TAL TECH

FACTORS AFFECTING SVI IN THE SMALL SCALE WWTPs

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INTRODUCTION

Euroopa Liit Ühtekuuluvusfond

Eesti tuleviku heaks

KIK ENVIRONMENTAL INVESTMENT CENTRE

- Most of Estonia is sparsely populated and as a result, there are 664 municipal WWTPs for 1.35 million people
  - 288 WWTPs have been constructed or reconstructed between 2004 and 2014 using grants by EU or Environmental Investment Centre
  - More than 1 000 000 000 EUR has been invested into these WWTPs during that period
- This study is based on the national survey on 245 small and medium size WWTPs that were studied during 2014–2015 and evaluated according to the novel method for rapid assessment of performance and the complexity of small WWTPs.
- This study analyses factors associated with bulking in 195 small-scale AS wastewater treatment plants (WWTPs) in Estonia.

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DATA COLLECTION

•In total 195 small-scale (less than 50 000 PEs) AS wastewater treatment plants were assessed in Estonia according to a uniform method over a period of 6 months, between October 2014 and March 2015.

•During the investigation, the following actions were performed:

- design parameters (e.g. flow rate, SRT) were collected;
- actual situation on the plant (e.g. flow rate, SRT, sludge volume index, equipment failures) was documented (taking photos, filling excel sheets of the model);
- samples from effluent and process reactors were collected to determine biological oxygen demand (BOD_7), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN) and total phosphorous (TP).
- The parameters pH, conductivity (K), dissolved oxygen (DO) and water temperature (T^o) were determined *in situ*.

•In addition to the data needed for evaluation of WWTP's performance, some additional data was collected during the plant inspection:

- the operator's knowledge about the process and evaluation of the operator's competence and
- additional data that was not used in any assessment, but was expected to be relevant in the interpretation of results.

•For studying the relationship between the plant performance, SVI and WWTP complexity, tools of correlation and regression analysis were applied

MOST COMMON PROBLEMS IN ESTONIAN ACTIVATED SLUDGE PLANTS

•All WWTPs had issues, but the severity of these problems varied in a great altitude

•Most common issues were associated with effluent quality (56.4 % of WWTPs had high TSS in the effluent), aeration problems (57.9 %), foaming (38.1 %), bulking (32.3 %) and ensuring of anaerobic (8.2 %) and anoxic (15.4 %) conditions in said reactors.

•Similarly to situation reported by Hegg *et al*. (1979), an average Estonian AS WWTP had 14.6 ± 3.9 issues as listed in the following Table.

FREQUENCY OF THE COEXISTING PROBLEMS IN ESTONIAN SMALL WWTPS (N = 190).

