INTRODUCTION

Municipal sewage treatment plants serving combined sewer collection systems are typically operating beyond their design treatment capacity. As the volume of combined waste streams increases with population growth, primary clarifiers often have to be expanded or upgraded due to throughput increases and/or the need for solids removal efficiency improvement. Similarly, the handling, processing and disposal of sludge can become increasingly challenging and costly in the face of digester and dewatering capacity limitations.

Budgetary constraints and environmental performance are two issues that must be dealt with simultaneously. In order to improve treatment plant performance and to avoid or defer heavy capital investment, alternative treatment enhancement technologies need to be identified and successfully implemented. One practical approach towards addressing this issue, without major capital investment, is to use inorganic or organic polymer treatments. Chemically enhanced treatment is intended to improve the removal of inorganic and organic particulates from the wastewater stream and is based on the addition of a primary coagulant and a coagulating aid.

A recently completed study at Toronto MTP has identified a low cost approach to address the issue of hydraulic over-loading of primary clarifiers and improve overall treatment process performance. The sewage influent flow averaging 300,000 m$^3$ per day was treated with ferrous chloride at a 15 mg Fe/ L dosage added to aerated grit tanks, and activated silica polymer at 1.0 to 3.0 mg SiO$_2$/L was added to the primary clarifier feed.

The addition of activated silica polymer yielded an average of 50% increase in effluent suspended solids (SS) removal from the entire primary treatment and improved compaction of primary solids by increasing solids content by approximately 30%.

Treatment with activated silica has been identified as a simple, low-cost technology for improving settling and compaction of settleable solids in clarification processes of wastewater treatment plant operations.
Activated silica (AS) is an anionic, inorganic coagulant aid which improves the entire flocculation process to a similar degree as commonly used synthetic acrylamide based long chain organic polymers [15]. The terms “activated silica” or “activated silicic acid” can be used interchangeably in describing stable silica sols. Activated silica is made by partially or completely neutralizing the alkali of a dilute sodium silicate to initiate the formation of silica micelles, aging to permit growth of these micelles and finally diluting to stop the further increase in size which leads to formation of gel. Activated silica sol concentrations and/or dosages are most often expressed in terms of % or mg/L SiO₂, respectively. The silica sols are usually made starting with a commercial solution of sodium silicate which contains about 8.9% Na₂O, 28.7% SiO₂ and has specific gravity of approximately 1.4. Many different methods are possible to activate the silicate and various dilution recipes and activating agents can be used in the preparation of the activated silica polymer. The most common technology is the Baylis Process, which uses sulphuric acid as the activator. Ammonium Sulphate, Sodium Aluminate, Sodium Bicarbonate, Ammonium Sulphate, Silicofluoride, Chlorine and Carbon Dioxide have also been used to activate silica solutions. Most recently, carbon dioxide is becoming a preferred activating agent because of the potentially hazardous aspects of using more acidic chemicals like H₂SO₄.

REVIEW OF ACTIVATED SILICA APPLICATIONS IN TREATMENT OF MUNICIPAL AND INDUSTRIAL WASTEWATERS

The effectiveness of AS polymer in the coagulation of suspended matter in aqueous systems has been known for decades. The AS polymer usually was used in conjunction with primary coagulants, such as aluminum sulphate, lime, or ferric salts. AS provides denser, larger and stronger flocs than organic polymer.

Widespread application of activated silica polymer technology in potable water clarification processes has been documented. Various flocculant surveys have shown AS treatment as superior or comparable to treatment with high molecular weight organic polymers [15]. Overall increases in coagulation process efficiency and reduction of the chemical consumption have resulted from AS use.
Additional applications include treatment of municipal wastewater and various types of industrial waste streams including those from petroleum refineries, pulp and paper and deinking operations [3,12].

The positive effect of AS addition for phosphorus removal in both primary and secondary wastewater treatments plants has also been previously documented [21,22].

