The effects of short-term temperature variations on activated sludge settling

by

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ABSTRACT

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. Batch MLSS settling tests are performed on a regular basis at most of the plants. The majority of these MLSS settling test reports reflect the complete absence of any form of temperature compensation or even MLSS sample temperature (T_s) recordings.

The objective of this study is to evaluate the effects of short-term temperature variations on MLSS settling parameters. This is done by means of simplified theoretical calculations, followed by operational reactor temperature (T_r) observations, and batch MLSS settling tests. The experimental work concludes with the implementation of an on-line MLSS settling test procedure at a full-scale plant reactor to develop settling models based on diurnal T_r fluctuations. These settling models illustrate that parameter correlations improve when T_r is included in on-line MLSS concentration-based settling models.

The unhindered settling velocity of a single solid biofloc in water is considered in a simplified calculation to estimate the effect of temperature variations on MLSS settling. Over a T_s increase of 20°C, water density and viscosity reductions result in a calculated biofloc settling velocity increase of less than 0.5 m/hr. Similarly, biofloc density, shape, and size changes result in calculated biofloc settling velocity increases of about 11, 10, and 2 m/hr respectively over the 20°C T_s range.

Plant temperature recordings show significant short- to long-term variations. Ambient temperature (T_a) and T_r fluctuate 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. The aeration method can have a significant impact on T_r. Differences in T_r in adjacent surface and bubble aeration reactors in the same plant were about 5°C. 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 full-scale plant. A basic polynomial fits 11 MLSS settling parameters that indicate in most instances improved MLSS settling at increased T_r. 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 the 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. 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 main contribution of this study is to present temperature-based MLSS settling models. 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. A suitable approach is provided to improve the reliability of MLSS settling data, as effects of short-term temperature variations can be practically eliminated from settling test.

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

SAMEVATTING

Besinkingskenmerke van geaktiveerde slyk of slykmengselsweefstowwe (SMSS) word al vir meer as 75 jaar by afvalwaterbehandelingsaanlegte bestudeer. Temperatuur, saam met SMSS konsentrasie, word erken as belangrike bydraers tot variasies in SMSS besinkingseienskappe. Lot SMSS besinkingstoetse word op ‘n gereelde grondslag by die meeste aanlegte uitgevoer. Die meerderheid SMSS besinkingstoetsverslae toon egter geen vorm van temperatuur kompensasie of SMSS monstertemperatuur (T_s) lesings aan nie.

Die doel van hierdie studie is om die gevolge van korttermyn temperatuur variasies op basiese SMSS besinkingsparameters te evalueer. Die evaluasie is gebaseer op vereenvoudigde teoretiese berekeninge, gevolg deur reaktor bedryfstemperatuur (T_r) observasies, sowel as om lot SMSS besinkingstoetse te doen. Die eksperimentele werk is afgesluit met die implementering van ‘n aanlyn SMSS besinkingstoets prosedure by ‘n volskaal aanlegreaktor. Wanneer T_r ingesluit word, verbeter besinkingsparameter korrelasies in die konvensionele SMSS konsentrasie-gebaseerde besinkingsmodelle.

SMSS besinking is vereenvoudig deur die vrye besinkingssnelheid van ‘n enkele soliede biovlok te bereken, sodat die effek van temperatuur variasies op die lot SMSS besinkingstoets benader kan word. Met ‘n T_s verhoging van 20°C sal waterdigtheid en -viskositeit verlagings tot ‘n biovlok besinkingssnelheid verhoging van minder as 0.5 m/hr lei. Soortgelyk sal biovlokdigtheid, -vorm, en -grootte veranderings lei tot biovlok besinkingssnelheid verhogings van ongeveer 11, 10 en 2 m/hr respektiewelik.

Aanlegtemperatuur lesings toon betekenisvolle kort- tot langtermyn variasies. Omgewingstemperatuur (T_a) and T_r fluktueer teen ongeveer 20°C en 1.8°C respektiewelik per dag, en T_r verander teen ongeveer 4°C per week, soos plaaslik aanlyn gemeet in winter. Die belugtingsmetode kan ‘n beduidende invloed op T_r uitoefen. ‘n Verskil van ongeveer 5°C is gemeet in T_r van oppervlak- en borrelbelugting reaktore in dieselfde aanleg. Daar is genoegsame T_r en T_a variasies op aanlegte om SMSS besinkingstoets resultate te beïnvloed.