	A01	A02	A03	A04	A05	A06	A07	A08	A09	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
A01	1,00	0,28	0,33	0,33	0,34	0,32	0,36	0,33	0,31	0,42	0,35	0,28	0,33	0,33	0,33	0,28	0,35	0,42	0,47	0,30
A02	0,40	1,00	0,38	0,54	0,48	0,51	0,36	0,45	0,47	0,52	0,45	0,44	0,50	0,44	0,58	0,62	0,44	0,37	0,33	0,47
A03	0,51	0,42	1,00	0,52	0,54	0,44	0,74	0,57	0,52	0,36	0,51	0,63	0,52	0,60	0,71	0,28	0,54	0,48	0,43	0,73
A04	0,73	0,86	0,76	1,00	0,79	0,73	0,71	0,75	0,76	0,67	0,69	0,83	0,81	0,73	0,58	0,80	0,68	0,69	0,53	0,83
A05	0,95	0,97	0,98	0,99	1,00	0,90	0,95	0,92	0,96	0,93	0,93	0,94	0,93	0,93	0,88	0,88	0,93	0,91	0,97	1,00
A06	0,21	0,24	0,19	0,21	0,21	1,00	0,17	0,24	0,22	0,21	0,20	0,28	0,30	0,19	0,17	0,30	0,26	0,31	0,27	0,27
A07	0,38	0,27	0,51	0,33	0,36	0,27	1,00	0,34	0,36	0,38	0,32	0,38	0,33	0,40	0,42	0,20	0,36	0,31	0,33	0,30
A08	0,63	0,63	0,71	0,65	0,63	0,71	0,64	1,00	0,63	0,53	0,63	0,95	0,81	0,65	0,71	0,68	0,65	0,67	0,57	0,73
A09	0,73	0,80	0,79	0,79	0,80	0,80	0,80	0,76	1,00	0,75	0,76	0,76	0,74	0,72	0,67	0,80	0,75	0,76	0,77	0,80
A10	0,49	0,43	0,27	0,35	0,38	0,37	0,42	0,32	0,37	1,00	0,47	0,28	0,31	0,38	0,33	0,34	0,36	0,25	0,40	0,17
A11	0,62	0,57	0,59	0,55	0,58	0,54	0,53	0,57	0,57	0,71	1,00	0,53	0,57	0,60	0,63	0,42	0,61	0,54	0,70	0,47
A12	0,35	0,39	0,51	0,46	0,41	0,54	0,45	0,61	0,40	0,30	0,37	1,00	0,72	0,44	0,38	0,46	0,40	0,42	0,27	0,50
A13	0,57	0,63	0,59	0,62	0,57	0,80	0,55	0,72	0,55	0,47	0,56	1,00	1,00	0,55	0,67	0,52	0,60	0,63	0,57	0,57
A14	0,59	0,57	0,70	0,59	0,59	0,51	0,68	0,60	0,55	0,59	0,61	0,64	0,57	1,00	0,79	0,50	0,65	0,51	0,50	0,53
A15	0,13	0,16	0,18	0,10	0,12	0,10	0,15	0,14	0,11	0,11	0,14	0,12	0,15	0,17	1,00	0,08	0,14	0,13	0,10	0,10
A16	0,22	0,35	0,14	0,28	0,25	0,37	0,15	0,28	0,27	0,23	0,19	0,29	0,24	0,22	0,17	1,00	0,17	0,33	0,07	0,27
A17	0,40	0,36	0,40	0,35	0,38	0,46	0,39	0,39	0,36	0,36	0,40	0,37	0,39	0,42	0,42	0,24	1,00	0,40	0,77	0,40
A18	0,44	0,28	0,33	0,33	0,34	0,51	0,32	0,37	0,34	0,23	0,32	0,36	0,39	0,30	0,38	0,44	0,38	1,00	0,60	0,53
A19	0,22	0,11	0,13	0,11	0,16	0,20	0,15	0,14	0,16	0,16	0,19	0,10	0,16	0,13	0,13	0,04	0,32	0,27	1,00	0,30
A20	0,14	0,16	0,23	0,18	0,17	0,20	0,14	0,18	0,16	0,07	0,13	0,19	0,16	0,14	0,13	0,16	0,17	0,24	0,30	1,00
