

***IMPACTS OF NEW CONCEPTS AND TECHNOLOGY  
ON THE ENERGY SUSTAINABILITY OF  
WASTEWATER MANAGEMENT***

To be presented at Conference on

**Climate Change, Sustainable Development,  
and Renewable Energy Sources**

Organized by

Environmental Council of the  
Aristotle University of Thessaloniki  
Thessaloniki, Greece  
October 15-17, 2009

George Tchobanoglous and Harold Leverenz  
Department of Civil and Environmental Engineering,  
University of California at Davis, Davis, CA  
and  
Petros Gikas  
Department of Environmental Engineering  
Technical University of Crete

# IMPACTS OF NEW CONCEPTS AND TECHNOLOGY ON THE ENERGY SUSTAINABILITY OF WASTEWATER MANAGEMENT

George Tchobanoglous<sup>1</sup>, Harold Leverenz<sup>2</sup>, and Petros Gikas<sup>3</sup>

<sup>1</sup>Professor Emeritus and <sup>2</sup>Research Associate  
Department of Civil and Environmental Engineering,  
University of California at Davis, Davis, CA

<sup>3</sup>Assistant Professor  
Department of Environmental Engineering  
Technical University of Crete  
73100, Chania, Greece

## ABSTRACT

The term "sustainability" has taken on many different meanings, depending on the area of life that is under consideration (e.g., population, cities, ecology, etc.). In a very broad sense, sustainability can be considered the ability or capacity of a service or entity to survive into the future. Water supply, wastewater management, and solid waste management are environmental services that are fundamental to the quality of life in a modern society. In the context of these services, sustainability involves finding new approaches that can be used to reduce: (1) the use of resources, (2) the consumption of energy, and (3) the carbon footprint of these activities, while providing the same or enhanced level of service, so that these services can continue to function effectively into the future with minimal environmental impact. Using new concepts, technologies, and alternative process configurations, the energy content in wastewater, a renewable source of recoverable energy, can be recovered and utilized to enhance the energy sustainability of wastewater treatment facilities and, ultimately, to transform wastewater treatment facilities into net energy exporters.

**Key Words** sustainability, wastewater management, resources, energy, carbon footprint

## INTRODUCTION

Over the past 100 years, the fields of water supply, wastewater management, and solid waste management evolved with relatively little concern for: (1) the use

of resources, (2) the consumption of energy, and (3) the carbon footprint. For example, when the cost of energy was \$0.03/kWh (not so long ago), it did not matter much if the most efficient pump was selected or if the pumping system was optimized. In wastewater treatment plants, excessive free falls at sedimentation tank weir collection troughs clearly were not influenced by energy considerations. It is the purpose of this paper to examine how new concepts and technologies can be applied to enhance the sustainability of these activities, while providing the same or enhanced level of service. Before considering the application of new technologies and concepts to wastewater management it will be useful to describe broadly current wastewater management. New technologies and concepts will then be applied to illustrate how the performance of current systems can be enhanced as well as the design of new systems.

## **WASTEWATER MANAGEMENT**

Wastewater management involves the collection, transport, treatment, and dispersal and/or reuse of wastewater removed from residences, institutions, and commercial and industrial establishments, together with any groundwater, surface water, and stormwater that may be present (Tchobanoglous et al., 2003). To assess how new concepts and technologies can be implemented in the wastewater management field, it is useful to review the characteristics of wastewater and the components that comprise the wastewater management infrastructure.

