Start-up and Operation of a Leachate MBR Plant

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ABSTRACT

The Pollution Control Financing Authority of Warren County (PCFAWC or Authority), New Jersey, operates a solid waste landfill. Leachate collected in the landfill cell underdrain system drains to a lined basin, from which it had historically been pumped via an adjoining wastewater collection system to a 1,890 m^3/d (0.5 mgd) regional Publicly Owned Treatment Plant (POTW). Significant increases in leachate flow volumes and ammonia loads required the PCFAWC to evaluate alternative leachate disposal options. Pretreatment of the leachate in a Membrane Bioreactor process (MBR) was ultimately selected after the evaluation of alternatives and the completion of pilot tests. The MBR plant has been successfully operating for two years, meeting its design requirements. Initial problems with the MBR reactor foaming and elevated effluent color were overcome. The plant achieves full nitrification and significant denitrification while requiring minimal cleaning of the ultrafiltration (UF) membranes. Elevated process temperatures experienced are demonstrated to be a result of the high energy mechanical equipment (high pressure pumps) and heat of the biological reactions.

KEYWORDS: MBR, landfill leachate, ammonia, TDS, color, foaming, elevated temperature, heat balance

INTRODUCTION

In late 2009, a Membrane Bioreactor (MBR) plant was commissioned to pretreat leachate generated at a municipal landfill in Warren County, New Jersey. The main treatment objective was to significantly reduce ammonia loads to the receiving POTW, in a manner compatible with potential future need to reduce Total Dissolved Solids (TDS). In a previous paper (Wilkinson, 2010), information on project development, conceptual design, and facility start-up were provided. This paper provides details of the plant's initial operations, with particular emphasis on denitrification performance, heat mass balance, and color removal.

SELECTION OF MBR FOR LEACHATE PRETREATMENT

The major alternative technologies for the pretreatment of leachate for ammonia removal are nitrifying activated sludge and ammonia stripping. The compatibility of the selected pretreatment technology with potential future need for TDS removal was also a major consideration. The MBR was selected as the preferred option based on the literature review and an inspection of the existing leachate treatment facilities as well as the following factors:

1. Based on treatability tests, activated sludge systems with sufficient sludge age could reliably nitrify leachate. Due to the high concentration of organics and ammonia in the leachate, an HRT of several days would be required in order to achieve a low enough F/M (high enough sludge age) to effect winter nitrification. A major concern in operating an extended aeration system with an HRT of several days in cold climates is the possibility of nitrification inhibition, or freezing, during periods of low ambient temperatures and low leachate flow. Due to the temperature considerations, and more critically, concerns about potential future TDS, the MBR was eventually selected.
2. Similarly, the operation of an ammonia stripping tower with once-through air flow at low ambient temperatures could lead to freezing. Additionally, ammonia release into the air would require significant permitting efforts. An alternative, closed loop system with an alkaline ammonia stripper and acid scrubber for ammonia recovery did not appear to have an adequate, full-scale operating track record, although, in recent years, additional companies have begun to market closed loop systems.

In summary, while an MBR facility is more expensive than conventional variants of an activated sludge system, it offered significant advantages to the owner, as follows:

- Effluent from an MBR will undergo a tight membrane ultrafiltration (UF), which is an ideal pretreatment for a Reverse Osmosis (RO) process, should control of TDS be required at some point in the future.
- Compact MBR reactors could be housed in a building, eliminating freezing concerns.
- As identified during the treatability test, supernatant from the aeration vessel was very turbid, indicating concerns about the control of biomass loss with the effluent; however, the use of an MBR provides a positive means of solids retention, eliminating such concerns.

MBR DESIGN

MBR design assumptions are summarized in Table 1.