A21	0,71	0,67	0,68	0,70	0,68	0,71	0,71	0,70	0,68	0,70	0,68	0,81	0,72	0,76	0,67	0,70	0,75	0,73	0,73	0,67
A22	0,24	0,16	0,18	0,13	0,17	0,34	0,26	0,19	0,19	0,14	0,16	0,17	0,17	0,19	0,04	0,26	0,25	0,31	0,30	0,23
A23	0,11	0,06	0,08	0,04	0,07	0,10	0,11	0,09	0,05	0,04	0,08	0,05	0,07	0,07	0,04	0,02	0,14	0,09	0,27	0,07
A24	0,11	0,09	0,08	0,04	0,07	0,15	0,09	0,10	0,06	0,07	0,07	0,08	0,06	0,09	0,00	0,08	0,11	0,10	0,10	0,23
A25	0,60	0,56	0,74	0,61	0,60	0,44	0,68	0,61	0,57	0,53	0,57	0,65	0,60	0,71	0,63	0,28	0,71	0,51	0,77	0,70
A26	0,38	0,41	0,48	0,48	0,44	0,41	0,53	0,39	0,43	0,41	0,41	0,50	0,48	0,46	0,50	0,10	0,51	0,34	0,63	0,43
A27	0,41	0,49	0,58	0,52	0,51	0,46	0,59	0,55	0,47	0,48	0,47	0,65	0,56	0,58	0,58	0,28	0,60	0,54	0,63	0,67
A28	0,25	0,32	0,29	0,28	0,26	0,44	0,32	0,27	0,26	0,23	0,23	0,29	0,33	0,29	0,33	0,42	0,29	0,34	0,23	0,33
A29	0,17	0,23	0,19	0,21	0,19	0,27	0,26	0,21	0,21	0,16	0,17	0,29	0,26	0,20	0,17	0,22	0,29	0,25	0,10	0,23
A30	0,14	0,22	0,11	0,18	0,16	0,12	0,09	0,16	0,15	0,16	0,14	0,14	0,21	0,12	0,13	0,12	0,17	0,16	0,23	0,23
A31	0,14	0,20	0,11	0,20	0,16	0,24	0,18	0,16	0,18	0,15	0,12	0,17	0,17	0,12	0,04	0,38	0,04	0,13	0,10	0,17
A32	0,17	0,23	0,16	0,21	0,19	0,12	0,26	0,17	0,20	0,25	0,20	0,24	0,20	0,25	0,08	0,12	0,18	0,10	0,17	0,20
A33	0,41	0,34	0,38	0,36	0,36	0,49	0,33	0,37	0,40	0,27	0,34	0,36	0,39	0,32	0,33	0,56	0,46	0,81	0,67	0,83
A34	0,44	0,51	0,47	0,52	0,45	0,44	0,50	0,42	0,41	0,47	0,41	0,50	0,53	0,41	0,42	0,24	0,46	0,51	0,53	0,63
A35	0,13	0,06	0,07	0,08	0,07	0,02	0,08	0,07	0,07	0,04	0,05	0,06	0,05	0,06	0,04	0,08	0,06	0,07	0,07	0,17
A36	0,44	0,45	0,49	0,53	0,49	0,54	0,58	0,48	0,46	0,56	0,48	0,54	0,53	0,46	0,33	0,48	0,43	0,49	0,53	0,50
A37	0,08	0,07	0,13	0,13	0,12	0,12	0,14	0,11	0,12	0,10	0,11	0,14	0,11	0,11	0,04	0,08	0,11	0,12	0,10	0,23
A38	0,51	0,52	0,58	0,59	0,56	0,66	0,68	0,60	0,55	0,60	0,53	0,63	0,63	0,55	0,46	0,58	0,50	0,58	0,60	0,63
A39	0,11	0,10	0,09	0,11	0,11	0,15	0,09	0,12	0,11	0,11	0,11	0,12	0,11	0,10	0,08	0,12	0,13	0,16	0,20	0,17
A40	0,30	0,28	0,32	0,32	0,29	0,29	0,29	0,30	0,28	0,33	0,26	0,36	0,32	0,32	0,38	0,28	0,28	0,30	0,30	0,33