### **Wastewater Characteristics**

Prior to about 1940, most municipal wastewater was from domestic sources. Today, wastewater also contains a significant amount of commercial and industrial waste, which has been pretreated to meet collection system discharge requirements. Typical data on the composition of untreated wastewater are reported in Table 1. The energy content of wastewater is comprised of the heat and the organic constituents found in wastewater. The heat in wastewater can be recovered using a heat pump. Although successfully applied in some locations, the economic feasibility of recovering heat energy from wastewater

Table 1  
Typical constituent concentrations and energy content of untreated domestic wastewater<sup>a</sup>

Item	Unit	Concentration	
		Range	Typical <sup>b</sup>
Constituent concentrations			
Solids, total (TS)	mg/L	390 - 1230	720
Dissolved, total (TDS)	mg/L	270 - 860	500
Fixed	mg/L	160 - 520	300
Volatile	mg/L	110 - 340	200
Suspended solids, total (TSS)	mg/L	120 - 400	210
Fixed	mg/L	25 - 85	50
Volatile	mg/L	95 - 315	160
Biochemical oxygen demand (BOD) 5-d, 20°C	mg/L	110 - 350	190
Total organic carbon (TOC)	mg/L	80 - 260	140
Chemical oxygen demand (COD)	mg/L	250 - 800	430
Nitrogen (total as N)	mg/L	20 - 70	40
Phosphorus (total as P)	mg/L	4 - 12	7
Chlorides <sup>c</sup>	mg/L	30 - 90	50
Sulfate <sup>c</sup>	mg/L	20 - 50	30
Oil and grease	mg/L	50 - 100	90
Energy content <sup>d</sup>			
Wastewater, heat basis	MJ/10°C•10 <sup>3</sup> m <sup>3</sup>	41,900	41,900
Wastewater, COD basis	MJ/kg COD	12 - 15	13
Primary sludge, dry	MJ/kg TSS	15 - 15.9	15.5
Bioslids, dry	MJ/kg TSS	12.4 - 13.5	13

<sup>a</sup>Adapted from Zanoni and Mueller, 1982; Tchobanoglous et al., 2003; Shizas and Bagley, 2004; Asano et al., 2003.

<sup>b</sup>Typical wastewater composition is based on an approximate flow rate of 460 L/capita•d (120 gal/capita•d).

<sup>c</sup>Values should be increased by amount of constituent present in domestic water supply.

<sup>d</sup>Note: 1.0 MJ = 0.278 kWh

depends on having a year-round use for the extracted heat. Heat extraction in satellite installations is being considered by a number of agencies. As will be discussed later, heat energy (see Table 1), extracted from wastewater with a heat pump, could be used for drying organic materials removed by fine screening, sludge, and/or biosolids for subsequent processing.

The chemical energy content of wastewater, based on chemical oxygen demand (COD), is about 13 MJ/kg COD (see Table 1). The energy content of wastewater is an important consideration as new technologies and concepts are evaluated. Typically, the total energy content in wastewater is two to four times the energy needed to operate a wastewater treatment plant (WWTP). For example, for the activated sludge process for wastewater treatment the energy required is approximately 1,100 to 2,400 MJ/1,000 m<sup>3</sup> (1,200 to 2,500 kWh/Mgal) of wastewater (Tchobanoglous et al., 2003), with the higher value being for biological nutrient removal. The energy in wastewater with the composition given in Table 1 is 5,590 MJ [(430 kg COD/1,000 m<sup>3</sup>)(1,000 m<sup>3</sup>)(13 MJ/kg COD)]. The key question is what is the best way to extract and utilize the chemical energy in wastewater, a renewable source of recoverable energy. The most common method in use today is by means of anaerobic digestion and the generation of electrical energy using the digester gas. However, depending on the technologies involved for wastewater management, thermal processes such as combustion and pyrolysis appear to offer significant advantages when the complete management of wastewater sludge and biosolids is evaluated, especially in large metropolitan areas.

### **Wastewater Infrastructure**

The infrastructure associated with wastewater management is illustrated on Fig. 1. As shown, the principal components are the wastewater collection pipes, pump stations, and treatment facilities. Depending on the topography, one or more pump stations may be required. In general, until recent times, it was common to have one centralized WWTP. The current trend is to consider the use of satellite WWTPs, especially where opportunities for effective water reuse exist (see Fig. 2). It is interesting to note that, for centralized systems, the collection system accounts for approximately 60 to 80 percent of the total cost of the wastewater management infrastructure. An example of a conventional activated sludge WWTP flow diagram is shown subsequently on Fig. 4(a).

