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EFFECT OF TEMPERATURE AND PHYSICO-CHEMICAL CHARACTERISTICS ON THE EFFICIENCY OF COAGULATION FLOCCULATION PRETREATMENT OF WATER ON DAIRY FARMS

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ABSTRACT The Canadian Quality Milk Program requires that the water used to wash milking equipment on dairy farms meet the provincial potability standards for bacteria. To comply with the program, some dairy farms will have to be equipped with onsite disinfection systems. However, the levels of turbidity and UV absorbance (UVA) are sometimes too high in water supplies, especially surface sources, for lower cost disinfection systems such as UV lamps. On some farms, the water will require the application of a pretreatment, such as coagulation flocculation (CF). The objective of this project was to examine the effect of water physico-chemical characteristics and temperature on the efficiency of coagulation flocculation of four surface sources supplying water to dairy farms in Eastern Ontario. Polyaluminum chloride (PACl) was used as the coagulant. For water sources with UVA remaining below 0.8 cm^{-1}, a single dose will be adequate throughout the year, but additional settling time should be provided in the winter when water temperature is below 8-10ºC. For water with high variations in UVA, a simple online UVA sensor could be used to automatically control coagulant dose. The dosing system can also include a temperature sensor, but allowing additional settling time should be sufficient to adequately pretreat the water in cold temperature. There was no correlation between turbidity and coagulant dose, and UVA-based doses should apply to a relatively large range of turbidities (5 to 143 NTU).

Keywords: Coagulation flocculation, onsite water treatment, temperature, dairy farms, UVA, turbidity

INTRODUCTION Human and animal wastes contain a wide variety of pathogenic bacteria, viruses and parasites. On farms, undesirable microorganisms can infiltrate water sources, because of defective septic installations, improper manure handling and storage, manure spreading, and wildlife intrusion. In 2003-2004, water samples were collected from the milk house of 5421 dairy farms in Ontario (Perkins et al. 2009). About 10% and 50% of the samples tested positive for *E. coli* and total coliforms, respectively. The presence of *E. coli* in the milk house water was linked to an increase in total bacterial count in raw milk. Other studies have reported the presence of coliforms, such as *Campylobacter* and *Salmonella,* in bulk tank milk (Oliver et al. 2005). The ability of raw milk to retain its quality during storage has been related to its bacterial content, and in many countries, bacterial content is one of the factors considered in milk payment (Saran 1995). In addition, pasteurization may not deactivate all milkborne pathogens (Oliver et al. 2005).

To maintain milk quality and ensure consumer safety, the Canadian Quality Milk Program, an on-farm Hazard Analysis Critical Control Point (HACCP) food safety program, requires that the water used for milking equipment sanitation meet the provincial potability standards for bacteria. To comply with the Program, some farms will need to be equipped with on-site disinfection treatment systems. Treatment selection will partly depend on the level of contamination, which could be high, especially in surface water sources. In 2007-2008, six surface sources supplying water to dairy farms in Eastern Ontario were sampled 23 times over a 16-month period (Masse et al., 2010). Total coliforms, fecal coliforms and *E. coli* were detected in 91%, 89%, and 75% of the samples, respectively. Maximum concentrations were one to two orders of magnitude higher than median values. Disinfection treatment technologies at the farm will thus need to be over-designed for most of the year, thereby providing a conservative safety margin.

The suitability of disinfection technologies also depends on the physico-chemical characteristics of the water, such as suspended solids (SS) and natural organic matter (NOM) contents. Particulates can shield bacteria from UV radiations and contribute to membrane fouling. Commercial membrane and UV technologies usually recommend a turbidity ≤ 1 NTU for incoming water. The average turbidity of the six surface sources supplying water to dairy farms in Eastern Ontario ranged from 0.7 to 69.0 NTU (Masse et al., 2010). Only one source had an average turbidity less than 1 NTU. In addition, variability was high, with maximum values 2 to 12 times the average. High turbidity will also be problematic for oxidizing technologies, such as ozonation, because it will increase required doses and thus cost, and may favour the formation of carcinogenic trihalomethanes (THM) if chlorination is used. In addition, doses will need to be periodically adjusted given the high variability in water quality. A pretreatment may be required to prepare these surface waters for disinfection treatment.