	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38	A39	A40		
A01	0,34	0,43	0,50	0,44	0,35	0,30	0,28	0,32	0,28	0,32	0,30	0,31	0,36	0,35	0,67	0,30	0,23	0,29	0,33	0,33	A01	SVI > 150
A02	0,44	0,40	0,36	0,50	0,45	0,46	0,46	0,56	0,51	0,68	0,60	0,56	0,41	0,56	0,42	0,43	0,27	0,42	0,43	0,44	A02	Design loading was not based on actual measurements
A03	0,50	0,49	0,57	0,50	0,65	0,59	0,60	0,56	0,46	0,39	0,37	0,44	0,51	0,57	0,58	0,51	0,59	0,51	0,43	0,54	A03	No balancing tank
A04	0,74	0,51	0,43	0,38	0,78	0,85	0,78	0,78	0,77	0,93	0,93	0,81	0,70	0,90	0,92	0,80	0,86	0,75	0,71	0,79	A04	No grit separator
A05	0,91	0,86	0,86	0,75	0,97	0,97	0,97	0,92	0,87	1,00	0,97	0,92	0,86	0,99	1,00	0,91	0,95	0,91	0,90	0,91	A05	No grease separator
A06	0,22	0,40	0,29	0,38	0,16	0,22	0,20	0,36	0,28	0,18	0,33	0,14	0,27	0,22	0,08	0,23	0,23	0,25	0,29	0,21	A06	AS process tanks are over- or undersized
A07	0,35	0,49	0,50	0,38	0,41	0,44	0,42	0,42	0,44	0,21	0,40	0,47	0,30	0,41	0,42	0,40	0,41	0,41	0,29	0,33	A07	Wastewater pumping station causes uncontrolled peak flows
A08	0,65	0,66	0,79	0,75	0,67	0,61	0,72	0,66	0,67	0,68	0,63	0,58	0,62	0,63	0,67	0,63	0,64	0,66	0,71	0,63	A08	Degree of utilisation is less than 0,5 or higher than 1,3
A09	0,76	0,80	0,57	0,56	0,76	0,80	0,74	0,76	0,79	0,79	0,90	0,83	0,81	0,74	0,83	0,72	0,82	0,74	0,76	0,74	A09	Industrial wastewater causes problems to the WWTP
A10	0,38	0,29	0,21	0,31	0,35	0,38	0,38	0,34	0,31	0,43	0,37	0,50	0,27	0,42	0,25	0,44	0,32	0,40	0,38	0,42	A10	Infiltration into the sewer system
A11	0,56	0,51	0,64	0,50	0,57	0,58	0,56	0,50	0,49	0,54	0,43	0,61	0,52	0,57	0,42	0,56	0,55	0,54	0,57	0,51	A11	Extreme peak flows
A12	0,47	0,37	0,29	0,38	0,46	0,49	0,55	0,46	0,59	0,39	0,43	0,53	0,38	0,48	0,42	0,45	0,50	0,45	0,43	0,49	A12	F/M > 0,15 g BHT7/g MLSS
A13	0,59	0,51	0,57	0,44	0,59	0,66	0,66	0,72	0,72	0,82	0,60	0,61	0,58	0,72	0,42	0,62	0,55	0,63	0,57	0,61	A13	Real SRT is less than needed
A14	0,65	0,63	0,57	0,63	0,73	0,66	0,70	0,66	0,59	0,46	0,47	0,78	0,49	0,57	0,58	0,55	0,55	0,56	0,52	0,63	A14	Problems with aeration system
A15	0,12	0,03	0,07	0,00	0,14	0,15	0,15	0,16	0,10	0,11	0,03	0,06	0,11	0,12	0,08	0,09	0,05	0,10	0,10	0,16	A15	DO < 1,0 mg/l in aerobic tank
A16	0,26	0,37	0,07	0,25	0,13	0,06	0,15	0,42	0,28	0,21	0,63	0,17	0,38	0,15	0,33	0,26	0,18	0,26	0,29	0,25	A16	WAS pump is not working
A17	0,41	0,51	0,71	0,50	0,46	0,47	0,46	0,42	0,54	0,43	0,10	0,36	0,45	0,41	0,33	0,33	0,36	0,33	0,43	0,35	A17	Floating sludge in aerobic tank
A18	0,37	0,60	0,43	0,44	0,31	0,29	0,39	0,46	0,44	0,39	0,30	0,19	0,74	0,42	0,42	0,35	0,36	0,35	0,52	0,35	A18	SRT is not adjusted for winter conditions
A19	0,17	0,26	0,57	0,19	0,21	0,24	0,20	0,14	0,08	0,25	0,10	0,14	0,27	0,20	0,17	0,17	0,14	0,16	0,29	0,16	A19	Floating sludge in anoxic tank
A20	0,15	0,20	0,14	0,44	0,19	0,16	0,22	0,20	0,18	0,25	0,17	0,17	0,34	0,23	0,42	0,16	0,32	0,17	0,24	0,18	A20	Anoxic conditions are not ensured