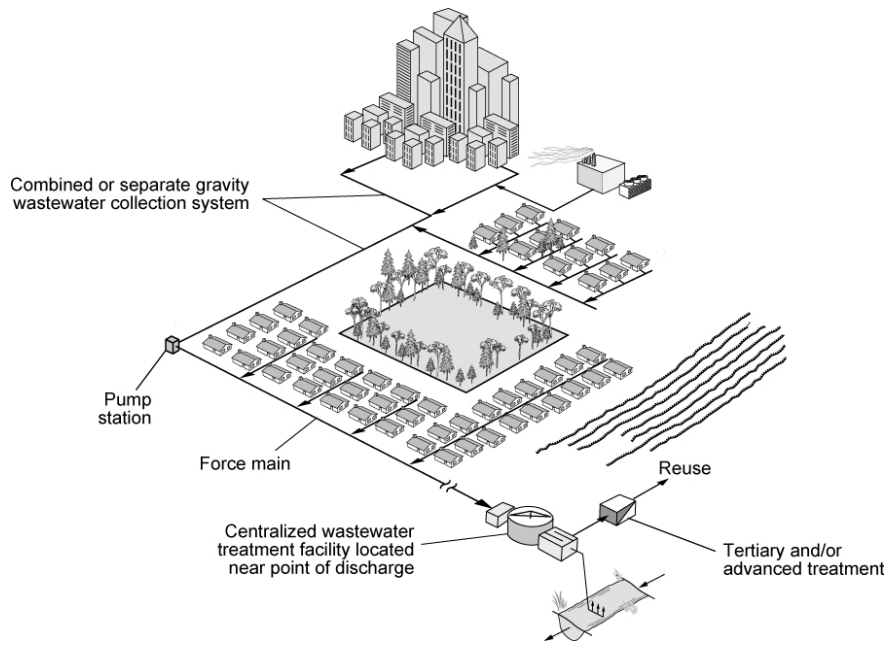


Figure 1  
Schematic illustration of the principal elements that comprise wastewater management infrastructure

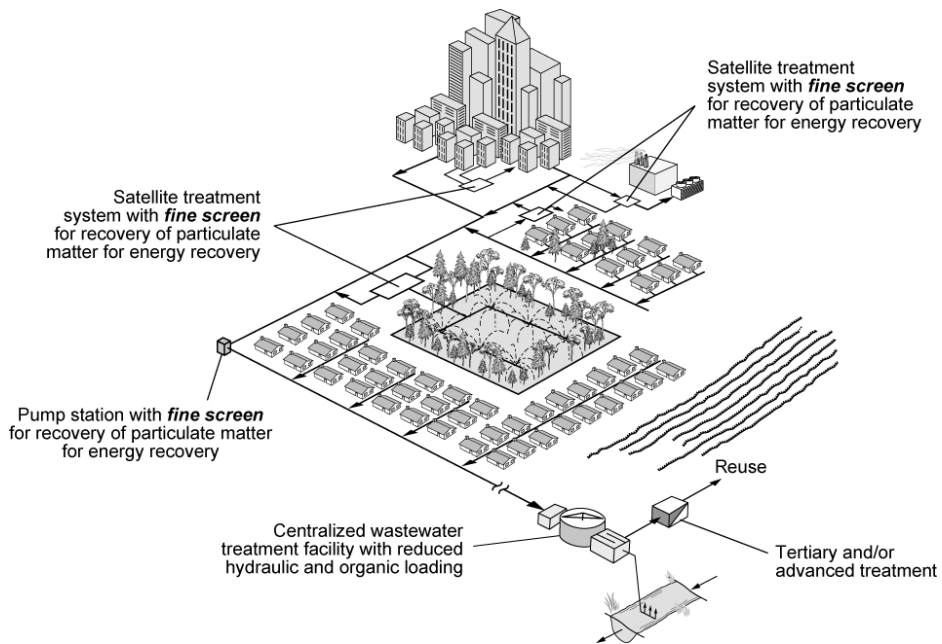


Figure 2  
Schematic illustration of the principal elements that comprise wastewater management infrastructure including the use of satellite treatment facilities for water reuse and fine screens for energy recovery