Coagulation-flocculation (CF) is typically used to reduce turbidity and NOM in municipal drinking water. Various inorganic coagulants have been used, such as alum and iron, but polyaluminum chloride (PACl) was found to consume less alkalinity, give more rapid flocculation and stronger flocs, produce lower volumes of sludge and lower residual aluminum, and be less affected by decreases in temperatures than other coagulants (Duan and Gregory, 2003; Zouboulis and Traskas, 2005). In recent years, flocculators have been designed for commercial operations requiring relatively small volumes of water compared to municipalities. However, the incoming water can present large variations in quality and temperature, and this could have an impact on required coagulant doses. This project examined the effect of temperature and physico-chemical quality of surface water on PACl dose and CF pretreatment efficiency. The objective was to determine if a simple monitoring device could be used to establish optimum dose for a CF system installed on a dairy farm.

MATERIALS AND METHODS

Experimental water In January and July, 2008, about 100 L of water were collected from four surface sources supplying water to dairy farms in Eastern Ontario. The water sources are presented in Table 1. Raw water samples were analysed for dry matter (DM), SS, turbidity, conductivity, hardness, UV transmittance (UVT) and absorbance (UVA), pH, and NO_3-N, according to standard methods (APHA et al., 2005). The water was kept at 4ºC and was transferred to a temperature-controlled room 12 h before the experiments.

Table 1. Surface water sources used in the experiment

Name	Description of the water source
Pond	Artificial pond dug in a peat bog
River	South Nation River in Fournier, Ontario
Creek 1	Horse Creek in Alfred, Ontario
Creek 2	Creek in a swampy area in Alfred, Ontario

Jar-test procedures The coagulant, polyaluminum chloride (PACl), was obtained from Clear Tech Industries (Saskatoon, SK). The commercial product (ClearPAC) contained on average 56 g Al/l and it had a basicity of 50-58%. It was diluted 10 folds in deionized water before use. Doses are reported as ml of ClearPAC product by litre of water.

Square 2-L jars were filled with 2 L of water and placed on a jar-test apparatus (Phipps & Bird, Richmond, Va) in a temperature-controlled room. Coagulation flocculation experiments were conducted at 8ºC, 12ºC, 15ºC, and 28°C. Tested temperatures covered most of the water temperature range in the milk house during the year. The jars were mixed at 160 rpm during PACl injection. Rapid mixing was maintained for 105 seconds, and then reduced to 45 rpm for 10 min. During floc settling, samples were collected from a valve situated at the bottom one third (4.6 cm) of total water height (14.2 cm), each 30 min up to 120 min. A total of 5 to 10 PACl doses were tested with each water. The optimum dose was defined as the dose required to reach a turbidity of 1.0 ± 0.1 NTU after 120 min of settling. A total of 12 doses were tested in triplicate at two temperatures, and an average coefficient of variation (CV) of 7 ± 2 % was obtained for water turbidity after 120 min of settling, indicating low variability in results.

RESULTS AND DISCUSSION

Experimental water The physico-chemical characteristics of the water samples are presented in Table 2. Turbidity and SS contents were consistently higher in the winter than summer samples for all water sources. In the five days preceding the winter sampling, 32 mm of rain were recorded at a weather station situated about 60 km west of the sampling points (Environment Canada, 2010). Temperature had remained above the freezing point, and the snow cover had decreased from 61 to 11 cm. High turbidity in all four water sources was probably caused by surface runoff which increased SS content in the water. In the summer, on the other hand, no rain was recorded in the 6 days preceding sample collection. There was also variations in other parameters such as UVT and mineral content, between the summer and winter samples, but no consistent trend across all water sources.

