Wastewater pond systems using chemical precipitation (fellings dams): state of the art in Sweden

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ABSTRACT

Chemical precipitation in wastewater stabilization ponds – in Scandinavia called fellings dams – has been in operation for more than 50 years. Slaked lime and aluminium salts are the most common chemicals used for precipitation. Long and narrow forms of the ponds and a detention time of at least 5 days have shown, even at a low water temperature and below an ice cover, to produce an average effluent quality of 70 mg COD_{Cr}/l, 0.2 mg Tot-P/l, 20 mg Tot-N/l (CODCr: chemical oxygen demand; Tot-P: total phosphorus; Tot-N: total nitrogen) and low levels of pathogenic bacteria. The systems use low amounts of energy and no wastewater is by-passed at the plants. Fellings dams have recently been tried to support overloaded wastewater collection systems.

Key words | chemical precipitation, ponds, wastewater treatment

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BACKGROUND

Wastewater stabilization ponds were introduced to Scandinavia during the first half of the 20th century and grew popular for small municipalities. At that time there was limited knowledge of the treatment processes involved, which needed solar radiation to activate the algae–bacteria system responsible for a positive treatment result.

Eventually, the poor winter functionality of these ponds was discovered (Hanaeus 1991) and other wastewater treatment methods, in general more compact plants, were recommended.

Combined with growing insight that phosphorus was the critical nutrient regarding excess growth and subsequent oxygen deficit in inland wastewater recipients, an upgrading of the pond systems was formulated and tested. Chemicals for the precipitation of phosphorus were added and a good year-round function was experienced. As the Swedish and Norwegian words for precipitation (chemical) are 'fällning' and 'felling', the term fellings dam was suggested (Ödegaard *et al.* 1987; Hanaeus 1991).

Such pond systems have operated in Sweden for almost 40 years and today about 70 plants are active (Norin 2015). In 2008–09, a survey of 22 fellings dams was performed (The Swedish Water & Wastewater Association 2009) and in 2015 an additional investigation was made. A good cold climate performance, a simple operation and a utilization of area for treatment have rendered the method successful in small municipalities (pop. <10,000) in Northern Sweden.

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In an international perspective, only Sweden seems to have adapted this technology, though some applications have been reported from America (Federation of Canadian Municipalities & National Research Council 2004; Cabral *et. al.* 1999; Harleman & Murcott 2001).

OBJECTIVE

The objective with this article is to present the development and current status of fellings dams in Sweden. Some ideas for the future will also be mentioned.

The system properties referred to are hydraulics and effluent water quality in terms of organic matter, phosphorus, nitrogen and, to some extent, pathogenic bacteria. There is also concern about energy use and sludge production at the fellings dams.

FIELD EXPERIENCES

In 2008 a survey of 22 pond systems was carried out (The Swedish Water & Wastewater Association 2009) to follow up the results of a previous work (Hanaeus 1991). The work included collection of samples by rowing a boat across the ponds or drilling with an ice bore (ice conditions during the spring were highly variable). Water samples at different depths were made with a Rüttner sampler while a barrel pump was used for sediment sampling. Temperature, pH and turbidity (Hach 2100P) were measured on the sampling occasion. Wastewater flows at the dosage position were measured and the dose of coagulant was registered.

The ponds investigated used aluminum sulfate (often as a granulate) or powdered slaked lime, $Ca(OH)_2$, and were thus operated at pH 6 or pH 11. Common dosage levels were 15 g Al/m^3 or 800 g $Ca(OH_2)/m^3$. Influent, domestic wastewater, was often diluted by rain or meltwater and gave typical values of 150 mg/l (7-day biochemical oxygen demand), 250 mg/l (COD_{Cr}; chemical oxygen demand, dichromate method), 5 mg Tot-P/l (Tot-P: total phosphorus) and 35 mg Tot-N/l (Tot-N: total nitrogen). The wastewater temperature was low in the winter and values of 0–5 °C were common.

Two main configurations of the fellings dams were identified:

(1) One or more pre-settling ponds followed by a dosage station and varying number of post-dosage settling ponds in series. An advantage of this design is that the pre-settling pond volume may be used for storage in periods of high loading. An example of this kind of fellings dam is given in Figure 1.
(2) A septic tank followed by a dosage station and a number of ponds in series.