A21	1,00	0,77	0,64	0,75	0,70	0,70	0,78	0,72	0,82	0,57	0,60	0,78	0,71	0,72	0,75	0,69	0,64	0,66	0,71	0,54	A21	The quantity of P-removal chemicals to be added does not correspond to the real need
A22	0,20	1,00	1,00	0,63	0,18	0,14	0,14	0,28	0,26	0,14	0,17	0,19	0,30	0,12	0,08	0,17	0,09	0,16	0,24	0,11	A22	Mixing is not effective
A23	0,07	0,40	1,00	0,25	0,12	0,09	0,06	0,06	0,05	0,07	0,03	0,06	0,10	0,06	0,00	0,11	0,05	0,08	0,14	0,07	A23	Floating sludge in anaerobic tank
A24	0,09	0,29	0,29	1,00	0,08	0,05	0,08	0,04	0,15	0,07	0,07	0,11	0,12	0,07	0,08	0,10	0,00	0,09	0,10	0,04	A24	Anaerobicc conditions are not ensured
A25	0,58	0,57	0,93	0,56	1,00	0,81	0,74	0,60	0,62	0,50	0,23	0,72	0,51	0,74	0,42	0,60	0,55	0,58	0,52	0,58	A25	Floating sludge in final clarifier
A26	0,41	0,31	0,50	0,25	0,58	1,00	0,57	0,46	0,49	0,46	0,27	0,72	0,34	0,56	0,33	0,49	0,50	0,46	0,29	0,46	A26	TSS in effluent of final clarifier
A27	0,55	0,37	0,43	0,44	0,63	0,67	1,00	0,54	0,62	0,50	0,33	0,50	0,49	0,68	0,50	0,53	0,68	0,55	0,48	0,53	A27	Mass surface loading rate is greater than 500 L/m2*h
A28	0,27	0,40	0,21	0,13	0,27	0,29	0,29	1,00	0,38	0,25	0,23	0,19	0,36	0,36	0,33	0,27	0,14	0,26	0,19	0,23	A28	Guidance for O&M is absent
A29	0,24	0,29	0,14	0,38	0,22	0,24	0,26	0,30	1,00	0,04	0,20	0,33	0,23	0,32	0,25	0,22	0,36	0,21	0,19	0,16	A29	Operator has not been educated on the field of wastewater treatment
A30	0,12	0,11	0,14	0,13	0,13	0,16	0,15	0,14	0,03	1,00	0,17	0,11	0,18	0,17	0,17	0,17	0,14	0,17	0,10	0,21	A30	Frequency of O&M is less than 2x months
A31	0,14	0,14	0,07	0,13	0,06	0,10	0,11	0,14	0,15	0,18	1,00	0,14	0,14	0,10	0,17	0,20	0,18	0,20	0,24	0,18	A31	Operator dos not supervise conditions in WWTP
A32	0,21	0,20	0,14	0,25	0,24	0,33	0,19	0,14	0,31	0,14	0,17	1,00	0,15	0,21	0,17	0,18	0,18	0,17	0,10	0,18	A32	DO sensors are not cleaned and calibrated
A33	0,39	0,63	0,50	0,56	0,34	0,32	0,39	0,52	0,44	0,46	0,33	0,31	1,00	0,46	0,42	0,36	0,41	0,38	0,48	0,40	A33	Operator does not regulate RAS rate
A34	0,44	0,29	0,36	0,38	0,55	0,57	0,59	0,58	0,67	0,50	0,27	0,47	0,51	1,00	0,33	0,48	0,50	0,44	0,43	0,42	A34	Operator does not know WAS rate
A35	0,07	0,03	0,00	0,06	0,05	0,05	0,06	0,08	0,08	0,07	0,07	0,06	0,07	0,05	1,00	0,07	0,09	0,06	0,00	0,14	A35	WAS is not removed
A36	0,49	0,46	0,71	0,56	0,51	0,58	0,54	0,50	0,54	0,57	0,63	0,47	0,47	0,56	0,58	1,00	0,95	0,84	0,57	0,70	A36	Effluent BOD over the limit
A37	0,11	0,06	0,07	0,00	0,11	0,14	0,16	0,06	0,21	0,11	0,13	0,11	0,12	0,14	0,17	0,22	1,00	0,20	0,10	0,19	A37	Effluent COD over the limit
A38	0,55	0,51	0,64	0,63	0,58	0,65	0,65	0,58	0,59	0,68	0,73	0,53	0,58	0,59	0,58	0,98	1,00	1,00	0,71	0,75	A38	Effluent TSS over the limit
A39	0,11	0,14	0,21	0,13	0,10	0,08	0,11	0,08	0,10	0,07	0,17	0,06	0,14	0,11	0,00	0,13	0,09	0,14	1,00	0,16	A39	Effluent TN over the limit
A40	0,23	0,17	0,29	0,13	0,30	0,33	0,32	0,26	0,23	0,43	0,33	0,28	0,32	0,30	0,67	0,43	0,50	0,39	0,43	1,00	A40	Effluent TP over the limit

