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Performance of a Modular Insulated Geosynthetics Floating Cover: Heat Loss Modelling and Verification

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ABSTRACT

In northern regions across North America, cold weather conditions can adversely affect microbial processes in waste water treatment facilities. The efficiency of microbial activity is largely determined by the activity of biomass and significantly influenced by ambient temperatures. Nitrification is a microbial process by which reduced nitrogen compounds (primarily ammonia) are sequentially oxidized to nitrite and nitrate. A municipality in northern Alberta was dealing with reduced nitrification efficiency in their treatment process during the winter season and was detecting higher than normal levels of ammonia from the final treatment cell before the treated water was discharged into a nearby creek.

In 2016, Layfield Geosynthetics designed, fabricated and installed a modular insulated floating cover (MIFC) system to enhance the nitrification process. A geosynthetic MIFC system was considered to be one of the cost effective and efficient ways to retain and maintain heat in the water treatment cells. The design of the cover took into consideration -40°C ambient conditions. Using computational fluid dynamics (CFD) simulation, a semi-empirical model was developed to predict heat conservation using a MIFC system. The CFD-verified convective heat transfer coefficients were mapped based on different parameters and configurations to calculate heat loss estimates. This paper outlines the development and verification of a heat loss model. This paper also outlines some of the technical challenges faced during the design and installation of the MIC system over the waste water lagoon.

1. INTRODUCTION

Current wastewater discharge limits and monitoring requirements have been more stringent with various environmental protection agencies (EPA) around North America. The new U.S EPA rules have mandated operators to remove ammonia from wastewater lagoon effluents. Regulatory agencies use water quality measures as indicators of treatment system performance. The biochemical oxygen demand (BOD), total suspended solids (TSS) and ammonia levels are primary indicators of the quality of waste water treatment.

Higher BOD, TSS and ammonia levels in the effluent can significantly impact the aquatic environment of the receiving waters. Many municipalities in North America operate small waste water treatment plants that primarily use lagoon systems for treating waste water. Lagoon based treatment plants are well suited for smaller communities because they can cost less to construct, operate, and maintain relative to other higher end mechanical treatment systems.

Some municipalities are often challenged with cold weather conditions that can adversely affect microbial processes in waste water treatment facilities. In 2016, a municipality in Western Canada was impacted by reduced nitrification efficiency of their waste water treatment process during the winter season. This resulted in the accumulation of higher than acceptable levels of ammonia before the treated water was discharged into a nearby waterway.

A modular cover was proposed to conserve the temperature of waste water in the lagoon cells. By reducing the heat loss and bacterial fluctuations in a wastewater system, the effluent becomes more consistent, predictable, and improves the overall performance of the system.

The objective of this technical paper is to present a general yet comprehensive temperature prediction model which is applicable to a wide range of climatic conditions. A heat loss calculator was designed to predict heat loss from open top lagoons and was verified by data obtained from field measurements through the year. This paper also outlines some of the technical challenges faced during the design and installation of the MIC system over the waste water lagoon.

2. NITRIFICATION ISSUES IN COLDER REGIONS

Nitrification is the most common way to biologically remove ammonia in wastewater lagoons. In this process, ammonia treatment occurs via bacteria already present in the water. These bacteria break down the ammonia and eventually promote the release of nitrogen gas into the atmosphere.

The efficiency of a biological system (sewage lagoon) is largely determined by the activity of biomass. Factors affecting biomass activity, such as substrate concentration, oxygen supply rate and oxygen saturation, are significantly influenced by temperature.

Thus, in colder regions, the waste water treatment is impacted by reduced nitrification efficiency and results in the accumulation of higher than acceptable levels of ammonia. Nitrification rate decreases at lower temperatures and is limited at temperatures lower than 7°C. (Kim et al, 2006)

2.1 HEAT LOSS FROM OPEN TOP LAGOONS

Ambient temperature significantly impacts biomass activity in a biological system. Biological treatment is effective between the temperature from 20°C to 35°C which is the normal ambient temperature for many regions around the world. For both Canada and in many parts of United States, the ambient temperatures in the winter season can be well below freezing.

Many smaller municipalities are faced with the challenge of improving treatment efficiency in colder months. One such municipality in northern Canada was facing heat loss issues and reduced biomass activity in their lagoon systems.

A review of previous year’s data showed unprecedented heat losses from the surface of lagoons. A report documented by the consulting engineer showed the following waste water temperatures at extreme conditions.