Effective application of AS with lime in clarification processes of low alkalinity combined sewers, stormwater, sewer runoffs and typical raw wastewater was reported [1,4]. It was found, at an AS dosage range of 2 to 4mg/LSiO2, up to 10 fold lime dosage reduction could be achieved and sludge volumes and pH requirements could also be significantly reduced.

Industrial wastewater recorded a number of case studies with activated silica polymer used in conjunction with primary coagulant [3,6,8,12,14]. It was found, that AS was superior to polyacrylamide technology in removal of inorganic contaminants from the wastewater containing Fe, Cr, Ni, F and hydrocarbons.[3,12,14] In a treatment of petroleum containing wastewater, AS treatment can be used instead of polyacrylamides. High surfactant, fatty acids and detergent condensation products removal efficiencies were recorded with AS added alone in synthetic fiber and detergent plant effluent treatment process. [8,9]

Also, better clarification resulted from AS application before alum and lime treatment in the sewage plant effluent treatment for industrial reuse.[13]

AS application in wastewater treatment plant is not limited to the clarification processes only. It was found, that improved dewaterability of the centrifuge sludge feed and reduced chemical consumption was obtained when dual chemical conditioning system with AS polymer and cationic organic polymer was applied. AS combined with Na polymethacrylate resulted in substantial organic polymer consumption reduction at an increased filtration rate, in both, municipal and industrial processes.[17]

Activated silica technology has not been implemented on full scale in any Ontario Sewage Treatment Plants yet. Over the past several years, the general lack of full plant trials and experimentation can be attributed to significant limitations in the capabilities and availability of suitable preparation systems for activated silica. With the development of modern and reliable preparation technology, it is anticipated that activated silica products will gain widespread acceptance and recognition as an effective and economical chemical enhancement for wastewater treatment.
ENVIRONMENTAL ASPECTS

Application of both AS and synthetic organic polymers to wastewater streams provides significant environmental pollution control in terms of the removal of solids and reduction of many other contaminants. Ecological assessment of individual polymer technology need to include risk characterization in the event of potential releases to the surface waters and the polymer fate in natural aquatic environments.

AS technology does not present any concerns with respect to polymer fate and aquatic toxicity even in case of overdosing. The produced polymer is usually of 0.5 to 1.0 % SiO₂ concentration at neutral pH and does not pose any risk in its final form or during polymer manufacturing process. The potential for respiratory toxicity or irritation being associated with polymer dust exposure for dry organic polymer make up systems [10,11] are non-existent for AS polymer systems. With the development of CO₂ AS technology, the issue of using hazardous raw chemicals like H₂SO₄ have been eliminated.

DESCRIPTION OF THE PLANT PROCESS

The Main Treatment Plant (MTP) is a conventional activated sludge wastewater treatment plant. The plant’s current rated capacity is 818 ML/d for secondary treatment and 2,532 ML/ day for the primary treatment. The treatment train consists of screening, grit removal, primary clarification and activated sludge (aeration tanks and secondary clarifiers) wastewater treatment processes. Following secondary treatment and phosphorus removal, effluent from the MTP is disinfected using chlorine. The solids or sludge removed during the treatment undergo conventional anaerobic digestion, dewatering, and incineration. Primary clarification consists of twelve rectangular sedimentation tanks. The clarifiers are arranged in three groups (1-6, 7-9, and 10-12). Primary clarification is used for the gravity settling and removal of suspended solids. The primary clarifiers treat raw wastewater after screening and grit removal.

