Variability of effluents from mills with advanced control

Neil McCubbin, Jens Folke, Alistair Stewart, and Kirsten Vice

ABSTRACT: The report analyzes the long-term variability of biochemical oxygen demand (BOD), total suspended solids (TSS), and adsorbable organic halogen (AOX) in effluent discharged from mills with advanced effluent-control systems. Variability of BOD and TSS levels in systems discharging low concentrations of BOD is comparable with or lower than variability for best-practical-treatment systems as defined by the U.S. EPA in 1980. The long-term average concentrations are also lower. Variability of AOX discharges is less than for the traditional pollutants, whether AOX control measures are implemented or not. Aerated-stabilization-basin systems operating in extremely cold climates demonstrated excellent long-term performance and suffered less degradation of performance in winter than is frequently claimed.

KEYWORDS: Adsorbable organic halogen, BOD, effluent treatment, mills (factories), oxygen demand, solids content, suspended solids, variables.

Much of the data in this paper were collected for the Ontario Ministry of the Environment in order to develop effluent-limit regulations for the 26 direct-discharge pulp and paper mills in Ontario. However, the data are useful for the design and operation of in-plant and external treatment systems for pulp and paper mills everywhere.

MISA program

Background

The Municipal/Industrial Strategy for Abatement (MISA) program is a regulatory program of the Ontario Ministry of the Environment. The program's ultimate goal is the virtual elimination of persistent toxic contaminants from all effluent discharges to Ontario waterways *(1)*.

Under the MISA program, the direct-discharge mills in Ontario were required to monitor the types, concentrations, and total amounts of up to 135 contaminants present in their effluent for a period of 12 consecutive months throughout 1990 *(2)*. The Development Document for the Effluent Monitoring Regulation for the Pulp and Paper Sector *(3)* provides background information on the MISA Pulp and Paper Sector and outlines the technical rationale used in selecting the parameters to be monitored and their frequency of monitoring.

Data sources

All data were extracted from records of the relevant regulatory authorities. In all cases, one of the authors or associates visited the mill concerned, and various information collected directly from the mills was used to assist in interpreting the data. This document is the work of the authors and does not represent an official record of the Ontario Ministry of the Environment.

Analytical protocols

Analyses were carried out generally in accordance with local regulatory requirements, which the authors consider equal to the well-known American Public Health Association procedures.

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I. Locations and capacities of the mills

Location		Mill type	Treatment	Effluent flow, m^3/day	Nominal production	
					Total, tons/day	Bleached, tons/day
BAT reference mills						
Corbehem	France	Mech/coated	AST	53,808	1,446	None
Whitecourt	AB, Can.	TMP news	AST	14,400	447	None
Spring Grove	PA, U.S.	Kraft/fine p.	AST	52,015	720	N/A
Canton	NC, U.S.	Kraft/fine p.	AST	171,402	1,498	N/A
Terrace Bay	ON, Can.	Market kraft	ASB	91,695	1,110	1,110
Espanola	ON, Can.	Market kraft	ASB	101,641	943	943
Hinton	AB, Can.	Market kraft	ASB	103,643	1,021	1,021
Peace River	AB, Can.	Market kraft	ASB	59,159	617	617
Typical mills (for AOX data)						
Dryden	ON, Can.	Kraft/fine p.	ASB	89,192	965	735
Fort Frances	ON, Can.	News & krft.	ASB	80,710	1,094	573
Thunder Bay	ON, Can.	News & krft.	Primary	174,877	2,290	1,279
Cornwall	ON, Can.	Kraft/fine p.	Primary	129,953	726	412
Smooth Rock Falls	ON, Can.	Market kraft	Primary	51,374	297	297

Effluent parameters

Targeted characteristics

The effluent parameters monitored under the MISA program include substances found on the Ontario Effluent Monitoring Priority Pollutants List *(4)*. This list is similar to the U.S. EPA priority pollutants list with respect to the substances found in pulp and paper mill effluents. The data collected under the effluent-monitoring regulation have been summarized by the Ministry in two reports *(5)*. Summaries of the data in two other formats are also available *(6, 7)*.

This paper is restricted to an analysis of the variabilities of five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), and adsorbable organic halogen (AOX). Dioxins and furans were monitored under MISA. However, 2,3,7,8-TCDD (tetrachlorodibenzo-*p*-dioxin) was detected so rarely (detection level 20 picog/L) that variability analysis would be of no practical value.

Variability analysis

MISA effluent limits are being developed in accordance with the statistical analytical procedures outlined in the Ontario Ministry of the Environment draft Issue Resolution Committee Reports on Limit Setting and Data Analysis *(8)*.