Table 1. Waste water temperatures at different locations

Ambient Temperature	Influent Temperature	Waste Water Temperature
-40°C	10°C	0.5°C
35°C	10°C	20°C

2.2 AMMONIA LEVELS IN THE EFFLUENT AND ITS IMPACT ON THE ENVIRONMENT

Ineffective nitrification process results in higher ammonia levels and toxicity in the effluent. It can cause over-fertilization or eutrophication, resulting in excessive growth of algae. Eutrophication reduces available dissolved oxygen, can have toxic effects on aquatic organisms, harm spawning grounds, alter habitat, lead to a decline in certain species, and impair the appearance of water. Municipal wastewater is the largest point source of nitrogen and phosphorus released to the environment.

With reference to Figure 1 below, the water enters Cell #3 and after the required retention time, the water is released to Cell #4. The flow of water is continued respectively to Cell #8 and Cell #9A after maintaining the specified retention time before releasing to the remaining area of Cell #9. Ammonia levels were measured for both the influent and effluent for cell #9. Figure 2 shows Year 2015 data for both unionized and ionized ammonia. During the winter months the unionized ammonia was exceeding the federal limit of 1.25 mg/L (WSER, 2012).

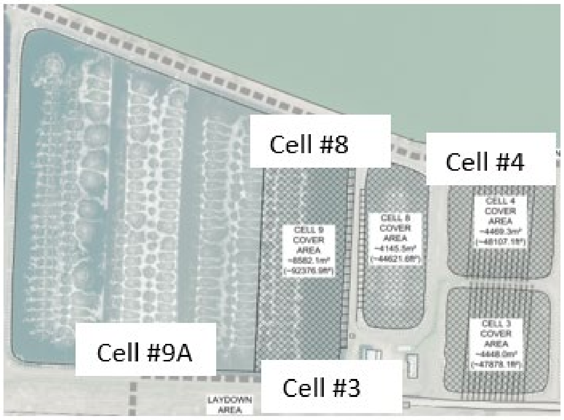

Figure 1. Schematic of the lagoon

Figure 2. Algae in receiving waters

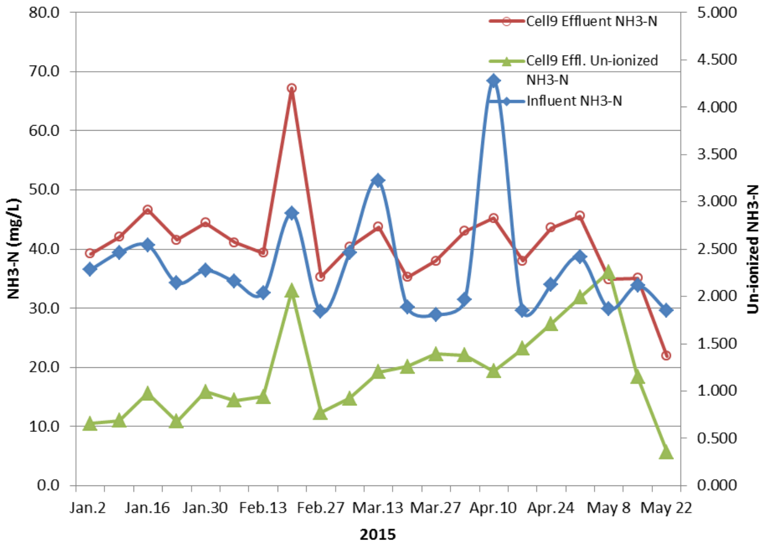

Figure 3. Influent, Cell #9 Effluent NH3-N and Cell #9 Un-ionized NH3-N

3. DEVELOPMENT OF A HEAT LOSS MODEL

A semi-empirical heat loss model was built to predict heat loss through MIC panels (thermal insulation) using the corresponding heat transfer coefficients and temperature gradient. The semi-empirical model calculates the average temperature of the pond at each time and provides results in a timely fashion compared to other CFD techniques that can take up to several weeks to dispense the results.

