CRD data, and 7℃ effluent being returned to the marine environment. For this scenario, which included a heat pump and flat plate heat exchanger in the system, the recoverable potential heat is approximately 2,950 GJ/d for current flow rates, increasing to 4,970 GJ/d for the Year 2065 scenario.

In terms of annual energy production, these values equate to about 1,076,800 GJ per year and 1,814,000 GJ per year for current and Year 2065 effluent flow rates, respectively. For a typical Vancouver Island household using about 58 GJ per year of energy from natural gas for space heating (Terasen Gas, 2007), the potential energy from effluent could supply between 18,500 and 31,300 households.

4 Summary

Technology currently exists to recover heat from both raw wastewater and effluent, with implemented examples found in Canada and elsewhere in the world. While there are more challenges in the operation and maintenance of raw wastewater heat recovery systems, relative to effluent applications, continued technology development will likely mitigate these challenges to some extent in the future. The potential heat energy available in wastewater/effluent warrants consideration as the CRD develops the Core Area Wastewater Management Program.

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