Table 1. Leachate Characteristics and Design Basis

Parameter	Units	Raw Leachate - Design Basis		Effluent Limits for Discharge to POTW (2)	
		Average or Range	Maximum or Range	Monthly Average or Range	Daily Maximum or Range
Flow	m^3/d (gpd)	50,000 (13.2)	60,000 (15.9)	50,000 (13.2)	60,000 (15.9)
pH	S.U.	7.4	6.8 - 7.9	5.5 - 9.0	5.5 - 9.0
Temp.	deg. C (deg. F)	18.3 (65)	12.2-25 (54 – 77)	NA	NA
TSS	mg/L	100	350	300	300
TDS	mg/L	7,500 (prelim.)	15,000	No Limit	
NH_3-N	mg/L	300	600	40	40
COD	mg/L	1,600	3,000	900	1,350
BOD_5	mg/L	139 (1)	960 (1)	300	300

(1) BOD_5 data may be artificially low/not reliable

(2) Limits for TSS, COD, BOD_5 and NH_3-N are calculated from the actual mass loading limits

The MBR reactor was provided by Dynatec Systems, with the overall process flow schematic of the pretreatment system as shown in Figure 1. The MBR is housed entirely in a new treatment building and consists of three main treatment tanks (one anoxic and two aerobic tanks). The anoxic zone was added in consideration of potential future denitrification requirements at the POTW, as well as to minimize supplemental caustic addition. Provisions for the addition of caustic, supplemental carbon source and phosphoric acid were included to provide operational control for treatment optimization.