## **APPLICATION OF NEW CONCEPTS AND TECHNOLOGIES**

During the past ten years there has been an increased focus on sustainability, as it relates to the use of resources, the consumption of energy, and the carbon footprint. In turn, this concern has led to the development of new concepts and improved technologies for wastewater management. In what follows, two new concepts for enhanced wastewater management employing a cloth screen at a WWTP and within the collection system are presented and discussed. The impact of a new screen technology for effluent filtration is also considered.

### **Fine Screen For Primary Treatment and Energy Recovery**

A relatively recent development involves the use of a cloth filter screen in place of conventional primary sedimentation tank. The 200 micron cloth screen filter, illustrated on Fig. 3, results in treatment equal to or better than primary sedimentation. It has been found that tissue paper captured on a 200 micron screen serves as a secondary filter for the removal of grease and oil. The solids removed from the filter cloth are then squeezed to dewater them. Depending on the degree of compaction and the application, solids concentrations of 30 percent or more have been achieved. The energy content of this particulate stream, when dried, consisting of tissue paper, food scrapes, feces, oil and grease, and other organic solids is comparable to that of softwood (about 15-16 MJ/kg solids), and can be dewatered further by extracting heat energy from wastewater, using other excess waste heat, or solar dried and converted to energy using a thermal process such as combustion or gasification.

A comparison of flow diagrams without and with the cloth screen is presented on Fig. 4. The treatment process flow diagram shown on Fig. 4(a) is that of a conventional activated sludge process. As shown on Fig. 4(b), the fine cloth filter has replaced the primary clarifier used on Fig. 4(a) and the waste return activated solids and the filter backwash are returned to the head end of the cloth filter. The solids recovered from the screen would be used for the recovery of energy. An issue that has been raised is whether there will be enough organic