Need for increased MTP treatment capacity and improved performance

MTP is rapidly approaching its treatment capacity limits based on population growth estimates. The MTP wastewater and Combined Sewer Overflow (CSO) treatment needs as well as ways of improving the effectiveness of the MTP at reducing environmental impacts, were reviewed under the Ontario’s Environmental Assessment Act. MTP Environmental Assessment (EA) has identified a potential future need for additional wastewater treatment capacity. Additional capacity is
also required to prevent CSO from discharging into receiving waters under wet weather conditions. During 1997 alone there were 19 occurrences of primary effluent bypassing secondary treatment into Lake Ontario [20]. Total bypassed flows were estimated to be 3,216.4 ML and underwent disinfection process. The EA Study completed in December 1997[12] identified the following needs: additional capacity to treat up to 102 ML/d of wastewater and 33 t/d of solids to year 2011, CSO treatment of up to 213 ML/d and 26 t/d of solids. The potential to meet near future wastewater/CSO treatment needs was examined and various alternatives assessed. The need for improvement of primary tank sedimentation efficiency was identified in MTP Optimization alternatives included in this study. The option of maximizing the existing primary settling capacity versus the upgrade and expansion alternative seemed the most preferred choice considering that no capital expenses are required. As concluded in numerous previous studies, chemically enhanced primary treatment can prove to be a very effective and inexpensive solution in maximizing primary treatment capacity [2,18 ]. The chemical primary treatment will result in considerable savings in capital costs which in turn, may offset part or all of the operating cost of chemical addition. In the process of continuing CSO management efforts, the MTP EA study recommended CSO primary treatment and disinfection processes for secondary bypasses before discharging into receiving waters. Additional cost savings can be achieved in disinfection costs when chemically treated primary effluent is disinfected with chlorine or UV light. Chemical primary treatment will also improve the effectiveness of the MTP at reducing environmental impacts.

METHODOLOGY AND RESULTS

The purpose of AS evaluation in MTP was to examine potential improvement of the primary treatment as well as to investigate impact on the plant downstream processes. Both, bench test and field test trials of the addition of AS polymer to the primary clarifier influent feed at the City of Toronto MTP were completed in 1996 and 1997.

Evaluation of Activated Silica Addition in Toronto Main Plant (MPT)

Laboratory tests

Jar tests on the effects of AS treatment were completed during the period from September to December 1996. Representative primary influent samples were collected from the influent distribution channel to primary clarifiers #7-9. The objective was to examine primary effluent and sludge quality with activated silica polymer addition. Jar tests were completed on primary influent samples treated with three types of AS polymer at dosages up to 10 mg/L expressed as SiO2. All of the jar tests also included primary coagulant, ferrous chloride at a dosage
of 15 mg/L (as Fe). The three types of activated silica polymer included polymer produced by activation with sulfuric acid (Baylis AS), ferric chloride and ferric sulphate. Baylis AS produced the best results at all dosages examined. Baylis AS at a dosage of 1-3 mg/L (as SiO₂) with a ferrous chloride dosage of 15 mg/L (as Fe) reduced total phosphorus to less than 1 mg/L and removed TSS to less than 25mg/L. In addition, total solids concentration in primary sludge increased to 1.4 %. Baylis AS also produced a compact and dense sludge. However, rates of compaction were not determined for the individual treatments. The jar test results indicated that AS addition improved the efficiency of solids removal from primary clarifier influent wastewater and increased sludge solids concentration.

**AS Field Trial Evaluation**

The results obtained in laboratory evaluations were used to establish conditions for the field trial conducted in November 1997. The trial set up is shown on Figure 1. Raw sewage influent flow of 300,000 m³ was pretreated with primary coagulant, ferrous chloride prior initial degritting. Baylis AS was injected into the distribution channel that carried initially coagulated sewage after screening and grit removal and prior to the primary settling tanks #7,8 and 9. Mixing was provided with air diffusers located along the distribution channel. In order to improve mixing and provide better polymer distribution into treated sewage for the future trials, it was recommended to relocate polymer injection points from the main distribution channel to each individual collection channel coming out from the grit tanks.