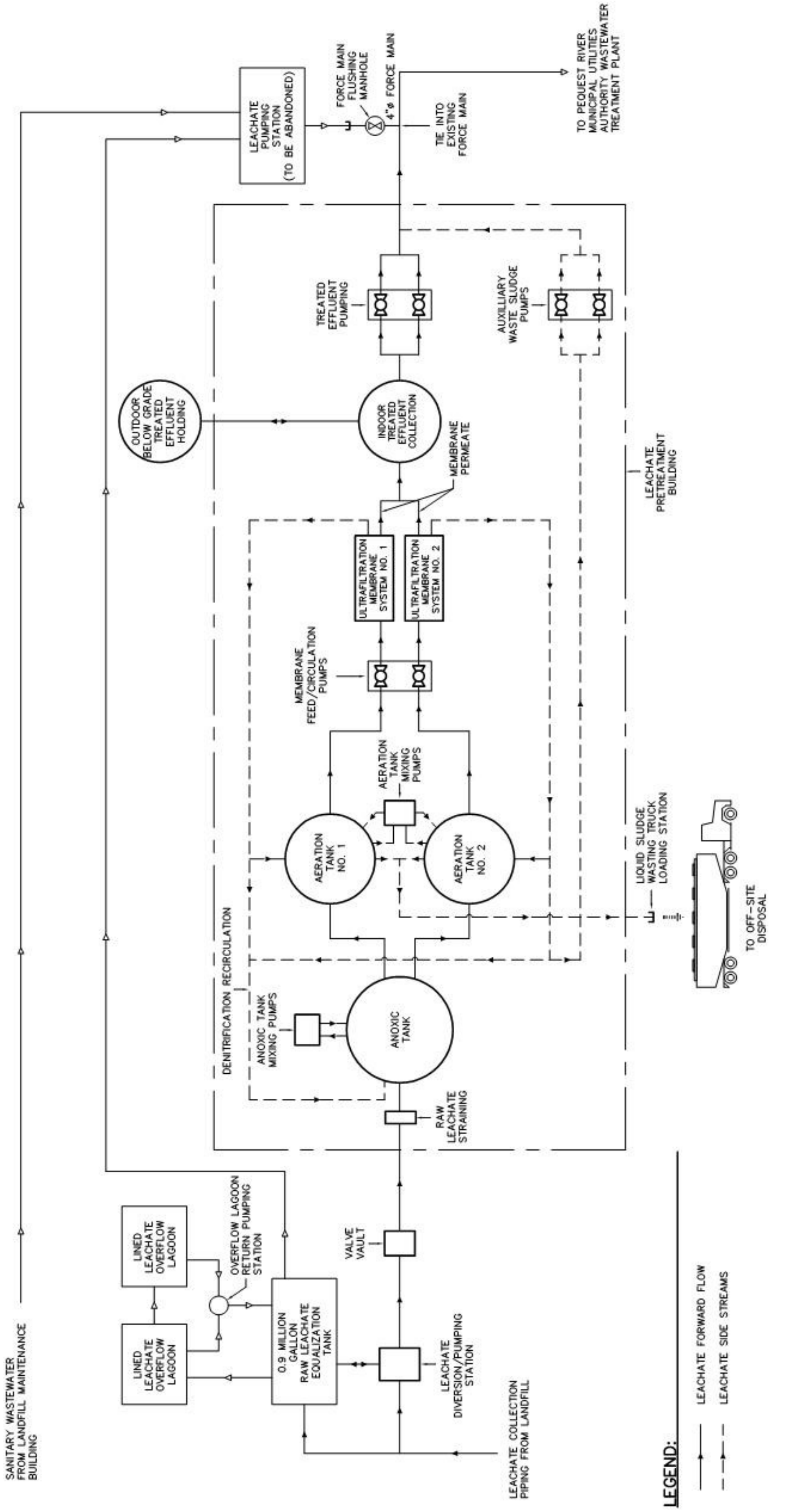

Figure 1. Process Flow Schematics

Figure 2. General View of the MBR Facility

The design MLSS concentration range was specified as 10,000 to 15,000 mg/L. The raw leachate is pumped to a single, 303 m^3 (80,000 gallon) (approximate working volume) anoxic tank mixed with a submerged jet mixing system, where it is combined with mixed liquor returned from the membrane reject (Figure 2). Partially denitrified effluent is split and flows by gravity to twin, 227 m^3 (60,000 gallon) aerobic tanks (approximate working volume) with jet aeration systems. With the overall working system volume of approximately 757 m^3 (200,000 gallons), the design average F/M of the system at 10,000 mg/L of MLSS is 0.04 #COD/#MLSS-day (including anoxic volume).

The mixed liquor is separated from the effluent by a battery of UF units. Two independent, pre-engineered membrane systems, each with a capacity of 189 m^3/d (50,000 gpd), were provided. Normally, only one UF system is expected to be on-line. Each system consists of 48 tubular, cross-flow membranes, mounted in eight parallel modules, each with six passes (six membranes in each module) (see Figure 2). An individual membrane consists of a 3½ - inch diameter PVC pipe, in which seven individual UF tubes are housed. The mixed liquor is pumped at a high surface velocity across the membranes using a 2.2 m^3/min (580 gpm) (16.7 times forward flow), high pressure pump. The reject stream is divided between the suction side of the membrane feed pumps with the balance returned to the aerobic and anoxic tanks. An in-place membrane cleaning system with acid is provided.

START-UP EXPERIENCES

The MBR reactor was seeded with well screened, debris-free nitrifying activated sludge from a nearby municipal WWTP. Due to the high biomass inventory needed (10,000 mg/L MLSS), biomass build-up was slow, as only one to two truckloads of sludge could be accepted at the facility per day. During the start-up, the leachate flow to the reactors was kept at a proportion to the biomass inventory. At no time was a problem encountered with achieving full nitrification.

Build-up of the biomass inventory was interrupted on several occasions when a sudden foaming in the aerobic reactors occurred, resulting in a loss of biomass. On at least one occasion, the foaming was caused by a sudden process change (batch ferric addition and pH change); on the other occasions, no specific cause could be identified. The addition of a non-silicone based antifoaming agent at regular intervals brought the foaming under control. As the process fully acclimated and stabilized, foaming ceased to be an issue.

Following the resolution of the initial mechanical and operational issues, the completed project is effectively removing ammonia and other permitted constituents and the facility meets all of the design criteria. A summary of the recent MBR performance is provided in Table 2.

As a comparison with the data in Table 1 indicates, the present leachate strength in terms of major parameters (NH_3-N, COD, TDS) is significantly higher than the design values. Nevertheless, the system provides almost complete nitrification at full design volumetric flows, the extent of which is generally limited only by the supply of oxygen (aeration dissolved oxygen (DO) set-point). Aeration intensity is monitored and adjusted on a regular basis in order to minimize DO input to the anoxic zone with the mixed liquor recycle stream, and thus maximizes denitrification. This is being performed in order to satisfy a request from the receiving POTW, which initially experienced process difficulties reportedly related to the high nitrate concentration in the treated leachate.

Table 2. Summary of Recent MBR Performance

Parameter, mg/L	Raw Leachate	Permeate
Flow, m3/d (gpd)	132 (35,000)	-
NH3-N, mg/L	887	5
NO3-N, mg/L	<2	50
COD, mg/L	3,750	1,520
BOD5, mg/L	782	<10
TDS, mg/L	14,800	13,400

The UF membrane performance is excellent. Only a single "demonstration" chemical cleaning was performed during the ten month start-up and operting period, and pressure losses at the membranes are stable. It is speculated that some of the incinerator ash in the landfill material is present in the leachate, acting as a gentle liquid abrasive for the membranes.