Effluent limits are calculated for each parameter by multiplying long-term average (LTA) concentrations and loadings by the appropriate variability factors for that parameter. Variability factors indicate the degree of fluctuation of the effluent-monitoring data from the mean or expected value. The method is generally similar to that used by the U.S. EPA *(9)*. The EPA defines the variability factor as the ratio of a value at a selected extreme probability of occurrence, such as 95% or 99%, divided by the expected mean for a given data set.

Statistical approach

Daily effluent limits are calculated using 1-day variability factors (VF1). These factors reflect the degree of fluctuation of the 99th percentile of the data greater than or equal to the detection limit, from the mean or expected value.

Monthly effluent limits are calculated using either 4-day or 30-day variability factors (VF4 or VF30). These factors reflect the degree of fluctuation of the 95th percentile of the data greater than or equal to the detection limit, from the mean or expected value. The use of either VF4 or VF30 in the calculation of effluent limits depends on whether the parameter will be monitored weekly or daily for compliance with the monthly effluent limit.

Although these variability factors were developed for regulatory purposes, the principal interest for this paper is that they provide a convenient and simple way of characterizing the reliability and stability of various combinations of in-plant and external treatment systems for effluent control. In all cases, the data were collected from full-scale operating mills. The data from mills outside Ontario were reported to the relevant regulatory authorities. The variability factors were calculated for the MISA program as described previously.

The breadth and depth of the available data, and the subsequent analysis, were less than in past EPA studies. However, the analysis includes AOX and gives some indication of the progress made as research advances and operating experience is gained.

Reference mills

In implementing the best available technology (BAT) definition study *(7)*, the characteristics of effluents from a number of mills were examined. Some mills exhibited exceptionally good performance, and the authors consider these mills to represent BAT as defined in Ontario *(7)*. Several European mills were investigated, and the performance of the best of these mills was judged to be similar to that of the BAT reference mills. However, only one European mill is included in **Table I** because of the lack of sufficiently detailed data on the others.

Other mills are included in this paper because there are extensive data available on their 1990 AOX discharges from the MISA effluent-monitoring program, and they had not implemented AOX control measures at that time.

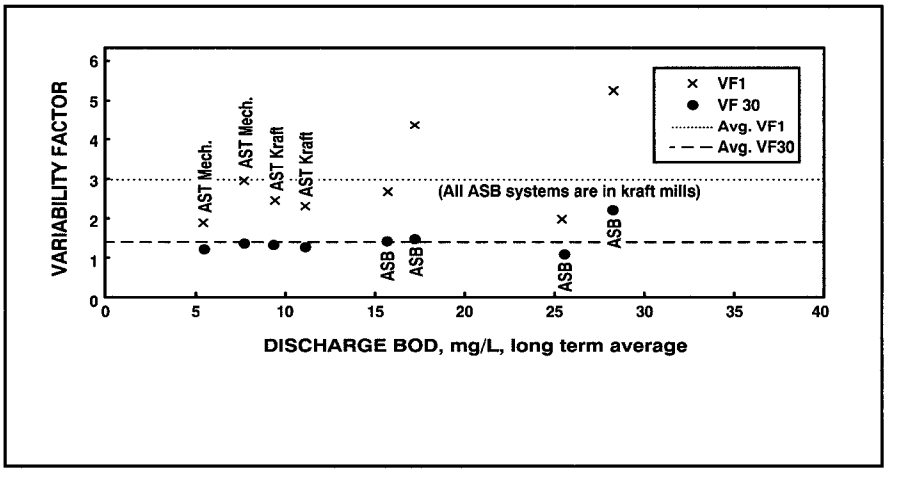
The BAT mills included in Table I all have conventional in-plant and external effluent-treatment technology. The authors believe that the performance of those mills with exceptionally low BOD_5 and TSS discharges is due more to operating skills than to any unusual design features. While none of these plants would be considered seriously overloaded, some are operating at or slightly above their design criteria. The effluent characteristics of several other mills with relatively exotic or lightly loaded treatment systems were examined. These treatment systems were found to be no better than the more-conventional systems.