Different heat transfer mechanisms associated with the system are:

1) Heat transfer through wastewater flow
2) Heat transfer through lower surface of insulation
3) Heat transfer through air flow
4) Heat transfer through the bottom of the wastewater pond

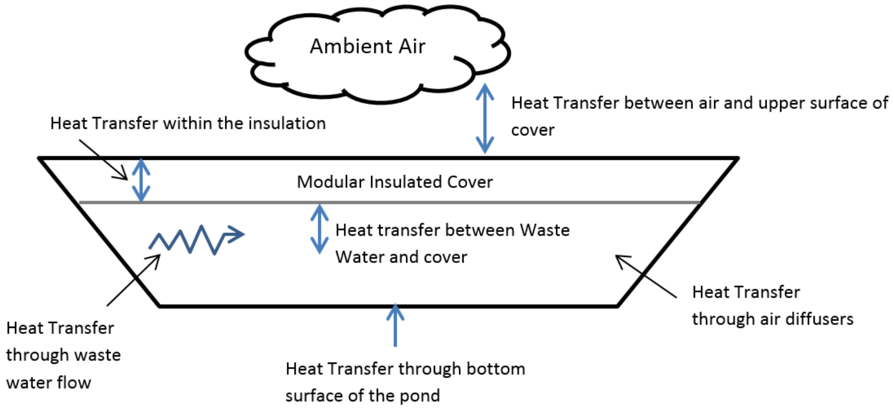

Figure 4. Schematic showing various heat transfer scenarios with the lagoon cell with MIC cover.

Taking into account all these heat transfer mechanisms, we get following set of equations:

Heat balance inside pond - Steady state:

$h_t (Ts_2 - T_l)a_t + m_l c_{p,l} (T_{l,in} - T_l) + m_a c_{p,a} (T_{a,in} - T_l) + h_b(T_b - T_l)a_b = 0$ ....(1)

Conductive heat transfer through insulation:

$\frac{kins}{\delta ins} (Ts_1 - Ts_2) = ht (Ts_2 - T_l)$ .... (2)

Heat balance at air-insulation interface:

$\epsilon\sigma(T^4\infty - T^4 s_1) + hs\infty(T\infty - Ts_1) = \frac{kins}{\delta ins} (Ts_1 - Ts_2)$ ...... (3)

All variables are explained in Table 2.

Table 2. Variable used in the semi-empirical model given by eqs (1)-(3).

h_t	heat transfer coefficient at the lower surface of insulation	m_a	mass flow rate of air through diffusers
h_b	heat transfer coefficient at the bottom of the pond	$c_{p,a}$	Specific heat capacity of air
Ts_2	Temperature of lower surface of insulation	$T_{a,in}$	Inlet temperature of air through diffusers
T_l	Outlet temperature of wastewater in pond	h_b	heat transfer coefficient at the bottom of the pond
a_t	cross sectional area of the lower surface of insulation	T_b	Temperature at the bottom of the pond
m_l	mass flow rate of wastewater through pond	a_b	cross sectional area of the bottom of the pond
$c_{p,l}$	Specific heat capacity of wastewater	k_{ins}	thermal conductivity of insulation
$T_{l,in}$	Inlet temperature of wastewater	δ_{ins}	insulation thickness
ϵ	emissivity	T_∞	Temperature of air
σ	Stefan-Boltzmann Constant	T_{s1}	Temperature of upper surface of insulation
$h_{s\infty}$	heat transfer coefficient at the upper surface of insulation		

To calculate heat transfer coefficients h_t and h_b, 3-D computational fluid dynamics (CFD) study was conducted. In the CFD study, both natural and forced convection heat transfer mechanisms were taken into consideration which allowed us to calculate a forced convection heat transfer coefficient.

Using this and well-known correlation for natural convection heat transfer coefficient, heat transfer coefficient for mixed convection was calculated and used in the semi-empirical model. CFD study also helped to analyze the flow behavior and temperature distribution in wastewater.

3.2 OPERATIONAL PARAMETERS

The following operating parameters were considered to predict the heat losses from the surface of the pond:

1. Wastewater inlet flow rate
2. Wastewater inlet temperature
3. Air inlet flow rate (aerators diffusing air into the pond)
4. Air inlet temperature

4. MODULAR INSULATED COVER DESIGN

A Modular Insulated Cover (MIC) system is an economical way to add insulation to open ponds or tanks requiring retention of heat to assist with the biological degradation of waste materials. A well designed MIC system retains heat in wastewater lagoons when the ambient temperature is different from the lagoon temperature. The design of the MIC required determining the thermal resistance (R value) of the MIC panel to meet the project specification, and then determining the dimensions required for fabrication and installation.

The MIC needed to be sufficiently buoyant so that our field crew could stand on it without significant deflection. The MIC panels are typically composed of expanded polystyrene foam encapsulated in a synthetic barrier on both sides.