Table 2. Physico-chemical characteristics of the water used in the coagulation flocculation experiments

	Pond		River		Creek 1		Creek 2	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
DM (mg/l)	346	311	401	342	329	220	403	792
SS (mg/l)	68.6	12.9	111.0	ND[b]	44.3	ND[b]	52.9	11.4
Turbidity (NTU)	73.2	26.5	143	5.4	61.4	15.7	73.5	11.2
UVT (%)	14.8	0.6	28.8	47.9	26.9	25.7	2.6	33.1
UV absorbance (cm^{-1})	0.83	2.23	0.54	0.23	0.57	0.59	1.58	0.48
Alkalinity (mg $CaCO_3$/l)	190	112	117	221	126	124	93.2	301
Hardness (mg CaCO3/l)	184	120	148	240	132	120	108	344
pH	7.80	7.80	7.70	8.30	7.90	8.10	7.60	8.10
Conductivity (µS)	469	287	415	600	438	386	379	1351
NO3-N (mg/L))	0.58	1.49	5.27	6.94	2.25	1.56	2.68	1.95
Iron (mg/l)	0.92	1.94	0.15	0.02	0.48	0.40	1.01	0.03
Aluminum (mg/l)	1.11	1.32	0.21	0.03	0.67	0.25	1.32	0.01

Optimum dose at 15ºC The optimum PACl dose was defined as the dose required to reach a turbidity of 1.0 ± 0.1 NTU after 120 min of settling. This set point was selected because most disinfection systems recommend a turbidity ≤ 1 NTU for incoming water.

In addition to decreasing turbidity, the CF treatment significantly increased the UVT (or decreased the UVA) of the water. At optimum dose, the UVT of all but one water sample ranged from 64% to 78%, making the water suitable for many UV disinfection technologies. The exception was the water from Pond in the summer, which had UVT values of 0.5% and 43% before and after CF treatment, respectively. UV transmittance or absorbance are often used as an approximation of dissolved organic matter (DOM) in water (Annadurai et al., 2004). Coagulation flocculation treatment removes DOM by charge neutralization, which reduces its solubility, and adsorption to the precipitated metal hydroxides (Duan and Gregory, 2003). Treating the water by CF also reduced iron concentrations below detection limit, but had no effect on hardness, conductivity, aluminum concentration, alkalinity, pH and nitrate concentration.

Figure 1 compares optimum dose at 15ºC for the summer and winter samples. There was no consistent seasonal effect on optimum dose. For two of the water sources (River and Creek 1), similar doses were required in summer and winter. Creek 2, on the other hand, required a low dose of 0.01 mg PACl/L for the sample collected in summer, and one of the highest doses (0.15 mg/L) for the winter sample. The Pond showed the opposite trend with a much higher dose in summer than winter. The large difference in optimum dose for these two samples suggested that, on these two farms, dose would have to be periodically adjusted based on an easily measurable parameter.