AS polymer dosages were estimated based on an average flow of 300,000 m³ per day. The flow-paced polymer injection method was not accessible. In the events of the significant sewage flow changes, pump flow rate adjustment was made. Over 1500 AS polymer batches were made during the trial. AS was applied at 1.0, 2.0, and 3.0 mg/L SiO₂ dosages. Observations were made with respect to the effect of activated silica polymer activity on the process performance. The polymer activity is measured by its aging time before final dilution with water, which halts the polymerization process. The aging time is expressed as the % of actual gel time of the polymer if the final dilution did not occur. The range of aging times for optimum polymer activity is 30-70 % of gel time. AS polymer aged at 35%, or greater, of gel time produced the highest solids concentrations. It is anticipated, that better results can be consistently achieved with full process optimization.

The primary clarifier operation data before, during and after the activated silica field trial period was collected from MTP. These data included influent flows, primary clarifier flow capacities, raw primary sludge generation rates, total and volatile solids concentrations for the complete set of clarifiers. There were no parallel control treatment trains run
concurrently with the chemical addition trials due to limitations of the plant structural design. A local engineering consulting firm was contracted for MTP operating data analysis.

Figure 1-AS field trial schematic

**Total solids concentration**

An average sludge total solids concentration during the trial was monitored and compared to that before and after the trial. An average sludge solids concentration of 3.2 % was achieved during the trial which compared to 2.1 and 2.0 % for pre-trial and post–trial conditions.(Fig.2)

**Suspended solids(SS) removal**

The effluent suspended solids (SS) concentration and SS removal from the entire primary treatment system was improved by approximately 50 % during the activated silica trial. Effluent SS concentrations and SS removals for Primary Tanks #7-9 (New PT), which received the activated silica treatment were estimated based on:
- total influent SS values for both Old and New PT,
- primary clarifier sizes,
- flow proportioning method
- and effluent SS values from New & Old PT.
Also, an average primary effluent BOD$_5$ concentration of 176mg/L with no chemical treatment was reduced to 124mg/L with chemical treatment.

**Sludge generation rate**

MTP has the capability of returning recycle streams to various locations upstream of the primary clarifiers in both, “P” and “D” sections of the primary treatment. The effect of the quality and quantity of recycle streams on primary clarifier performance and primary sludge characteristics can be significant. Prior to, during and after the chemical trial, all recycle streams were returned to primary clarifiers section “D” of the plant, which was not tested for the AS effects of enhanced coagulation on clarifiers performance. As a result of directing recycle streams to primary treatment “D” section, the raw primary sludge generation rates in tested primary clarifiers #7-9 have changed prior to the activated silica field trial, as shown in Table 1. The redirection of the recycle streams significantly reduced the sludge generation rate prior to the trial period. Similar sludge volumes were generated during and after the activated silica field trial, however, the solids mass generated was 30% higher during the field trial, compared to after the trial. The activated silica trial improved suspended solids removal and compaction of the solids. The assessment of the performance benefits of activated silica polymer addition on the primary clarifiers performance has been completed based on the available MTP operating data.
Table 1: Raw Primary Sludge Generation Rates for Primary Clarifiers # 7-9 October – December 1997

<table>
<thead>
<tr>
<th>Period (1997)</th>
<th>Raw Primary Sludge Generation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume (m³/d)</td>
</tr>
<tr>
<td>Oct. 1 – Nov. 10</td>
<td>3,243</td>
</tr>
<tr>
<td>Nov. 10 – Dec 10</td>
<td>1,050</td>
</tr>
<tr>
<td>Dec. 10 – Dec. 31</td>
<td>1,035</td>
</tr>
<tr>
<td>Oct. 1 – Dec. 31</td>
<td>2,001</td>
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</tbody>
</table>

¹AS field trial period

Considering that higher Volatile Solids (VS) were generated in the primary sludge during the trial, less of VS ended up in primary effluent stream to the aeration tanks. More compacted sludge also suggests lowering WAS quantity in the future.