Figure 5. Snow and Ice build-up


Figure 6. Aeration lines

Some of the design parameters included the following:

- An insulated cover design that met the heat loss criteria.
- Fabrication of MIC panels in the shop with tight quality control tolerances.
- Installation of MIC panels in winter conditions.
- Installation of MIC over the aeration lines.
- Minimizing exposed areas along the irregular shoreline to reduce the evaporative heat losses.
- Ballasting MIC panels with sufficient weight to prevent wind uplift.
- In-house testing of attachment hardware and weld strengths.
- Removal of debris and vegetation within and around the perimeter of the pond.

Figure 7. MIC fabrication in the shop

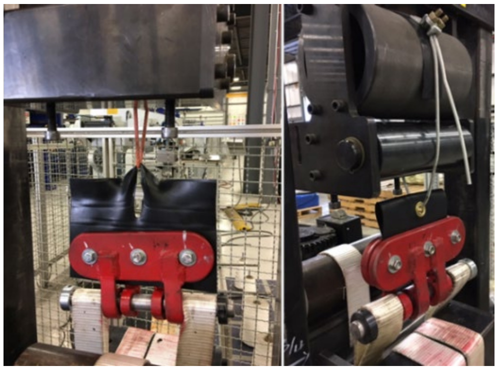

Figure 8. Custom test rig to qualify the attachment hardware

Some of the above design parameters have been discussed in the sections below.

4.1 MODULAR INSULATED COVER FABRICATION AND INSTALLATION

MIC panels were installed under frigid conditions and posed challenges to our field technicians. Material handling and installation of the materials was a major challenge as the MIC panels needed to be installed in temperatures as low as -26°C ambient with a wind chill factor often reaching -35°C.

The project stakeholders acknowledged that prefabrication of the MIC panels in the plant was beneficial during field installation in the extreme cold environment. The prefabricated panels significantly reduced the field welding component of the project allowing our crews to finish the installation of MIC on schedule and budget. MIC panels were fabricated at the Layfield Edmonton plant. Fabrication of MIC panels included:

Figure 9. Geosynthetics Technicians walking on the cover during panel deployment

- Encapsulation of the foam with synthetic liner.
- Panels required to be fabricated with tight tolerances to reduce heat losses.
- The corners were sealed to make them leak proof.
- Testing the entire panel for leakage
- Optimize size and weight of panel to aid in shipping

Wind imposed uplift was an important consideration during the design process. To provide the required ballast Layfield designed sand tubes with sufficient weight to hold the panels in place. Custom equipment was built to fill sand in pre-formed tubular bags. The material for the sand bag was a U.V resistant material. Some MIC panels had sand tubes strapped to them to hold the ballast in place. Custom tensile testing was performed to ensure the weld strength of the strap to MIC panels (Figure 8).

5. RESULTS, DISCUSSIONS AND CONCLUSIONS

Using the CFD, heat loss for each of the lagoon was determined. Figure 10. show a colour coded schematic of the lagoon with and without the cover. The model predicted that with 4” insulation, the lagoon temperature will only drop marginally. The model assumed $T_{ambient}$ at -20°C and the influent temperature at 10°C. This was verified with the actual field test report from the municipality. Figure 11. show temperature of the lagoon and the ambient temperature during the year 2017.