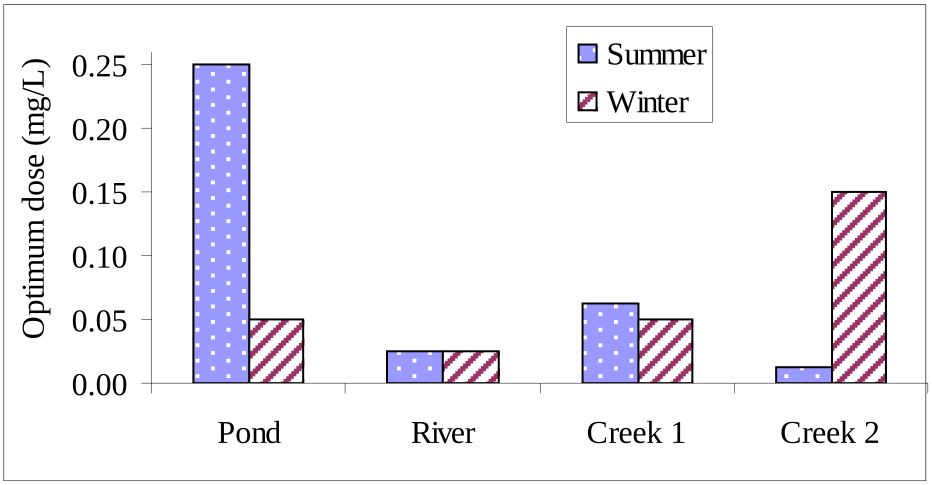

Figure 1. Optimum PACl dose at 15ºC

Optimum dose and physico-chemical characteristics Figure 2 presents optimum coagulant dose at 15ºC with respect to turbidity and UVA, two parameters that can be relatively easily monitored on-line. Optimum dose was linearly correlated to UVA (R^2 = 0.96), but not turbidity. Other studies have shown that NOM controls the coagulation process, when water contains both mineral particles and organic matter, because of the high surface area and charge of organics compared to minerals (Duan and Gregory, 2003; Rebhun and Lurie, 1993). Optimum dose was also correlated to iron concentration (R^2 = 0.88), but radiations at 254 nm are strongly absorbed by iron ions in water (Savoye et al., 2001) and both parameters were highly correlated (R^2 = 90).

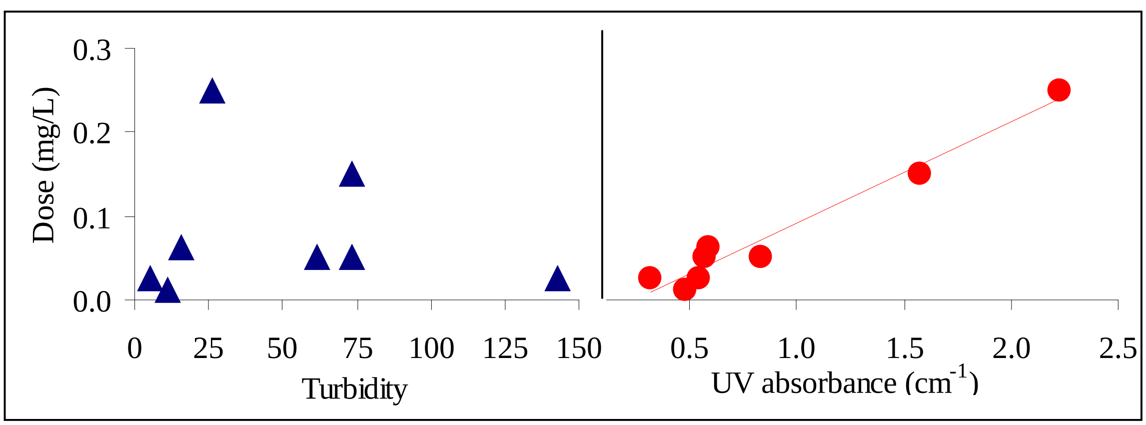

Figure 2. Relation between turbidity / UVA and optimum dose at 15ºC

Temperature effect on optimum coagulant dose Figure 3 presents the effect of temperature on optimum dose. Decreasing process temperature from 15°C to 8ºC increased required dose for six of the eight water samples. The increase ranged from 20% to 100%. Conversely, increasing temperature to 28ºC decreased the required dose of four samples, by 10% to 50%. However, for all samples, using the optimum dose at 15ºC produced a turbidity of less than 1.8 NTU at all other tested temperatures. PACl is known to be less affected by variations in temperature than non prehydrolyzed coagulants, such as alum (Van Benschoten and Edzwald, 1990).