Omgewings- en meteorologiese toestande by die besinkingstoets silinder het ‘n direkte invloed op T_s gedurende lot SMSS besinkingstoetse. Direkte sonbestraling verhoog die gemiddelde T_s met 4.3°C, of teen 0.15°C per minuut, gedurende ‘n tipiese 30-minute besinkingstoets periode. Hierdie T_s variasie veroorsaak ‘n slykvolume-indeks (SVI) verandering van 63 mℓ/g, teen 'n gemiddelde SVI verlaging van 14.8 mℓ/g per 1°C T_s verhoging. Veranderinge aan ander besinkingsparameters sluit in 'n aanvanklike besinkingssnelheid (ISV) verhoging van ongeveer 0.12 m/hr vir elke 1°C T_s verhoging, sowel as 'n verhoging van verhelderde bowater turbiditeit van ongeveer 1.4 formasien nephelometriese eenheid (FNU) per elke 1°C T_s verhoging. T_s verander na T_a voor en gedurende 'n lot SMSS besinkingstoets, en beïnvloed sodoende SMSS besinkingsresultate. T_s kompensasie werkswyses vir roetine SMSS besinkingstoetse is nieteenstaande steeds nie algemene praktyk nie, wat gedeeltelik toegeskryf kan word aan die gebrek aan temperatuur beheerbare besinkingstoets toerusting.

'n Outomatiese SMSS besinkingsmeter demonstreer 'n semi-kontinue aanlyn metode om besinkingsparameters te bepaal teen die operasionele T_r van 'n volskaal aanleg. 'n Basiese polinoom pas data van 11 besinkingsparameters om in die meeste gevalle 'n verbeterde SMSS besinkbaarheid by hoër T_r te toon. SVI verlaag teen 14.8 mℓ/g vir elke 1°C T_r verhoging. Vir die 1°C T_r verhoging is die maksimum besinkingssnelheid (u_max) verhoging 0.1 m/hr, en die verlaging in die tyd om u_max te bereik (t_umax) is 2.4 minute. In die eerste 15 minute van 'n besinkingstoets neem besinkingssnelheid toe soos SMSS konsentrasie afneem en T_r toeneem. Die direkte tendens tussen besinkingssnelheid en T_r is omgekeerd in die laaste 15 minute, en besinkingssnelheid neem dan toe by 'n verlaagde T_r.

Die insluiting van T_r in konsentrasie-gebaseerde besinkingsmodelle met SVI, u_max en t_umax verhoog die koëffisiënt van veelvuldige determinasies (R^2) teen 'n gemiddelde van 0.32. SVI modelle met u_max en t_umax het R^2-waardes van 0.90 en 0.95 respektiewelik. Die ontwikkelde modelle is slegs geldig vir die individuele reaktor SMSS kondisies in die eksperimentele parameter gebied.

Die hoofbydrae van hierdie studie is om temperatuur-gebaseerde SMSS besinkingsmodelle te ontwikkel. Hierdie modelle illustreer dat 'n outomatiese SMSS besinkingsmeter geskik is om temperatuur-verwante SMSS besinkingsdata aanlyn te identifiseer en te modelleer met minimum eksperimentele moeite. 'n Geskikte benadering word verskaf om die betroubaarheid van SMSS besinkingsdata te verbeter, omdat invloede van korttermyn temperatuur variasies prakties uitgeskakel word in SMSS besinkingstoetse.
Sleutelwoorde: afvalwater, besinking, biovlok, geaktiveerde slyk, lot toets, model, riool, SMSS, SVI, temperatuur.

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NOMENCLATURE

Symbol / Acronym	Definition	Page when first used
a, b, c, d, e, f, g, h, i, j, k	regression coefficients	87
a, b, c	three periods of settling process	27
a, b, c	plant reactors used in experimental work	40
A, B, C, D, E	five settling stages of MLSS setting profile	27
Ave.	average	87
BNR	biological nutrient removal	1
C	Carbon	144
°C	degree(s) Celsius	18
$CaCO_3$	calcium carbonate	145
C_d	drag coefficient	29
Cl_2	chlorine	148
cm	centimetre	52
COD	chemical oxygen demand	144
d	day(s)	148
d_a	diameter biofloc	29
DO	dissolved oxygen	20
DSVI	diluted sludge volume index	13
e.g.	for example	22
et al.	and others	1
exp, e	exponent	9
ECP	exocellular polymers	143
EPBNR	excess phosphorus biological nutrient removal	148
f	function	9
FOG	fats, oils and grease	145
FNU	formazine nephelometric unit	52
g	gram(s)	146
g	gravitational acceleration constant	29
G	solids flux	9
g/ℓ	gram per litre	9
gSS/ℓ	gram suspended solids per litre	54
g/mℓ	gram per millilitre	34
h	settling meter liquid / MLSS interface height	67
hr	hour(s)	73
HRT	hydraulic retention time	146
i, ii, iii, iv	4 methods to acquire G	9
in situ	in natural or original place	23
ISV	initial settling velocity	8
kg	kilogram(s)	150
kHz	kiloHertz	140
kg/m^3	kilogram per cubic metre	29
ℓ	litres	1
LCVFA	long chain volatile fatty acid	144
m	metre(s)	15
mm	millimetre	29
mA	milliAmpere	64
mg	milligram(s)	59