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FACTORS CORRELATING WITH SVI

- For statistical analyses, the SVI was divided into two groups with "good" (SVI < 150 ml/g) and "bad" settleability (SVI > 150 ml/g) and was evaluated with "1" or "0" respectively.
- All questions regarding CCPs were formed to be answered as "yes" or "no" and were evaluated with "1" or "0" respectively.

Parameter	Pearson		Spearman	
	R	p-value	P	p-value
Performance of biological reactor (on the 10p scale)	0.247	0.001	0.234	0.003
30 minute settling test (V_{30}), ml	-0.244	0.002	-0.226	0.004
Is the real mass surface loading rate in final clarifier less than 500 kg/(m^2·d)?	-0.215	0.012	-0.215	0.012
Industrial sources in the influent cause problems to the WWTP	-0.380	0.022	-0.380	0.022
MLSS, g/l	-0.307	0.021	0.168	0.031
Effluent TSS, mg/l	0.096	0.226	0.163	0.038
Does an operator measure TP for process control?	-0.161	0.039	-0.161	0.039
Effluent TN, mgN/l	0.185	0.018	0.162	0.039
Is effluent quality within limits?	-0.146	0.061	-0.146	0.061
Are there any hydraulic problems in final clarifier?	0.160	0.062	0.160	0.062
Is biological P-removal possible?	-0.148	0.064	-0.148	0.064
SRT(real)/SRT(designed), d/d	-0.088	0.358	0.172	0.071
Real SRT, d	-0.117	0.204	0.172	0.071
Performance of final clarifier (on the 10p scale)	-0.103	0.212	-0.148	0.083
Are WAS pumps working?	0.087	0.293	0.145	0.091
Is there any infiltration to the sewer system?	-0.132	0.093	-0.132	0.093
Volumetric fraction of anaerobic reactor (AN/OX)*	0.304	0.080	0.282	0.106
Anaerobic fraction (f_{AN})*	0.313	0.071	0.264	0.132
Effluent TP, mgP/l	0.139	0.077	0.051	0.496

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DESIGN AND CONSTRUCTION

- One-way ANOVA showed that the statistically relevant (p-value < 0,05) possible causes for bulking were a) the type of biological reactor used, b) infiltration to the sewer system and c) use of phosphorous removal (bulking was observed 45,9 % of AS plants with bio-P).
- The balancing tank is usually needed to reduce variations in wastewater flow and concentrations. In many cases it helps to reduce effect of peak flows and the risk for hydraulic overloading. In small WWTPs where balancing tank was absent, the average SVI value was 134.7 ml/g (n=90) whereas in WWTPs with balancing tank the average SVI value was 173.0 ml/g (n=57). The effect was significant (p-value 0.05), but could be misleading as an average HRT in balancing tanks was 1.6 d^{-1}. This period could be long enough for wastewater septicity to develop.
- Selectors are usually considered to be an effective way for bulking control, but they do not work for all filamentous micro-organism (Martins *et al*., 2004).
- The role of volume fraction of an anaerobic reactor could be significant and needs further investigation.