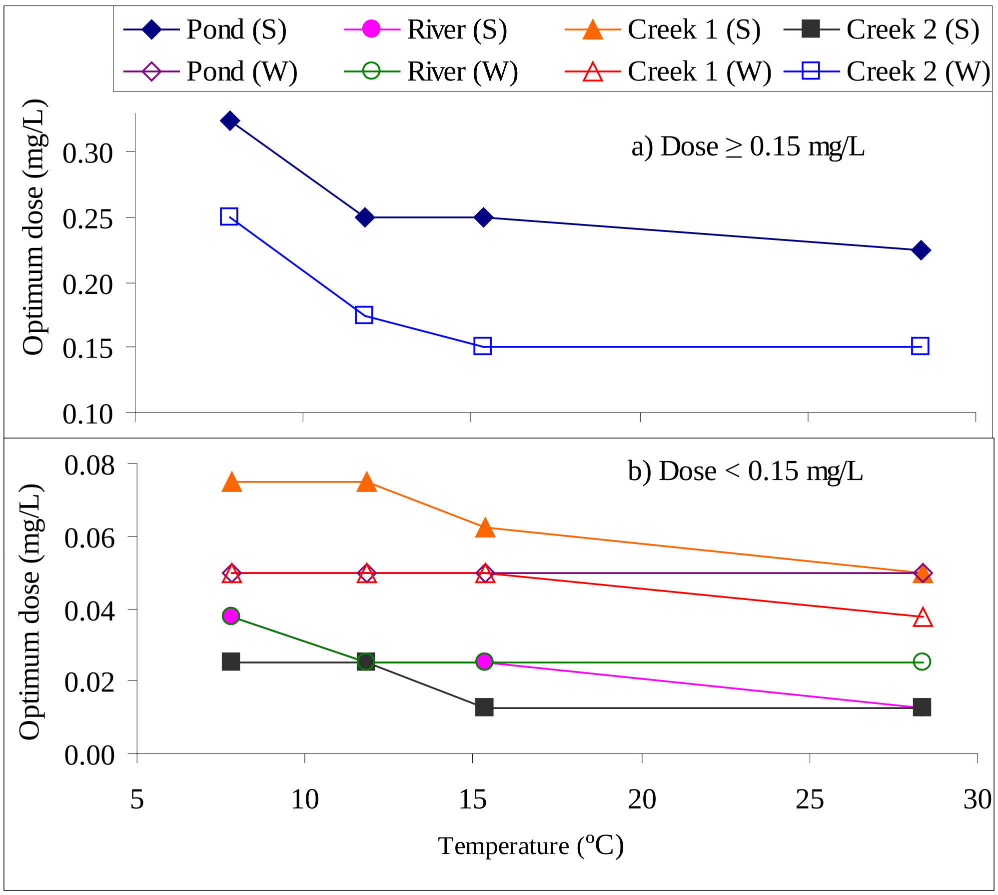

Figure 3. Optimum PACl dose at various temperature

Decreased efficiency of inorganic coagulants at lower temperatures has been attributed to various factors, such as slower chemical reactions and the formation of smaller and weaker flocs (Duan and Gregory, 2003). In addition, higher water viscosity at low temperature reduces floc settling rate. Figure 4 presents decreases in turbidity with time when Creek 2 water in winter was treated with 0.15 mg/L of PACl. This dose corresponded to the optimum dose at 15ºC. The slope of the lines at 8ºC and 12ºC suggests that the water would have reached the limit of 1 NTU if more time had been allowed for settling. The higher doses required to reach 1 NTU at 12ºC (0.18 mg/L) and 8ºC (0.25 mg/L) were probably mainly due to slower floc settling.

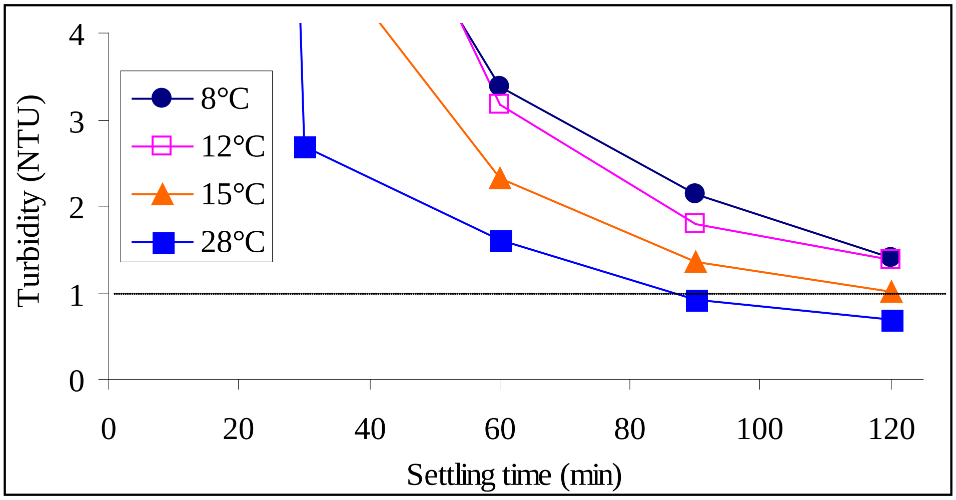

Figure 4. Floc settling during the flocculation of Creek 2 water in winter at the optimum dose at 15ºC (0.15 mg/L)