The Hydraulic Retention Time (HRT) in anaerobic digestion process was increased from an average 8 days to 13 days during the AS trial. Consequently, increased HRT resulted in more sewer gas produced [20]. As previously demonstrated, longer HRT could increase volatile solids destruction, reduce pathogen levels and overall improve dewatering process[19]. Future work will also examine impact of AS addition in primary treatment on activated sludge processes. One study has demonstrated, that addition of inorganic solids Fe (OH)₃, Al (OH)₃ and SiO₂ enhanced activated sludge process by accelerating bacterial metabolism.[7] A longer trial period is required to confirm the received data and to draw more conclusions as to further potential performance benefits of AS addition downstream from primary treatment processes.

COST BENEFIT ANALYSIS

Application of the enhanced coagulation process with addition of AS polymer in primary treatment stage could yield significant financial benefits, particularly in the area of capital cost savings due to deferred upgrades. The potential operational costs were also estimated in this study. However, the savings accrued from avoidance of the construction costs were of much greater significance compared to the operational cost
savings. The economic attractiveness of applying AS technology in treatment of municipal wastes would be plant specific. Capital and operational cost savings for MTP include savings generated by 30% sludge compaction increase, 50% SS removal increase and total solids concentration to an average 3.2% increase. Also, longer HRT in anaerobic digestion resulted in more sewer gas produced, increased oxygen transfer efficiency and therefore lower secondary treatment operating costs.

**Sludge digestion**

Based on an average increase of primary sludge solids concentration from 2.0% to 3.2%, and HRT increase from 8 to 13 days, the savings obtained in sludge digestion process would be due to deferred digester upgrades. Estimated MTP capital cost savings would be in an order of $20 millions. Operational cost savings would be obtained as a result of increased sewer gas production which could be used for digester heating processes instead of natural gas.

**Aeration**

MTP like any other typical wastewater plant, spends about 50% of total energy costs for aeration processes. The BioWin statistical biological process model was used to estimate aeration cost savings. Model input included an average daily flow of 800,000m³/d and an average primary effluent BOD₅ concentrations of 176mg/L and 124mg/L for no chemical treatment and chemical treatment scenarios, respectively. Model configuration and operation assumptions included influent TKN=37mg/L, with no nitrification, temperature of 20°C, and solids retention time(SRT) of 8 days. The coarse bubble system with oxygen transfer efficiency (OTE) of 6.0% and MTP estimated blower power requirements were applied in this model. Based on this preliminary analysis, the estimated operational cost savings in aeration would be in an order of $300K to $500K per year. More detailed analysis of this saving is required.

All of these estimated savings must be balanced against the costs of AS polymer and AS make up equipment. The AS manufacturing equipment cost for an 800,000 m³/day size plant was estimated to be in a range of $50 –80 K. As an example, chemical costs for CO₂ AS polymer applied at 1.0 mg/L were estimated at $200 K for 800,000 m³/day flow size plant.

**CONCLUSIONS**

The addition of activated silica polymer yielded an average of 50% increase in effluent suspended solids (SS) removal from the entire primary treatment and improved compaction of primary solids by increasing solids content by approximately 30% compared to after the trial. An average sludge solids concentration of 3.2 % was achieved during the trial which compared to 2.1 and 2.0 % for pre-trial and post–trial conditions. As a result, HRT in anaerobic digestion was increased from 8 days to 13 days.
The improved performance of hydraulically overloaded clarifiers could result in reduced primary treatment, digestion and aeration upgrade requirements.

Potential further impacts of AS could be reduced recycle loads on primary and secondary treatment processes and reduced flows to dewatering process. In addition, substantial capital and operational cost savings can be achieved. Treatment with AS has been identified as a simple, low-cost technology for improving settling and compaction of settleable solids in clarification processes of wastewater treatment plant operation.

ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of Toronto Main Treatment Plant staff especially of Peter Wimmer, Plant Manager, Tony Byrne, JH&SC Supervisor and Operations. The assistance of NSL staff, Tim Evans, Technical Director and Barbara Lempka, Senior Sales Representative was greatly appreciated.

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