Parameter	Unit	SVI < 150 ml/g	Variance	SVI > 150 ml/l	Variance	Number of WWTPs	Mean square	F-value	P-value
f_{OX}	-	0.772	0.038	0.739	0.032	188	0.045	1.250	0.265
f_{AN}	-	0.320	0.052	0.312	0.063	37	0.001	0.011	0.916
f_{AX}	-	0.355	0.019	0.363	0.019	122	0.002	0.101	0.751
AN / OX	m^3/m^3	0,400	0.135	0.187	0.011	37	0.428	5.352	0.027
AN / OX*	m^3/m^3	0.259	0.030	0.187	0.011	35	0.048	2.243	0.143
AX / OX	m^3/m^3	0.954	0.871	0.521	0.086	122	1.571	2.979	0.094
AN / AX	m^3/m^3	1.054	0.955	0.521	0.086	32	2.199	4.107	0.052
AN / (AX + OX)	m^3/m^3	0.291	0.066	0.135	0.005	32	0.223	5.820	0.021
AN / (AX + OX)*	m^3/m^3	0.195	0.013	0.135	0.005	29	0.031	3.392	0.074
HRT_{AN}	d^{-1}	0.399	0.051	0.369	0.058	32	0.007	0.131	0.719
HRT_{AX}	d^{-1}	1.240	1.277	1.091	0.624	113	0.596	0.582	0.447
HRT_{OX}	d^{-1}	3.717	14.186	2.478	3.174	165	58.671	5.752	0.018

Design and construction	No of occasions	%
Designing of WWTP was done without actual loading measurements	113	48,29%
Equipment on site is different than designed	3	1,28%
Installation of equipment or facilities is inadequate	30	12,82%
Indoor ventilation is inadequate	5	2,14%

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INFLUENT CHARACTERISTICS

- Infiltration to the sewer system had significant impact (p-value 0.03) to the SVI value. Average SVI value in WWTPs that had infiltration was 177.9 ml/g while in these plants that did not have any infiltration it was 133.1 ml/g.
- Industrial sources caused problems in 35 WWTPs and the impact to the SVI value was important (p-value 0.07) causing bulking (an average SVI value 180.4 ml/g) in these plants. WWTPs without industrial sources had average SVI value 139.9 ml/g.
- It was not possible to analyse influent quality in all WWTPs due to the financial limitations, but 24h composite samples were collected from 15 AS plants. Microscopic analyses of activated sludge was performed n 13 WWTPs. Analyses showed that *Microthrix parvicella* was dominant in 8 WWTPs and 3 plants had foaming problems caused by *Nocardioforms*.

Parameter	Unit	With *M.parvicella*	Variance	Without *M.parvicella*	Variance	Number of WWTPs	Mean square	F-value	P-value
SRT	d	39,10	352,96	14,56	155,91	13	1 852,96	6,59	0,03
F/M	$kgBOD_7$/ kgMLSS	0,033	2,721E-04	0,107	0,005	13	0,017	8,10	0,02
Filament index	-	4,13	1,55	2,00	0,00	13	13,89	14,05	3,22E-03
BOD_7	mgO_2/l	350,00	5 314,29	576,00	13 480,00	13	157 156,92	18,97	1,14E-03
COD	mgO_2/l	632,50	42 221,43	1 012,00	79 320,00	13	443 139,23	7,95	0,02
TSS	mg/l	263,00	3 609,14	433,20	23 171,20	13	89 132,43	8,31	0,01
BOD_7/N	-	4,15	1,41	6,07	2,37	13	11,33	6,44	0,03
BOD_7/P	-	28,71	104,46	47,57	147,07	13	1 094,74	9,13	0,01