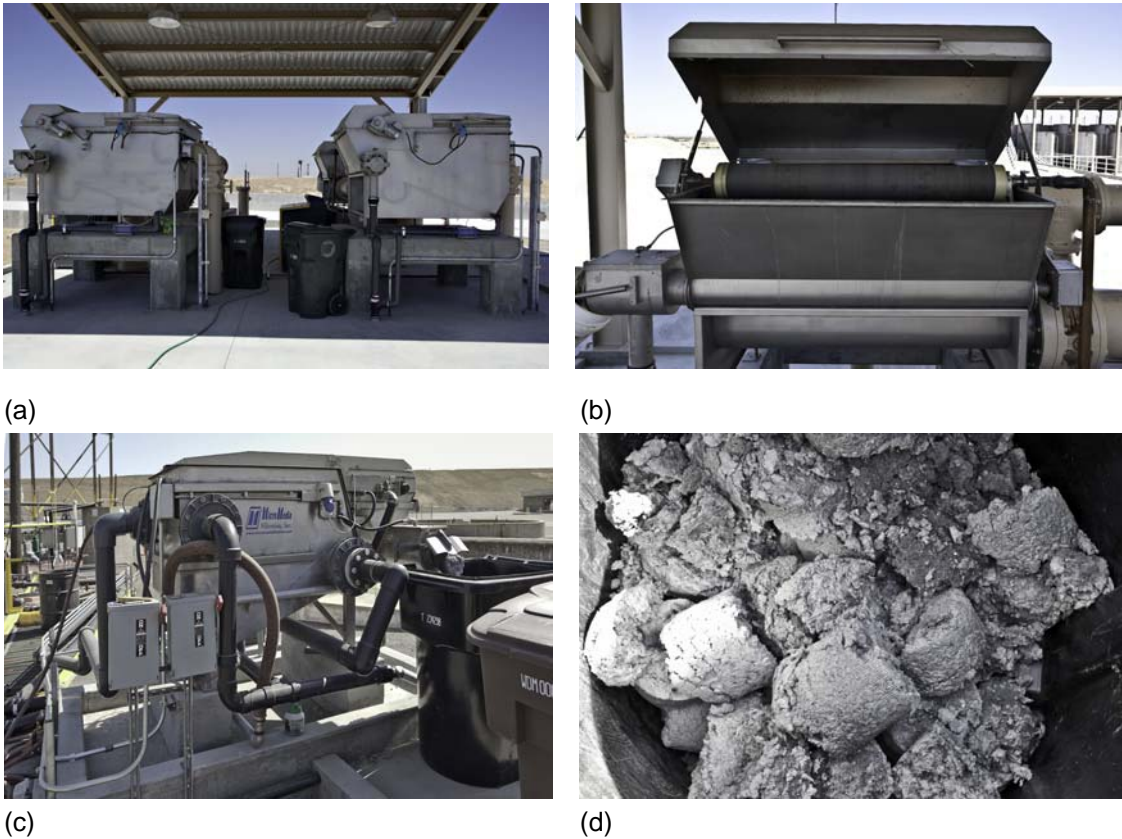


Figure 3

Views of fine cloth screen: (a) four screen installation at Adelanto, California, (b) cover of screen housing opened to expose cloth screen, (c) single screen installation at Fontana, California, and (d) pressed screen solids at Fontana, California

matter left in the screened wastewater for the biological denitrification if too much of the organic matter is removed by the fine screen. The problem with internal carbon can be managed depending on the degree of compaction to which screened solids are subjected. If the maximum pressure is applied during the compaction of material removed by the screen, the liquid returned to the influent of the screen will be high in organic matter.

In addition to simplifying the treatment process flow diagram, the use of the cloth filter has some significant benefits with respect to the biological treatment process. First and foremost, use of the cloth filter alters the particle size and particle size distribution of the wastewater applied to the biological treatment process. It was recognized early on that wastewater treatment kinetics are