DENITRIFICATION PERFORMANCE

Immediately upon seeding and start-up, the system was fully nitrifying, with periods of increased ammonia concentration (above 5 mg/L) observed only when oxygen supply to the aerobic basins was limited as a result of attempts to increase denitrification. While the pre-anoxic tank was incorporated into the treatment train, no specific denitrification requirements or total nitrogen limits were part of the original design objectives. However, in order to minimize the impact of the nitrates on the primary clarifiers at the POTW, attempts to optimize denitrification were made. These included control of oxygen supply to the aeration basin, changes to the internal recirculation, and carbon source addition. A substantially complete denitrification was eventually attained, marked by a significant decrease in Oxidation-Reduction Potential (ORP) in the anoxic zone. It is suspected that a sudden inception of essentially full denitrification (Figure 3) is associated with the development of a fully acclimated heterotrophic bacterial population capable of denitrification in the potentially inhibitory environment, which has a high concentration of nitrous acid (high NO_2-N concentrations present due to high operational temperatures).

A complete nitrification was achieved when the residual DO concentration in the aeration basins was maintained at 1.5 mg/L or more. However, higher DO levels inhibited denitrification, as the internal recycle stream with a relatively high rate of flow delivered excessive oxygen flux to the anoxic zone. Consequently, operating the plant with a complete nitrification and with a significant denitrification required careful operational attention. Balancing the air supply to the two aeration basins under the variable flow and loading conditions was difficult as only one blower was needed to match the total air demand. That task was made easier by a minor modification to the blower manifold (additional valve) that allowed air flow to each of the two aeration basins to be controlled independently.

