7 SUMMARY OF RESULTS

The results of this project are summarised according to the project aims, with a summary of the experimental results provided in Table 7-1:

- The literature review confirms the lack of basic temperature compensation procedures and equipment, and the recording of temperature data, required in the determination of MLSS settling parameters. Limited research information is available on operational temperature conditions during MLSS settleability evaluations, and it appears that temperature-based MLSS settleability models are not readily available.

- Large settling velocity increases are calculated for a simplified single biofloc settling over an extended temperature range. Basic theoretical principles simulate the effect of changes in temperature related water and biofloc characteristics.

- A preliminary temperature survey at pilot- and full-scale plant reactors identifies short- and long-term T_r fluctuations that follow T_a profiles. Meteorological factors and unidentified plant specific factors influence T_{raw}.

- A batch MLSS settling evaluation indicates that container size and reactor zone sampling points have a limited influence on the SVI and ISV of a well-settling MLSS. Supernatant turbidity improves from the anaerobic zone throughout the reactor up to the end region of the aerobic zone. The immediate environment of the MLSS sample has a direct influence on MLSS settling test results. A 4.3°C temperature increase over 30 minutes, by MLSS sample placement in direct sunshine instead of shade, results in a 63 mℓ/g SVI decrease. This relationship illustrates the essential need for temperature compensation and environmental conditions recordings during MLSS settling tests.

- The diurnal variations in MLSS settling meter data show distinct sinusoidal wave profiles. Best-fit models of settling parameters illustrate statistically with improved data fitting the positive impact of T_r inclusion in MLSS concentration-based models. The SVI relationships with the two settling parameters u_max and t_umax reflect the ease of development of on-line-based parameter correlations. Simulations of settling parameters with MLSS concentration and T_r illustrate the extent of parameter change during a temperature variation. A 1.8°C diurnal T_r fluctuation results in a 26.5 mℓ/g SVI change. This SVI increase of 14.8 mℓ/g per 1°C T_r decrease illustrates the close inverse relationship between MLSS settleability and temperature. Additional parameter relationships that are identified in the project are listed in Table 7-1.

- Incremental settling data indicates that MLSS concentration and T_r determine the t_umax, which in turn indicates during which 5-minute period the settling velocity will be the highest. There is a direct relationship between the settling velocity and T_r. The only exception occurs during the last three stages of the incremental 5-minute settling periods over 30 minutes. The on-line-based diurnal settling profiles indicate that settling velocity increases later in the 30-minute settling period during high MLSS concentration and low T_r conditions. The colder MLSS sample only starts settling after a longer reflocculation period (e.g. 15 to 30 minutes).

- The significant effects of short-term temperature variations on MLSS settling parameters have been determined theoretically and experimentally, thereby achieving the main project aim.

Table 7-1 MLSS settling parameter variation summary

Index / Parameter	**Batch MLSS settling tests** **T_s increase** **Constant MLSS concentration**	**On-line full-scale plant** **T_r increase** **Constant MLSS concentration**	**On-line full-scale plant** **Constant T_r** **MLSS concentration increase**	**Relationship with BNR reactor zones**
SVI	Inverse, -14.8 mℓ/g/1°C	Inverse, -14.8 mℓ/g/1°C	Direct correlation	Relatively constant
t_umax	-	Inverse, -2.4 min./1°C	Direct correlation	-
u_max	-	Direct, 0.1 m/hr/1°C	Inverse correlation	-
u_ave	-	Direct, 0.04 m/hr/1°C	Inverse correlation	-
ISV	Direct, 0.12 m/hr/1°C	-	-	Relatively constant
h	-	Inverse, -19 mm/1°C	Direct correlation	-
u1	-	Direct 0.08 m/hr/1°C	Inverse correlation	-
u2	-	Direct 0.19 m/hr/1°C	Inverse correlation	-
u3	-	Direct 0.07 m/hr/1°C	Inverse correlation	-
u4	-	Inverse -0.01 m/hr/1°C	Inverse correlation	-
u5	-	Inverse -0.05m/hr/1°C	Inverse correlation	-
u6	-	Inverse -0.05 m/hr/1°C	Inverse correlation	-
Turbidity	Direct 1.42 FNU/1°C	-	-	Reduction through reactor

8 CONCLUSIONS

- The impact of MLSS concentration dominates other MLSS settling factors, according to the format of existing settling models. The effect of diurnal T_r fluctuations is not easily detected with conventional batch settling tests due to rapid changes in T_s. An on-line MLSS settling meter combines both diurnal MLSS concentrations and T_r fluctuations, to generate improved temperature dependent MLSS settling models.