mg/ℓ	milligram per litre	53
mgN/ℓ	milligram nitrogen per litre	21
mgSS/ℓ	milligram suspended solids per litre	8
meq/gSS	milliequivalent per g suspended solids	143
mMol	milliMole concentration	144
m/hr	metre per hour	8
min.	minute(s)	8
mℓ	millilitres	13
mℓ/g	millilitres per gram	8
mℓ/ℓ	millilitres per litre	10
MLSS	mixed liquor suspended solids	1
MLVSS	mixed liquor volatile suspended solids	145
mV	millivolt	143
n	number of observations	53
n	constant in empirical Vesilind equation	9
N	nitrogen	144
N/A	not available / applicable	54
NDBEPR	nitrification-denitrification biological-excess-phosphorus removal	150
NH_4^+	ammonium	144
NO_3^-	nitrate	21
NO_2^-	nitrite	21
Ns/m^2	Newton seconds per square metre	29
o-PO_4	ortho-phosphate	131
P	phosphorus	144
pH	logarithmic scale of activity of hydrogen ion	145
PLC	program logic controller	64
p value	probability value	151
R^2	coefficient of multiple determinations	30
RAS	return activated sludge	21
RBCOD	readily biodegradable COD	147
Re	Reynolds number	29
rpm	revolutions per minute	12
s	second	148
S	sulphide	144
SBR	sequencing batch reactor	38
SBCOD	slowly biodegradable chemical oxygen demand	144
SG	specific gravity	143
SRT	sludge retention time	148
SS	suspended solids	8
SSVI	stirred specific volume index	12
$SSVI_{3.5}$	stirred specific volume index at 3.5 g/ℓ	13
St. dev.	standard deviation	53
SV_{30}	30-minute settled sludge volume	7
SVI	sludge volume index	3
$SVI_{3.5}$	SVI at 3.5 g/ℓ	13
T	temperature	131
T_a, Ta	ambient temperature (atmospheric)	1
T_s, Ts	sample temperature	1
T_r, Tr	reactor temperature	1

T_{raw}, Traw	raw sewage (wastewater) temperature	17
T_0, T_5, T_{15}, T_{30}	temperature after 0, 5, 15, and 30 minutes	132
t	time	3
TDS	total dissolved solids	144
Temp	temperature	139
Tur	supernatant turbidity	132
t_umax	time to reach u_max	3
t-ratio	ratio of estimated parameter value to estimated parameter standard error	151
u	discrete biofloc settling velocity	29
u1, u2, u3, u4, u5, u6	incremental 5-minute settling velocities	68
u_max	maximum (constant) 1-minute settling velocity	3
u_ave	average 30-minute settling velocity	70
V	volt	64
v_o	constant in empirical Vesilind equation	9
vs.	versus	9
V_s	ZSV in empirical Vesilind equation	9
VFA	volatile fatty acid	144
WCW	water care works	98
X	MLSS concentration	9
x	independent regression variables	31
x, x_1, x_2	horizontal axes coordinates in 2- and 3-D graphs	30
y	dependent regression variables	31
y, y_1, y_2	vertical axes coordinates in 2- and 3-D graphs	30
ZSV	zone settling velocity	8
Φ	shape factor of biofloc	28
ε	random error	87
μ	dynamic (or absolute) viscosity	29
µm	micrometre(s) [10^{-6} m]	29
ρ_a	density of biofloc	29
ρ_w	density of liquid	29
σ^2	error variance	87
1, 2	experimental plants	40
1, 2, 3, 4	four stages in MLSS settling profile	8
1, 2, 3, 4	successive sections in aerobic zone	54
2-D	2 dimensional graphs or correlations	29
3-D	3 dimensional graphs or correlations	30
I, II, III, IV	four classes of MLSS settling	6
<, <=, =, >	smaller, smaller or equal, equal, larger	8
/, .	divide, multiply	9
%	percentage	21

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