RESULTS

Hydraulics at fellings dams

Rhodamine B tracer studies using fluorometer detection had been carried out already circa 1980 (Hanaeus 1991) showing that converted stabilization ponds (often rectangular but with sides of similar length, depth 1–1.5 m) deviated much from the idealized models of completely mixed flow and plug flow.

Common curves found from one-pond or two-pond systems are shown in Figure 2.

Since it was possible for the eye to follow a red-colored tracer stream far into the pond, a complete mixing was not considered a realistic model. The maximum tracer concentration arrived after 10–15% of the mean detention time, which of course is unfavorable with respect to the treatment result, as the main process in fellings dams after chemical addition is sedimentation. The hydraulic inlet pulse was also an important reason for the distribution of the tracer stream.

The tracer response curves found for this kind of pond geometry were interpreted as follows.

(a) A good mixture takes place within a limited part of the pond. Water is travelling the shortest way possible. Hence, the completely mixed flow-model with an e^{-t} function may represent the time axis well, except for the initial part. However, a normalization of the tracer concentration (mass of tracer divided by the pond volume) compared to the measured (much higher) concentration shows that the pond is far from completely mixed.
(b) The inlet hydraulic pulse should be minimized. From experience less than 0.5 m head was recommended.
(c) Water should be forced to travel as long a distance as possible within the ponds to approach a plug flow, which is favorable for sedimentation. Thus, a system of several long and narrow ponds (length > 10 width) was recommended.

Effect of the detention time

A few fellings dams were designed strictly after the findings above. Turbidity recordings along the fellings dam of Hede (pop. 3,000, 602 m^3/d; there are seven ponds after the addition of 21 g Al^{3+}/m^3 aluminum sulfate (granulate)) are shown in Figure 3.

From these findings, a detention time of 5 days under the conditions close to plug flow was suggested as a realistic design value for fellings dams after the chemical addition. The build-up of flocs is, because of resource savings and simplicity in operation, not given any special reactor, but takes place along the ponds with time.

Organic matter

A fellings dam is successful at separating particles but has no efficient biological system to deal with dissolved organic matter. Average yearly values in terms of COD_{Cr} from regular monthly or biweekly sampling during 2001–2007 are presented in Table 1 (The Swedish Water & Wastewater Association 2009).

Thus, effluent values of 40–100 mg COD_{Cr}/l, dominated by the dissolved fraction of organic matter, may be expected from fellings dams.

Phosphorus

Since 1970 phosphorus has been considered a very important effluent parameter in Sweden due to the generation of secondary growth and related oxygen consumption at

Figure 1 | The fellings dam at Hede (pop. 3,000) with dosage station, a pre-settling pond and seven post-settling ponds in the background.

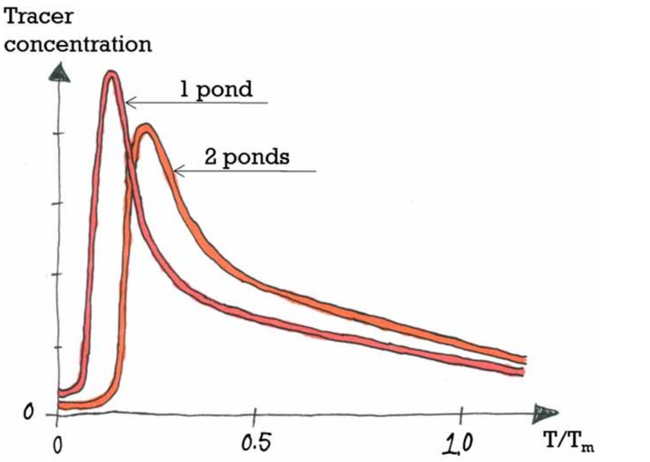

Figure 2 | Generalized curves from tracer studies in wastewater ponds in Middle-Sweden. Tracer concentration was measured at the outlet. T is time from tracer addition and T_m is mean detention time; that is V/q where V = pond volume and q = water flow, volume/time unit. The concentration axis has not been normalized.

