EXECUTIVE SUMMARY

Settling properties of activated sludge or mixed liquor suspended solids (MLSS) have been studied for more than 75 years at wastewater treatment plants. Temperature, together with MLSS concentration, has been acknowledged as important contributors to MLSS settling variations. These settling variations can be detected over short-term, from minutes up to diurnal periods, or over long-term, from weeks up to annual periods based on seasonal meteorological changes. Batch MLSS settling tests are performed on a regular basis at most treatment plants. The majority of these short-term MLSS settling test reports reflect the complete absence of any form of temperature compensation or even MLSS sample temperature (T_s) recordings.

This research project evaluates the effects of short-term temperature variations on MLSS settling parameters. The extent of typical plant temperature variations is demonstrated by short- and long-term reactor temperature (T_r) observations. Traditional batch MLSS settling tests are subsequently performed over such operational temperature ranges to quantify the variation in MLSS settling behaviour. The experimental work concludes with the implementation of an on-line MLSS settling test procedure at pilot- and full-scale reactors to develop settling models based on diurnal T_r fluctuations. These settling models demonstrate that parameter correlations improve when T_r is included in on-line MLSS concentration-based settling models.

Plant temperature recordings show significant short- to long-term variations. Local ambient temperature (T_a) and T_r fluctuate by about 20°C and 1.8°C respectively per day, and T_r changes by about 4°C within a week, as measured on-line at local plants during the test period in winter and spring. The method of aeration can have a significant impact on T_r. The difference in T_r of adjacent surface and bubble aeration reactors in the same plant was about 5°C, as T_r increases due to the warm air from blowers supplied to aeration diffusers. Large enough T_r and T_a variations exist at these local plants to affect MLSS settling test results.

The MLSS settling test cylinder environment and meteorological conditions have a direct influence on T_s during batch settling tests. Direct solar radiation increases the average T_s by 4.3°C, or by 0.15°C per minute, during a 30 minute MLSS settling test duration. This T_s

change leads to a sludge volume index (SVI) change of 63 mℓ/g, at an average SVI decrease of 14.8 mℓ/g per 1°C T_s increase. Changes to other parameters include an initial settling velocity (ISV) increase of about 0.12 m/hr for every 1°C T_s increase, together with a clarified supernatant turbidity increase of about 1.4 formazine nephelometric unit (FNU) for every 1°C T_s increase. T_s adjusts towards T_a before and during a batch MLSS settling test, thereby influencing MLSS settling results. Compensation for T_s variations during routine MLSS settling tests is nevertheless not reported as a common practice. To some extent, this is due to a lack of temperature-controlled MLSS settling test equipment.

An automated MLSS settling meter demonstrates a semi-continuous on-line method to determine settling parameters *in situ* at the operational T_r of a pilot- and full-scale plant. A basic polynomial fits 11 MLSS settling parameters that indicate in most instances improved MLSS settling at increased T_r. For the full-scale plant conditions, the average SVI decreases by 14.8 mℓ/g for every 1°C T_r increase. Similarly, for every 1°C T_r increase, the maximum settling velocity (u_max) increase is 0.1 m/hr, and time to reach maximum settling velocity (t_umax) decreases by 2.4 minutes. The incremental 5-minute duration average settling velocities increase over the first 15 minutes of a MLSS settling test, as the MLSS concentration decreases and the T_r increases. This direct incremental settling velocity trend with T_r is reversed between 15 and 30 minutes, as the average 5-minute MLSS settling velocity increases at a reduced T_r.

The inclusion of T_r in MLSS concentration-based settling best-fit correlations with SVI, u_max, and t_umax improves the coefficient of multiple determinations (R^2) by an average of 0.32 for full-scale plant conditions. Best-fit SVI models with u_max and t_umax have R^2-values of 0.90 and 0.95 respectively. The developed models are only valid for the individual reactor MLSS conditions within the experimental parameter ranges.

The original Water Research Commission (WRC) research proposal (nr. 1274 of 2001) contained three research products:

1. Augmentation of mathematical process and clarifier models to incorporate floc conditions,
2. A pilot plant to simulate secondary wastewater treatment processes, and
3. Process control methodologies to generate floc with optimal settling properties to enhance final clarification.

The three research products were delivered as follows in this report:

1. Temperature was introduced and modelled as a variable in MLSS settling correlations,
2. A three-stage biological nutrient removal (BNR) pilot plant was commissioned to simulate typical activated sludge operation over an extended temperature range, and
3. Batch test methodologies to measure MLSS settling were determined with regards to reactor sample position, sample handling equipment and sample temperature. An on-line MLSS settling meter was developed and commissioned to reduce the inherent disadvantages of temperature changes occurring during batch MLSS settling test conditions.

The developed research products resulted in the following recommendations:

1. Sample or reactor temperature should be included in BNR and MLSS settling models, to ensure design and operational process control simulations are representative of plant conditions.
2. The successful pilot plant-scale operation, with a continuous raw sewage feed to simulate full-scale operational conditions, presents many challenges. The advantages related to the operational flexibility of a pilot plant provide sufficient reasons for future use of such plants for research and development work.
3. Temperature compensation and recording is necessary for batch MLSS settling tests. On-line settling monitoring removes most of the variable temperature conditions experienced during sample handling and testing in manual batch MLSS settling tests.

The main contribution of this project is to present temperature-based MLSS settling models, based on on-line pilot and full-scale plant studies. These models illustrate that an automated on-line MLSS settling meter is suitable to identify and model temperature related MLSS settling data with minimal experimental effort. The on-line MLSS settling detection method eliminates inherent temperature-based variations resulting from traditional batch MLSS settling tests.

Keywords: activated sludge, batch test, biofloc, clarifier, MLSS, model, settling, SVI, temperature, wastewater.