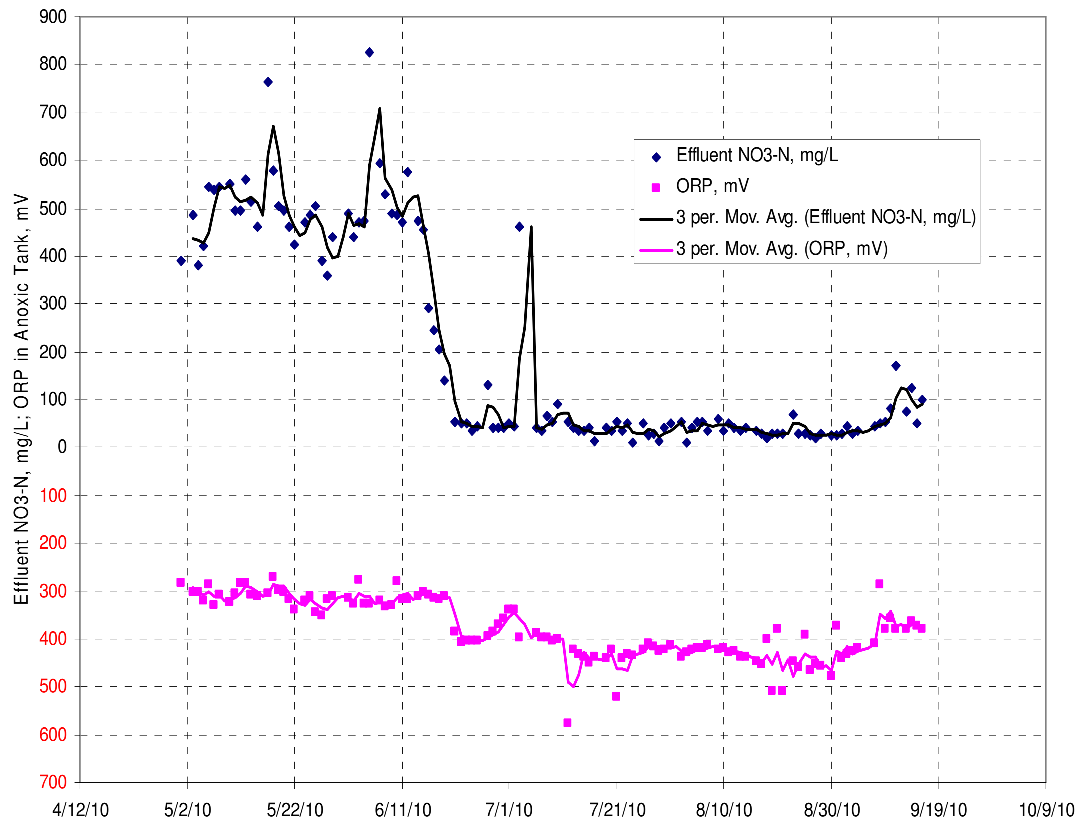

Figure 3. Denitrification Performance

TEMPERATURE CONCERNS AND HEAT BALANCE

One of the secondary reasons for selecting the MBR process was the concern about an outdoor, extended aeration system freezing during winter. However, the constructed MBR system causes concerns due to the potentially dangerously high temperatures. Since MBR reactors are housed indoors, heat exchange with the ambient air is minimized. Due to the substantial energy input from the high pressure recirculation pumps, mixing pumps and other equipment, as well as the heat created by the biological oxidation processes, MBR reactors operate at elevated temperatures. The temperatures are typically above 80° F (27° C) in winter and have reached 107° F (42° C) during a summer heat wave. Despite the fact that this temperature is at the very end of acceptable temperatures for nitrification, as detailed in a review paper by Rabinowitz et al. (2004), no detrimental impacts on the nitrification were observed.

Pumps

The main energy consumers at the plant (in addition to blowers) are the high pressure recirculation pump (50 HP) and 20 HP each, individual tank mixing/jet aeration pumps, with all units operating continuously. Consequently, 110 HP worth of equipment (pumps) is always on-line inside the main treatment building. Assuming that the actual energy draw is 70%, this corresponds to 57.4 kW or 1.2x10^6 kcal/day. Considering that the specific heat capacity of water is 1 cal/g/deg C, this amount of energy, if transmitted in its entirety to the wastewater stream with a flow of 35,000 gpd, could increase the leachate temperature by 9 deg C (16.2 deg F). Naturally, only a part of this energy is transmitted directly to the pumped liquid through the adiabatic compression and friction losses. However, in a closed building (assuming for the sake of argument that no ventilation/AC is provided) heat lost from the hot mechanical components of the motors and pumps will accumulate inside the structure, eventually contributing to an increase in the temperature of the reactors. Building ventilation will provide some cooling of both hot mechanical parts and of the reactor tanks themselves for most of the year; however, when the ambient temperature reaches 100 deg F (and even more inside the building), cooling of the reactors is not effective and the thermal effect of the mechanical equipment could be significant.

Aeration Blowers

Blowers are housed in a separate room, thus only direct air stream heat effects need to be considered. On a hot summer day, the compressed air temperature was measured at 48.9 deg C (120 deg F). Considering that the specific heat of dry air is 8.8 cal/ft3/deg C, and that the approximate air flow in summer conditions is 500 scfm, the theoretical heat delivered to the rector contents at equilibrium temperature of 37.8 deg C (100 deg F) is 70.4x10^3 kcal/day. When transferred to 35,000 gpd of leachate, this corresponds to the leachate temperature increase of 0.54 deg C, a rather minor effect. Additionally, if the intake air humidity is below 100% (in reference to the reactor's temperature), as usually is the case, the evaporative heat loss associated with the air stream could more than compensate for this. Consequently, aeration is not judged to be a significant contributor to the elevated temperatures inside the reactors and could actually provide some cooling effect.

Heat of the Biological Reaction

Aerobic biochemical reactions are exothermic and could contribute measurable heat for concentrated wastewater. Argaman and Adams (1977) stated that under typical conditions the heat release from organic matter oxidation is:

$$H_B = 1.8 \times 10^6 \times S_r \qquad (1)$$

Where:
H_B = Heat gained from biological reaction, cal/day
S_r = Organic removal rate, kg/day

It could be thus readily calculated that with 2,500 mg/L of COD oxidized, heat release is approximately 4.5×10^3 cal/L. Consequently, the net heat gain from COD oxidation will increase water temperature by 4.5 deg C (8.1 deg F), a significant effect. Additionally, nitrification and denitrification will contribute further to these process heat releases, although at this time these effects have not been quantified.