II. Differences between concentration and loading-based variability factors, in percent

	BOD VF1	*BOD VF4*	*BOD VF30*	*TSS VF1*	*TSS VF4*	*TSS VF30*	*AOX VF1*	*AOX VF4*	*AOX VF30*
Corbehem	1	2		2	1				
Whitecourt	13	6	4	7	4	2			
Spring Grove	2	7	0	1	0	5			
Canton	0	0	0	0	0	0			
Terrace Bay	17	4	3	5	1	1	13	6	6
Espanola	11	2	0	8	1	1	2	3	0
Hinton	-28	-6	8	12	5	8	9	3	
Peace River	4	3	-3	19	10	9	0	0	
Dryden	-8	0	0	4	9	9	3	2	1
Ft. Frances	0	0	1	0	1	0	-1	1	0
Thunder Bay	-2	1	0	6	2	1	-7	0	0
Cornwall	-2	1	-1	-3	0	-1	1	1	0
Smooth Rock Falls	-3	-1	-2	0	0	0	-2	-1	-1
Averages	0	1	1	5	3	3	2	2	1

Values shown are difference between the variability factor calculated from concentration data and the corresponding factor calculated from loading (kg/day) data on the same effluent for the same sampling period. A positive value indicates that the loading based variability factor is the higher.

1. BOD_5 VF1 and VF30 for BAT mills. Left to right order of the mills corresponds to the order of the BAT reference mills in Table I.



Effluent characteristics

Concentrations vs. loadings

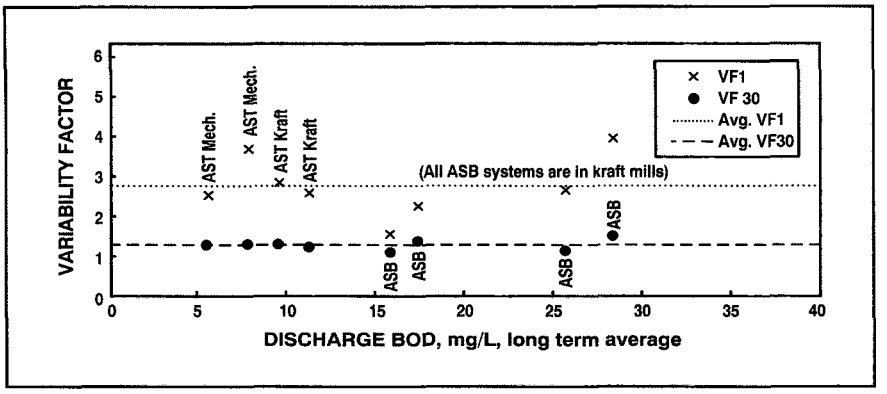
The data collected were analyzed both on the basis of the loadings (kilograms of discharge per day) and the concentrations of substances in the discharges. A review of the calculated variability factors—and the differences between VFs based on loading and on concentration—demonstrated that there is little practical difference between the two, in most cases. However, there are some notable exceptions. Variability factors based on loading are slightly higher than those based on concentrations. Individual differences are shown in **Table II**.

The average difference between the variability factors for any one effluent parameter calculated from concentration and from loading-based data is 2%. Most of the concentration-based data are within a few percent of the respective loading-based values. There are some exceptions, but not sufficient to modify the general conclusions. The remaining BOD_5 and TSS data discussed herein are based on concentrations. AOX data are presented as production-based loadings (kg/metric ton bleached pulp), since these are the most widely used units.

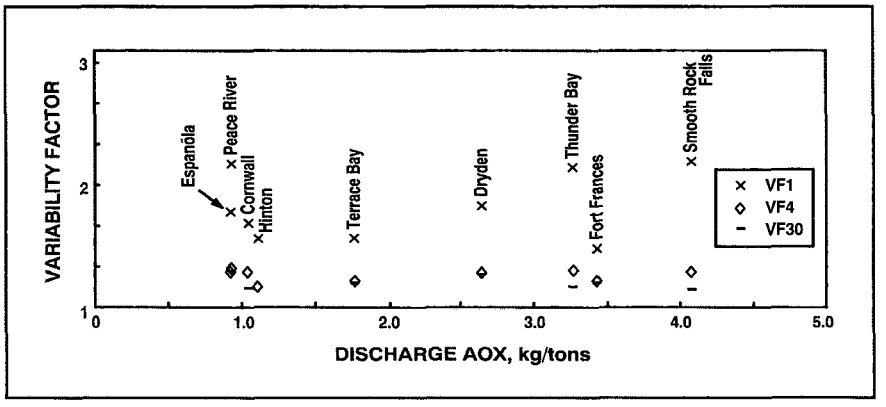
BOD variability

The variability factors for BOD_5 discharges from the BAT reference mills are shown in **Fig. 1**.

2. TSS VF1 and VF30 for BAT mills. Left to right order of the mills corresponds to the order of the BAT reference mills in Table I.