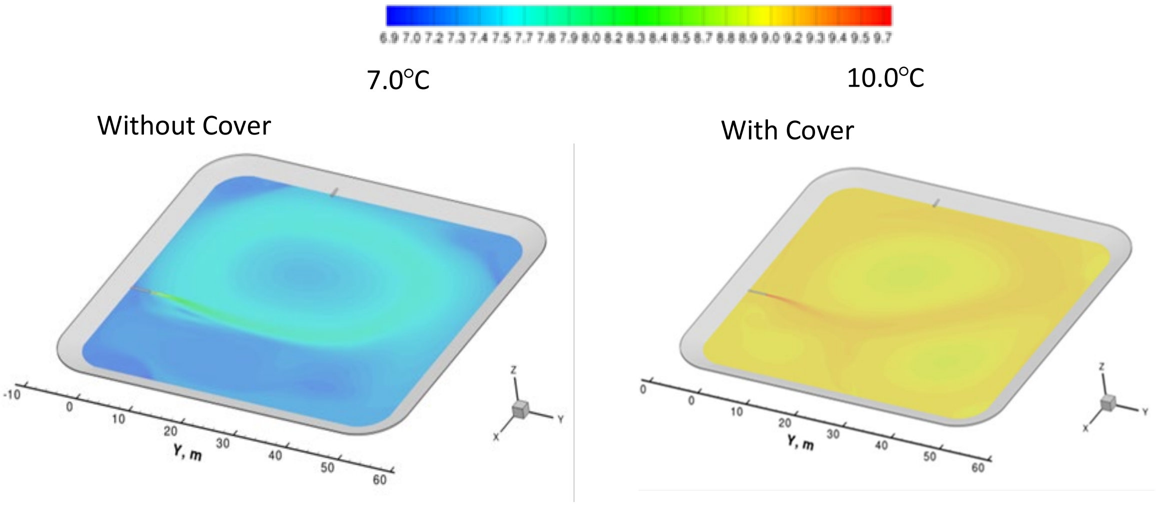

Figure 10. CFD Model predicting the temperature profile with and without cover.

There was significant fluctuation in the air temperature between February and March 2017, similar conditions were observed in November 2017. With the MIC covering the lagoon cell, the waste water temperature in the lagoon showed no deflection. It was steady at 10°C (Figure 11). Unfortunately, the municipal operators did not record the temperature of the incoming influent. In our discussions with the lagoon operators we were informed that the temperature of the influent in winter months was observed between 10-12°C.

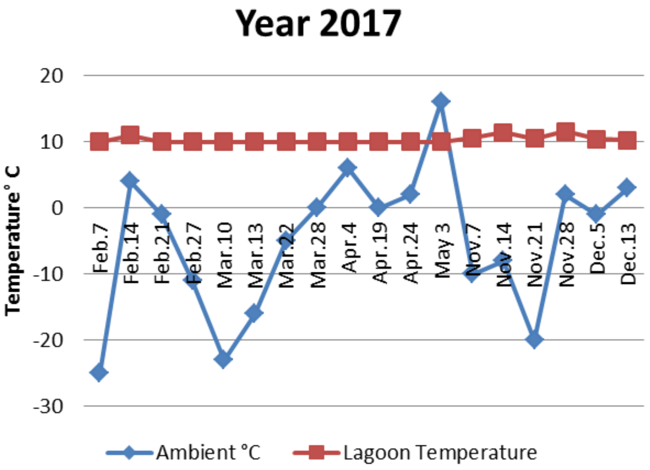

Figure 11. Ambient and waste water temperature during winters.

The results of unionized ammonia were very interesting. In 2015, the average levels of unionized ammonia were found to breach the 1.25 mg/L regulation set by Environment Canada. After the MIC was installed in 2016-2017, the heat loss was significantly reduced and thus improved the unionized ammonia levels in the effluent. The results shown in Figure 12 clearly indicate significant improvements in the unionized ammonia levels in the effluent. They were found to be consistently below the 1.0 mg/L even in extremely cold temperatures (Feb-Mar 2017).

The placement of the MIC covers provided a low cost alternative compared to other proposed alternatives that improved the overall wastewater treatment by reducing the heat losses from the pond surface.

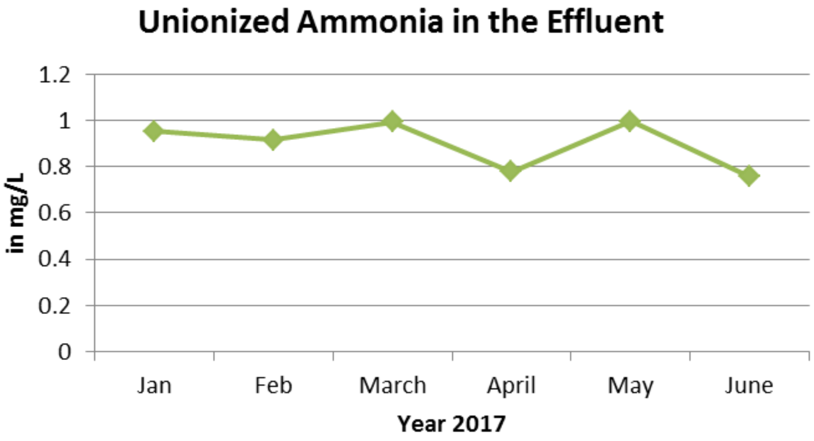

Figure 12. Unionized ammonia results from Jan-June 2017

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