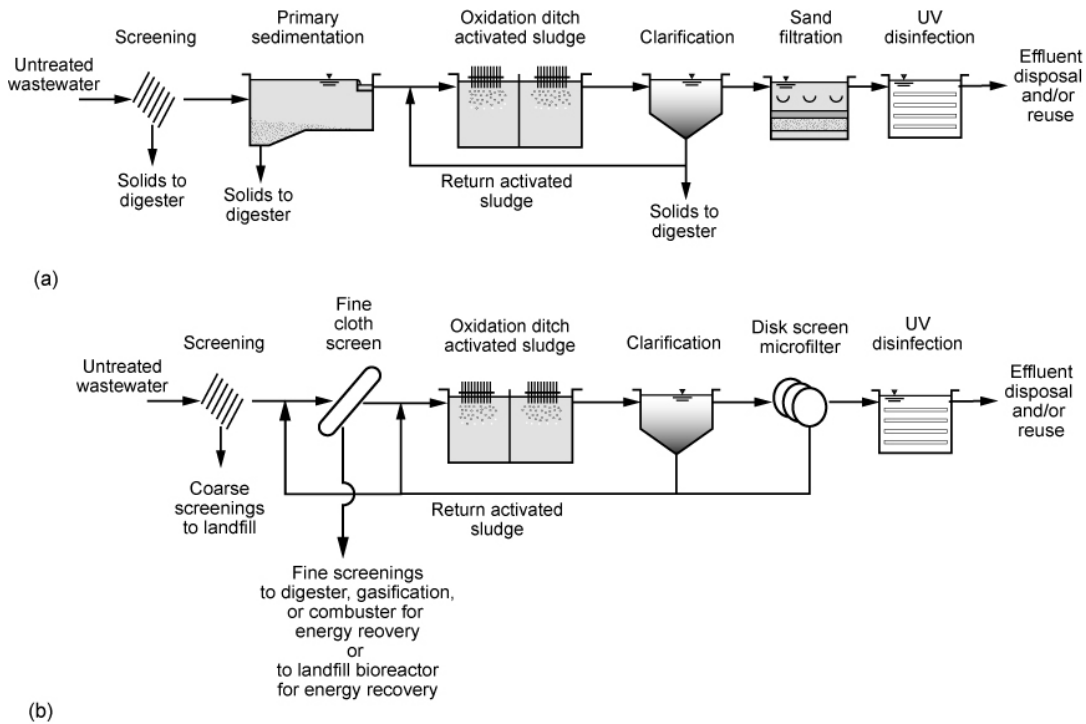


Figure 4

Two different wastewater treatment process flow diagrams without and with influent and effluent screens: (a) conventional activated sludge process and (2) activated sludge process with fine cloth screen in place of primary clarifier and high-rate disk microfilter in place of sand filtration

influenced by the particle size (Balmat, 1957). By reducing the size of the particles, the performance of the biological treatment process is enhanced. Another potential advantage of using the cloth screen is that it may be favorable for the use of the Anammox process for the removal of nitrogen (Mulder et al., 1995; Strous et al., 1997).

### Satellite Recovery of Energy Using Fine Screens

The deposition and accumulation of solids in wastewater collection systems often results in the blockage of pipelines and contributes to overflow events. In addition, the recovery of energy from the constituents in wastewater is more difficult following transport through the wastewater collection system. As wastewater moves through the collection system, particulate matter is reduced in size due to abrasion, mixing, and liquefaction and a fraction of the chemical energy is also lost through biological conversion. The use of fine screens on collection mains or trunks, at satellite treatment facilities, and at pump stations

can be used to recover the particulate matter upstream in the collection system before deposition and particle size reduction occurs. Two methods of satellite recovery of the constituents in wastewater are illustrated on Fig. 5: (a) scalping (or mining) from a wastewater collection main or trunk sewer and (b) full flow capture at a pump station.

**Benefit of Satellite Filtration** In addition to the recovery of organic matter for the production of energy, an ancillary benefit of satellite filtration is a significant reduction of the influent organic loading to existing WWTPs. Based on initial estimates, the organic loading may be reduced by as much as 50 percent. Reduced organic loading may benefit plants that experience unstable operation due to overloading or variable loading. Reduced loading would also reduce the need for new facilities, thus, reducing the utilization of resources and improving the process sustainability.

**Implementation Challenges for Satellite Energy Recovery** The use of satellite solids collection systems presents several engineering challenges, including (1) the need for installation of satellite recovery stations upstream in the collection system (see Fig. 2), (2) the logistics of material collection and hauling

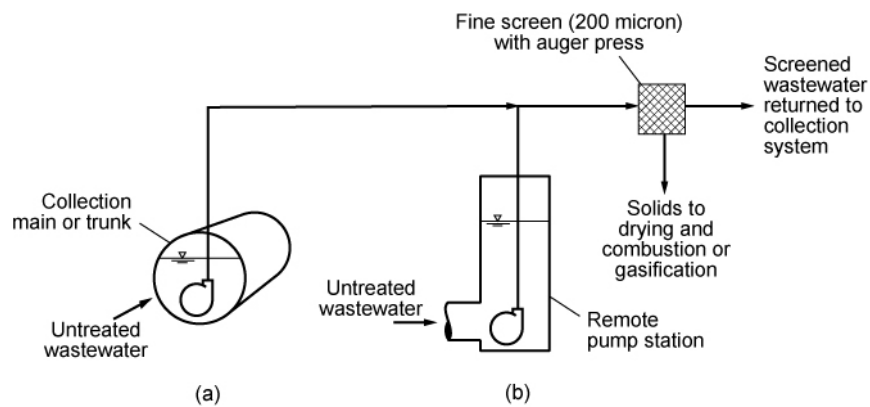


Figure 5

Definition sketch showing various types of satellite energy recovery systems: (a) scalping (or mining) from a wastewater collection sewer and (b) co-location of filtration system at pump station. Material such as toilet paper, removed on the screen, acts as a secondary filter for the captures of grease and oil.

to processing sites, (3) the design and operation of wastewater treatment plants with modified influent characteristics, and (4) implementing facilities for drying the solid material removed by fine screening for thermal processing. It should be noted that based on a preliminary analysis, enough energy could be recovered using satellite recovery to offset the energy required for material collection and processing, and wastewater treatment.