At all temperatures, optimum PACl dose was correlated to raw water UVA (R^2 between 0.94 and 0.99). Figure 5 presents the linear relation between temperature and optimum dose at 8ºC, 12ºC, and 28ºC. At low UV absorbance, temperature and UVA effect on optimum dose was weak. At UVA below 0.84 cm^{-1} (UVT above 14.5%), a PACl dose of 0.05 mg/l provided a turbidity≤ 1.0 NTU with all water and at all temperatures, except for two samples which had a turbidity of 1.9 NTU at 8ºC and 12ºC. For water sources with low variations in UVA, a single dose will thus be adequate throughout the year, while settling time could be increased in winter. At UVA above 1.5 cm^{-1} (UVT below 3%), however, both temperature and UVA had a significant impact on dose. At these UVA levels, a dose of 0.05 mg/L had no effect on decreasing turbidity. With water having high variations in organic matter content, relatively simple online UVA and temperature sensors could thus be used to automatically control coagulant dose. The temperature sensor could also be replaced by increased settling time in the winter. Results suggest that the UVA-based dose would apply to a relatively large range of turbidities (5 to 143 NTU).

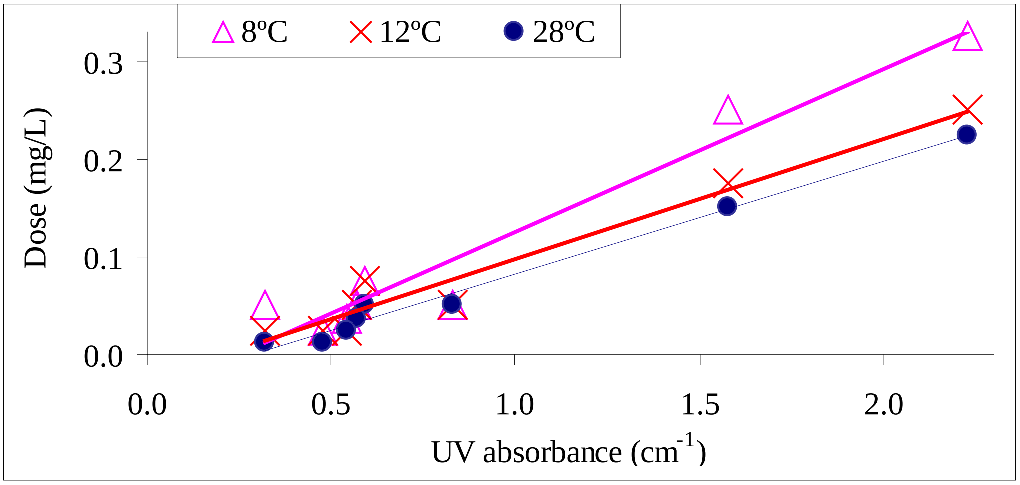

Figure 5. Relation between UV absorbance and optimum PACl dose at 8ºC, 12ºC and 28ºC

Sludge production Sludge production was measured at optimum dose for each temperature after 120 min of settling in Imhoff cone. Sludge volume ranged from 0.5% to 5% of the initial water volume. At constant dose, sludge volume tended to be higher at lower temperatures, which was probably due to slower settling time. At 15ºC, sludge volume was related to UVA (R^2 = 0.94) and dose (R^2 = 0.89), two correlated parameters.

CONCLUSION Results from this study indicated that for water sources with UV absorbance remaining below 0.8 cm^{-1}, a single PACl dose will be adequate throughout the year, but additional settling time could be provided in the winter when water temperature is below 8-10ºC. With water having high variations in organic matter content, however, online UVA and temperature sensors could be used to automatically control coagulant dose. The UVA-based dose should apply to a relatively large range of turbidities (5 to 143 NTU).

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