- The batch MLSS settling test in a graduated cylinder is the most widely used method to determine settling parameters such as SVI, but temperature compensation or recording procedures are rarely implemented. The significant effect of short-term temperature variations on MLSS sample settling is illustrated with two evaluations (batch and on-line), at an average 14.8 mℓ/g SVI increase per 1°C decrease.

- There is a direct relationship between MLSS settling velocity and T_r. The only exception occurs during some of the incremental settling velocity stages. The incremental settling velocities increase in the second half of the 30-minute settling period in the lower T_r range, because the colder MLSS sample only starts settling after a longer reflocculation period. Incremental settling data indicates that MLSS concentration and T_r determine t_umax, and it also specifies the highest settling velocity during the six 5-minute settling stages in the 30-minute period.

- Existing MLSS settling parameter models are based on MLSS concentration, without incorporating temperature. The effect that temperature inclusion has on settling models is illustrated with three settling parameter models, where the statistical improvement is illustrated by an average R^2 increase of 0.13.

- Conventional batch settling equipment and basic procedures are not suitable to effortlessly identify temperature dependent MLSS settling changes over small operational T_r ranges. The settleability impact of diurnal T_r fluctuations and T_s change during sample handling are not easily detected from routine batch MLSS settling tests performed on a daily basis.

- Automated MLSS settling meters are ideally suited to perform semi-continuous MLSS settling tests. These MLSS settling profiles were not linked before to diurnal T_r fluctuations. The effect of diurnal T_r variations on settling parameters is illustrated on a full-scale plant with on-line based correlations between SVI and two settling velocity parameters at an average R^2 of 0.93.

- SVI test results are used for operational settleability control and design purposes, but do usually not include information about MLSS concentration, environmental test conditions or container dimensions. Temperature variations of about 4.3°C during 30-minute settling test periods result in an average SVI change exceeding 60 mℓ/g. These rapid T_s variations illustrate the need to include reference temperature conditions in MLSS settling reports and experimental methods.

- Temperature is not a process parameter observed at most operational plants. Preliminary temperature recordings indicated significant short- and long-term temperature changes of a few degrees Celsius in full-scale and pilot plant reactors and at different aeration systems.

- Basic MLSS settling models that are based on fundamental theories are not readily available to simulate dynamic plant temperature conditions. Preliminary calculations illustrate large settling velocity changes of about 2 to 11 m/hr, created by water and biofloc property changes, over an extended temperature range of 20°C.

9 RESEARCH CONTRIBUTION

This study quantifies the significant effects of short-term temperature variations on batch and on-line MLSS settling parameters. An automated MLSS settling method is introduced to reduce the effects of sample temperature variations observed before and during settling tests. This method is suitable to determine MLSS settling parameters on-line during dynamic operational conditions. Effects of short-term temperature fluctuations are thus included in settling parameters, together with the long-established MLSS concentration.

A future research need would be to use such an automated MLSS settling meter at a wider selection of plant reactors to develop plant specific settling models. The effects of different reactor temperatures, based on surface or bubble aeration systems, will be represented by distinctive MLSS settling profiles and associated settling parameter correlations. Specific temperature sensitive processes such as nitrification and MLSS settling influences reactor and clarifier design and operation, which will be enhanced with the availability of the improved parameter correlations.

A second research need would be to use an on-line settling meter to measure alternative settling indexes, such as SSVI and DSVI, during diurnal temperature fluctuations. The principle aim of the current study is to illustrate the effects of short-term temperature variations on MLSS settling. Basic settling parameters are modelled to illustrate the temperature effect, without considering the limitations of certain settling parameters and test methods, such as the SVI. Future temperature-based SSVI and DSVI models will be beneficial for the management and design of wastewater treatment plants.

The established BNR reactor design procedures, which are used in countries with extreme weather patterns such as South Africa, consider long-term T_r fluctuations to ensure nutrient removal is guaranteed at a low T_r. In future, this lowest operational T_r should be included in secondary settling tank design. Specific reactor design to limit the effect of meteorological factors, as well as the use of bubble aeration applications, are two design steps that can be promoted to reduce the lowest operational T_r. The future inclusion of modelled and plant specific T_r-based plant performance data, obtained from on-line MLSS settling meters, establishes opportunities to optimise not only BNR, but also improve secondary settling tank design.