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OPERATION & MAINTENANCE

- O&M is dependent of human factor.
- The importance of human factor in wastewater treatment process has been described very briefly in literature (Olsson, 2012; Hegg *et al.,* 1979) and in many cases it is considered to be the main reason for poor process performance (Hegg et al. 1979).
- Hegg *et al*. (1979) listed improper operator application of concepts and testing to process control as well as inadequate sewage treatment understanding as two highest ranking factors contributing to poor plant performance.
- The competence of operator has been outlined as one of the key factors for successful plant control (Olsson, 2012; Hegg *et al*. 1979; Muga & Michelic, 2008).
- The competence of the operator was evaluated during the data collection in the form of hidden test on the scale of 10 points. The average result was 7.31 and the minimum result 1.5. Although statistical analyses revealed that operator's competence did not influence the bulking directly, it could have severe consequences to the WWTPs performance.
- Procedures for operation and maintenance constitute the key factors for successful pollution removal.
- ANOVA showed that in WWTPs where Instrumentation, control and automation (ICA) was used, average SVI was 136.0 ml/g while in the other group it was 173.8 ml/g (p-value 0.02).

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EXAMPLE HOW O&M CAN INFLUENCE

- There was a negative weak correlation (Pearson's r = - 0.161, p-value 0.039) between bulking and the operator's claim about adjusting chemicals for phosphorous removal.
- Further analyses showed that contradiction between desired effect of chemical precipitation (less bulking) and operator's claim was driven by operator's tendency for adding too much of chemicals.
- In WWTPs where operator claimed to be making adjustments according to the real measurements the ratio of chemicals added to the amount actually needed was 1.6 ± 1.5, but in the other group the same ratio was 1.3 ± 1.2.
- Although the difference between groups was not statistically relevant (p-value 0.29), it shows that while operators make decisions for chemical addition based on effluent results (according to ANOVA average TP was 2.4 mgP/l in the group that made adjustments against 4.3 mgP/l in the group that did not, p-value 0.02), they tend to add too much iron salts and as a result it affects negatively activated sludge properties.
  - The chemical precipitation of phosphorous thickens and compacts the activated sludge (Lind, 1998), but it might also initiate toxic effects and the control over chemical addition is crucial (Akshaykumar Suresh *et al.,* 2018).

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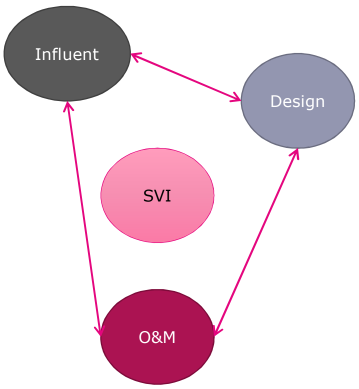
CONCLUSIONS



- Usually it is not possible to point out only on a single reason behind the high SVI values.
- Influent characteristics have a significant influence to the filamentous growth.
- The increasing need for nitrogen and phosphorous removal has evoked an even wider use of selectors. Analyses of hydraulic retention time in anaerobic and anoxic reactors revealed that in small WWTPs the contact time was much higher than recommended by Henze et al. (2008) with an average values for anaerobic reactor 10.5 ± 6.8 h and for anoxic reactor 27.9 ± 24.0 h respectively.
- The role of volume fraction of an anaerobic reactor could be significant and needs further investigation.
- Good operation and maintenance practice as well as operator's competence plays a crucial role in bulking prevention.
- Statistical analyses of operational conditions (incl. influent characteristics and identification of filamentous organisms) on the broad range of WWTPs could simplify ascertainment and impact the assessment of the factors that affect bulking.

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