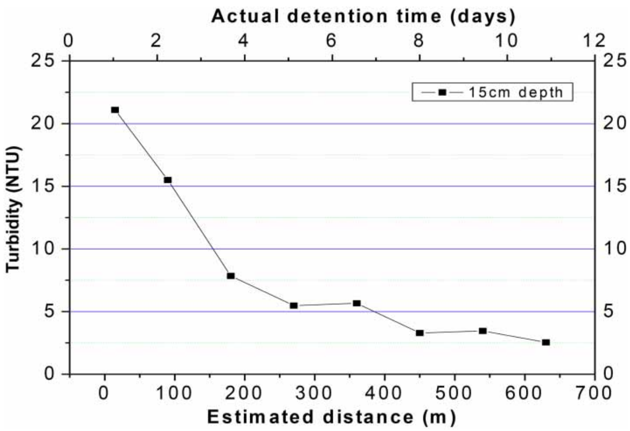

Figure 3 | Turbidity values along the ponds of Hede at a depth of 0.15 m. The system is close to plug flow.

degradation in inland waters. Average yearly values from quarterly sampling during 2001–2007 are shown in Table 2 (The Swedish Water & Wastewater Association 2009).

Nitrogen

Nitrogen has not been a target parameter for fellings dams as almost all the receiving bodies are growth limited by phosphorus. However, measurements were carried out and the effluent content of total nitrogen is shown in Table 3 (The Swedish Water & Wastewater Association 2009).

Pathogenic bacteria

Previous work has shown a high reduction of pathogenic indicator bacteria, fecal coliforms (44 °C), with the use of slaked lime for fellings dams (Hanaeus 1991). Considering a pH at precipitation of about 11 and a good separation of

Table 1 | COD_{Cr} (mg O_2/l) in effluent water from nine fellings dams. Non-weighted yearly averages from monthly or biweekly sampling. The number of connected inhabitants is given

Fellings dam	Persons connected	2001	2002	2003	2004	2005	2006	2007
Slaked lime								
Gottne	226	64	156	154	127	136	117	n.a.
Skorped	261	14	29	47	25	26	25	n.a.
Bredbyn	1,352	56	79	121	110	78	135	n.a.
Funäsdalen	3,978	66	66	73	69	73	73	82
Tänndalen	3,914	46	64	77	74	74	63	95
Yearly average		55	86	104	89	83	101	88
Aluminium								
Solberg	157	27	34	32	30	30	31	n.a.
Björnrike	2,137	73	107	109	120	85	120	113
Bruksvallarna	2,000	38	36	33	45	55	37	n.a.
Hede	2,156	33	52	62	58	58	55	62
Yearly average		43	57	59	63	57	61	87

Table 2 | Total phosphorus (mg P/l) in effluent water from nine fellings dams. Non-weighted yearly averages from monthly or biweekly sampling

Fellings dam	Persons connected	2001	2002	2003	2004	2005	2006	2007
Slaked lime								
Gottne	226	0.22	0.75	0.25	0.21	0.16	0.20	n.a.
Skorped	261	0.10	0.09	0.13	0.21	0.21	0.29	n.a.
Bredbyn	1,352	0.16	0.12	0.31	0.21	0.29	0.55	n.a.
Funäsdalen	3,978	0.22	0.23	0.18	0.15	0.17	0.20	0.12
Tänndalen	3,914	0.23	0.16	0.21	0.25	0.20	0.28	0.27
Yearly average		0.19	0.27	0.22	0.21	0.20	0.30	0.20
Aluminium								
Solberg	157	0.10	0.06	0.11	0.09	0.16	0.10	n.a.
Björnrike	2,137	0.16	0.46	0.15	0.16	0.10	0.23	0.20
Bruksvallarna	2,000	0.16	0.12	0.14	0.15	0.38	0.07	0.08
Hede	2,156	0.05	0.07	0.04	0.04	0.03	0.04	0.05
Yearly average		0.12	0.18	0.11	0.11	0.17	0.11	0.10

particles, slaked lime precipitation represents a useful hygienic barrier.

In 2015 measurements at the fellings dam in Hede were carried out using *Escherichia coli*, coliforms (35 °C) and intestinal streptococci as indicators. Results from the fellings dam at Hede at well-controlled detention times are shown in Figures 4 and 5.

The turbidity values on the same sampling occasion showed a similar relation to the detention time as did the logarithmic bacteria numbers.

Sludge handling

Sludge has accumulated in the ponds over long periods, 1–20 years. A common magnitude of sludge accumulation is 3 l/m^3. The dry solids content increases slowly by compression in the pond (Hanaeus 1991); for hydroxide, sludge values of 2–15% have been found.

The technology for emptying sludge improves slowly, with an example in Figure 6. For the dewatering of sludge, natural freezing and thawing were applied successfully.