### **New Effluent Screen Technology**

During the past ten years, a number of new effluent filtration technologies have been developed and approved for use in reuse applications (Asano, et al., 2007). In general, these newer technologies are less energy and resource intensive than conventional deep bed sand filters. The new depth filters include several versions of the continuous backwash filter, two-stage depth filtration, and the compressible medium filter. Surface type filters include several cloth filters, stainless steel (SS) cloth filters, and porous membrane filters. In general, all of these filters work well with a high quality effluent. What differentiates them is the rate of filtration and the degree of backwash water. Filtration rates of 15 to 25 m/h (6 to 10 gal/ft<sup>2</sup>·min) have been achieved with cloth media filters, rates of 29 to 40 m/h (12 to 16 gal/ft<sup>2</sup>·min) have been achieved with SS cloth screens (Bourgeois et al., 2009), and rates as high as 98 m/h (40 gal/ft<sup>2</sup>·min) have been achieved with the compressible medium filter.

Of equal or greater importance than the filtration rate is the percentage of backwash water based on forward flow. With conventional sand filters, the percentage of backwash water is typically in the range from 8 to 15 percent. With the newer surface filtration technologies, the backwash water percentage has varied between 1 and 4 percent. Because the backwash water is returned to the head end of the treatment process, filters with high backwash water percentages are no longer sustainable because of the additional treatment capacity needed to process the excess water. To overcome the problem of

excessive backwash water, separate treatment facilities are used at large WWTPs to process the backwash water.

In the WWTP flow diagram shown in Fig. 4(a), a conventional sand filter is used with a nominal filtration rate of 5 to 10 m/h (2 to 4 gal/ft<sup>2</sup>·min) and a backwash water percentage of about 10 to 12 percent. In Fig. 4(b) the sand filter has been replaced with a SS cloth screen filter operating at a filtration rate of 30 m/h (12 gal/ft<sup>2</sup>·min) with a backwash water percentage of about 3 percent (see Fig. 6). The implication of replacing the sand filter with a stainless steel cloth filter are obvious: (1) less use of resources (3 to 6 times less volume), (2) less energy consumption, and (3) reduced overall carbon footprint.

## DISCUSSION

The application of new concepts and technologies to enhance the long-term sustainability of wastewater management, a required public service, has been illustrated in the previous discussion. The concept of using a fine cloth screen filter to replace primary clarification and to remove organic material within the wastewater collection system challenges conventional thinking and engineering approaches to wastewater management.