In summary, it appears that both mechanical equipment (pumps) and the heat of biological reactions are significant contributing factors to the elevated temperatures experienced at the plant, particularly during the summer.

COLOR MANAGEMENT

An unexpected complication that arose during process start-up is related to concerns about color impact resulting from the presence of the treated leachate in the effluent discharged from the POTW. For many years, the POTW was accepting raw, untreated leachate for treatment without color concerns. However, after approximately three years of interruption in accepting the leachate, during which time the Authority trucked its raw leachate to other municipal WWTPs, the introduction of the MBR-treated leachate to the POTW resulted in noticeable color in the POTW effluent. Following a series of jar tests, ferric chloride addition was implemented in full scale at the MBR facility.

Laboratory evaluations were carried out with use of activated carbon, chlorine, and coagulants such as ferric and alum. The addition of ferric chloride was successful in reducing the color intensity to acceptable levels (Figure 4). The application of ferric in the full scale at a dose of 500 mg/L (as FeCl3) proved to be an effective solution to the color concerns.

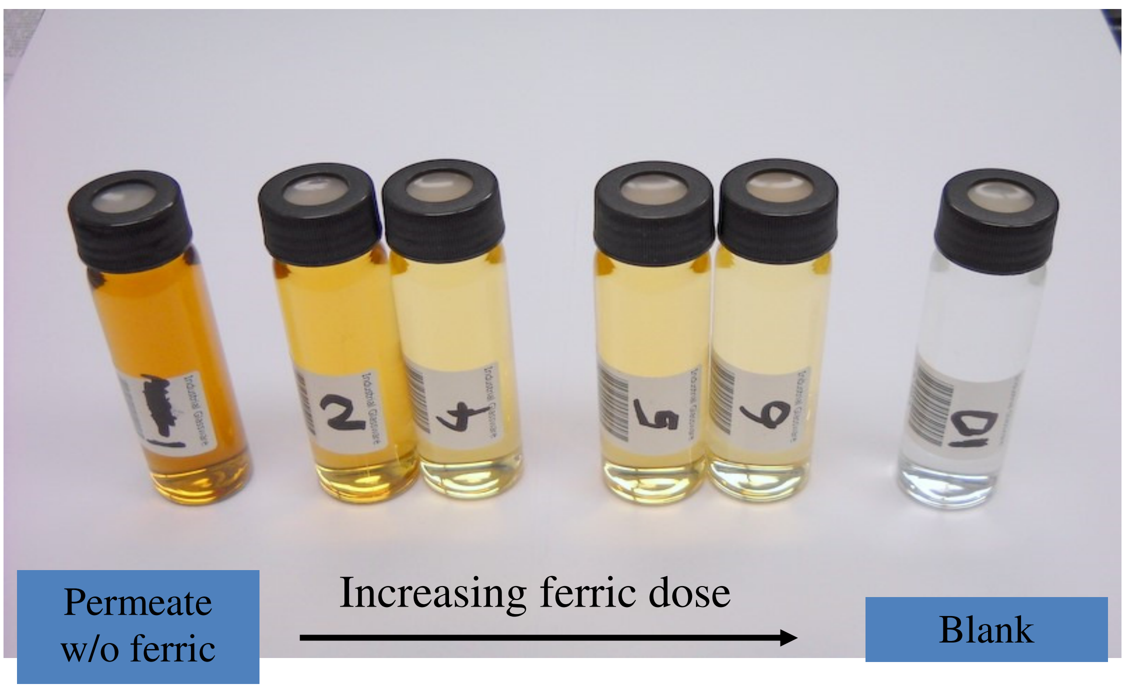

Figure 4. Effect of Ferric Addition on Permeate Color.

SUMMARY

The following are observations and conclusions from the start-up and initial operation of this MBR facility pretreating raw municipal leachate:

- The leachate pretreatment facility is fully nitrifying and accomplishing a significant degree of denitrification
- UF membranes operate without a need for frequent cleaning and with a stable pressure loss
- Sudden foaming was a major issue during the start-up and initial operting period but has subsided
- Excessive color of the pretreated leachate was successfully managed by ferric addition
- High pressure recirculation pumps and the heat of the biological reactions appear to be significant contributors to the elevated operational temperatures of the reactor

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