Table 3 | Concentrations of total nitrogen (mg/l) in effluents from nine fellings dams. Non-weighted yearly averages from monthly or biweekly sampling

Fellings dam	Persons connected	2001	2002	2003	2004	2005	2006	2007
Slaked lime								
Gottne	226	12	25	29	25	25	23	n.a.
Skorped	261	7	12	16	11	12	10	n.a.
Bredbyn	1,352	8	13	17	15	10	16	n.a.
Funäsdalen	3,978	19	23	25	27	30	26	27
Tänndalen	3,914	12	13	17	17	11	19	15
Yearly average		11	17	21	19	18	18	21
Aluminium								
Solberg	157	4	6	6	4	7	5	n.a.
Björnrike	2,137	24	33	32	43	35	42	41
Bruksvallarna	2,000	13	13	13	18	18	18	n.a.
Hede	2,156	17	22	26	26	24	20	21
Yearly average		15	19	19	23	21	21	32

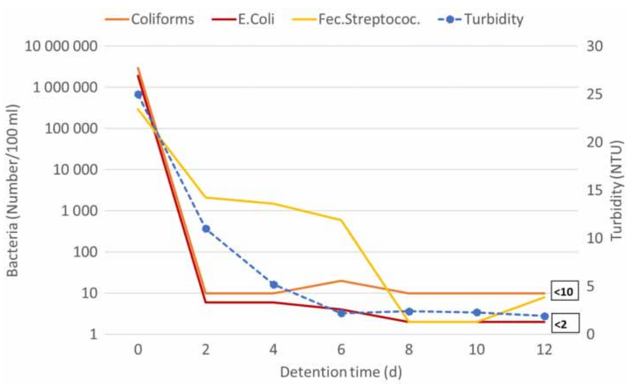

Figure 4 | Numbers of pathogenic indicator bacteria, coliforms (35 °C), *E. coli,* and fecal streptococci, after different detention time in the pond system at Hede. April 9, 2015, aluminum sulfate, pH 6.0, temperature 4.5 °C.

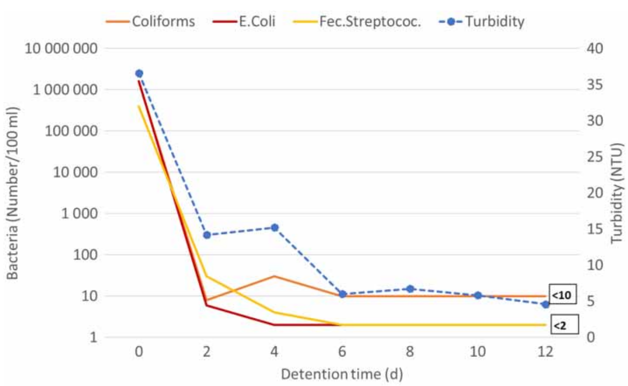

Figure 5 | Numbers of pathogenic indicator bacteria, coliforms (35 °C), *E. coli,* and fecal streptococci, after different detention time in the pond system at Hede. May 15, 2015, aluminum sulfate, pH 6.0, temperature 7.5 °C.

Energy

The energy used for the systems was electrical energy, to pump and heat small dosage-station buildings in the cold climate. Between 2001 and 2007 the median value was 0.24 kWh/m^3 influent wastewater ($n = 8$).

DISCUSSION

The simplicity of the fellings dams has been an important condition in the development process. The systems are easy to operate and robust as the time interval between operators' visits may be several days. If some component (pump) ceases to work, the system performance is still satisfactory for many days. However, the quality of the effluent is not excellent mainly due to the lack of a strong biological process. On the other hand, the energy-consuming aeration is avoided. The advantage is that the system is quite insensitive to changes in the influent wastewater quality and quantity. There is no need to by-pass influent wastewater at a fellings dam.

Fellings dams are also utilized to support large wastewater nets by treating overflow water at critical points, like pumping stations and compact treatment plants.

CONCLUSIONS

About 70 fellings dams are operating in Sweden with satisfactory treatment results; average values are COD_{Cr}

Figure 6 | Sludge emptying by a combination of pumping and excavation.

70 mg/l, Tot-P 0.18 mg/l and Tot-N 20 mg/l. Aluminium salts and slaked lime are most frequently used for the precipitation. A well-controlled detention time after chemical precipitation of 5 days was shown to give a low effluent turbidity and low effluent concentrations of indicator bacteria.

FUTURE DEVELOPMENT

To improve the fellings dams, especially regarding the separation of dissolved organic matter in a cold climate, attempts to add units like forest fertilization, wetlands or infiltration areas are being discussed.

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