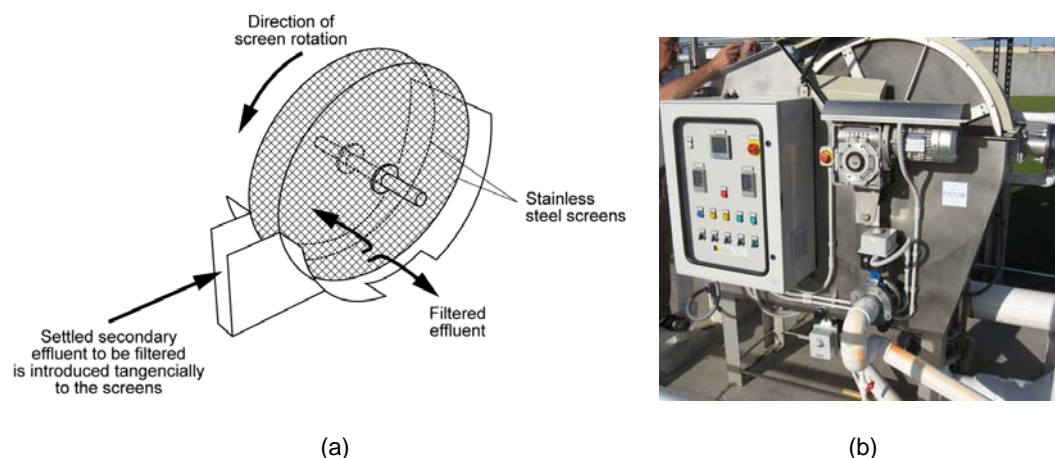


Figure 6

Schematic diagram and photograph of Ultrascreeen<sup>®</sup> stainless steel cloth filter for filtration of secondary effluent: (a) operationally, water enters tangentially to the disk screen, which rotates continuously. The accumulated solids are removed by backwashing (not shown). Adapted from Nova Water Technologies and (b) photograph of test unit (Bourgeois, et al., 2009)

A few years ago, it was thought that filtration rates as high as 98 m/h (40 gal/ft<sup>2</sup>·min), which are currently possible could not be achieved while maintaining adequate quality. However as new designs for secondary sedimentation tanks have evolved, effluent turbidity values of less than 2 NTU can now be achieved consistently. As a result, the incorporation of new filter technologies in wastewater treatment plant designs can also be used to enhance the sustainability wastewater treatment.

## **SUMMARY**

Using new concepts, technologies, and processes configurations, it will be possible to recover and utilize the energy content present in wastewater to enhance the energy sustainability of wastewater treatment facilities. Ultimately, wastewater treatment facilities could become net power exporters. Clearly, if significant advances are to be made in improving the energy sustainability of existing wastewater management systems, new concepts such as described in this paper must be developed and implemented.

## **REFERENCES**

- Asano, T., F.L. Burton, H. Leverenz, R. Tsuchihashi, and G. Tchobanoglous (2007) *Water Reuse: Issues, Technologies, and Applications*, McGraw-Hill, New York.
- Balmat, J.L. (1957) "Biochemical Oxidation of Various Particulate Fractions of Sewage," *Sewage and Ind. Wastes*, **29**, 7, 757-761.
- Bourgeois, K., N. Fontaine, J. Stokke, K. Marks, Sean Poust, D. Loy, and D. Popowitch (2009) "Pilot Testing of a High-Rate Disk Filter for Water Recycling Applications and Title 22 Approval," To be presented at WEFTEC.09, October 10 – 14, 2009, Orlando, FL.
- Mulder, A., A.A. van de Graaf, L.A. Robertson, and J.G. Kuenen (1995) "Anaerobic Ammonium Oxidation Discovered in a Denitrifying Fluidized Bed reactor." *FEMS Microbiol. Ecol.*, **16**, 3, 177-183.
- Shizas, I., and D.M. Bagley (2004) "Experimental Determination of Energy Content of Unknown Organics in Municipal Wastewater Streams," *J. Energy Eng.*, **130**, 2, pp. 45-53.

Strous, M., E. van Gerven, P. Zheng, J.G. Kuenen, and M.S.M. Jetten (1997)  
"Ammonium Removal From Concentrated Waste Streams with the  
Anaerobic Ammonium Oxidation (ANAMMOX) Process in Different Reactor  
Configurations," *Water Res.*, **31**, 1955-1962.

Tchobanoglous, G., F.L. Burton, and H.D. Stensel (2003) *Wastewater  
Engineering: Treatment and Reuse*, 4th ed., Metcalf and Eddy, Inc.,  
McGraw-Hill Book Company, New York.

Zanoni, A.E., and D.L. Mueller (1982) "Calorific Value of Wastewater Plant  
Sludges," *J. Environ. Eng. Div. (Am. Soc. Civ. Eng.)*, **108**, 187-195.