3. AOX for all kraft mills



The values for VF1 suggest that the activated sludge treatment (AST) systems for effluent discharging low BOD_5 concentrations are more stable than the aerated stabilization basin (ASB) systems. The VF30s for the eight mills are in the range 1.06–2.19. There is no practical difference among the four AST systems, although the mill types vary and the ages of the treatment systems vary from 2 years to 30 years. The four ASB systems are less consistent, but there is no clear relationship between effluent quality, as judged by BOD_5 concentration, and variability.

The data contradict the commonly held belief that the ASB process is inherently more stable than AST. In the authors' experience, there has been steady development in operating know-how, operator training, and management commitment over the past 20 years, particularly with respect to AST systems, which perhaps explains the contradiction.

Figure 1 supports the generally held opinion that AST can produce better quality effluent, as defined by BOD_5, than ASB but, of course, ignores the associated costs and the environmental disadvantages of the AST process, such as sludge generation, as well as higher energy and chemical consumption.

Suspended solids variability

The variability factors for the TSS discharges of the BAT reference mills are shown in **Fig. 2.** The x-axis shows the corresponding BOD_5 long-term average discharge concentration, since this is a practical measure of the overall quality of the operation of the effluent-treatment system. When the same data are plotted against the discharge TSS concentrations, the graph is similar, except that the x-axis is about 50% longer.

The values shown for both VF1 and VF30 suggest that there is no practical difference in variability between the ASB and AST systems. Neither is there any relationship evident between BOD_5 discharge concentrations and effluent variability.

Variability factors

U.S. EPA

As part of the process of developing effluent limit regulations for the pulp and paper industry in the late 1970s and early 1980s, the U.S. EPA examined the variability of BOD_5 and suspended solids discharges (TSS) in the effluents from treatment systems then operating *(9)*. While their statistical procedures were not identical to those used by the Ontario Ministry of the Environment, they were sufficiently similar to merit comparison.

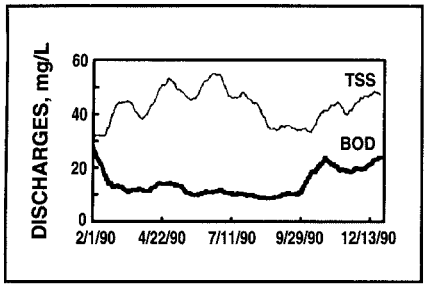
The EPA analysis was based on mill data from the late 1970s and early 1980s, and concluded that the values of VF1 and VF30 for BOD_5 to be used for regulation would be 3.5 and 1.9, respectively. Most, but not all, of the data presented here represent better effluent-treatment system performance.

The corresponding values of VF1 and VF30 for TSS were 3.6 and 1.9, respectively. Most, but not all of the data presented here represent better effluent-treatment system performance. The two highest variability factors for TSS are for the newsprint mill at Whitecourt (VF1 =3.72) and the kraft mill at Peace River (VF1 =3.94). These are new mills, and the database for calculating the variability factors included the initial startup of both the mills and the effluent-treatment systems.

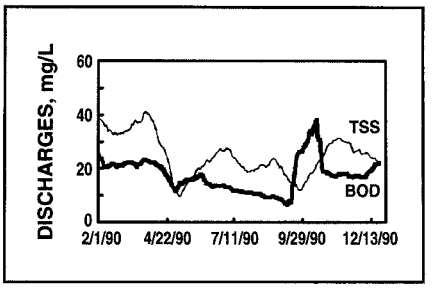
Environment Canada

Environment Canada's basis for its current regulation for the Canadian pulp and paper industry *(10)* is based on two assumptions:

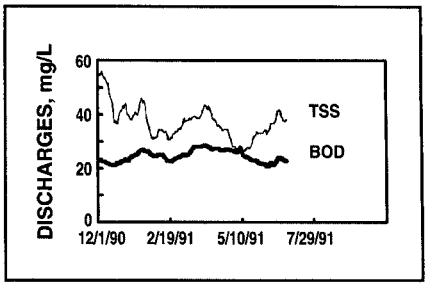
4. Terrace Bay mill discharges



5. Espanola mill discharges



6. Hinton mill discharges



1. The maximum monthly average discharges of BOD_5 and TSS from biological treatment systems would be 1.5 times the long-term average.
2. The maximum daily discharges would be 2.5 times the long-term average.

Thus they are implicitly assigning values of 2.5 for VF1 and 1.5 for VF30. It is apparent from the data that mills will find it very difficult to operate with variability factors as low as these. Canadian mills will have to operate with lower long-term average discharges than indicated by Environment Canada if they are to comply with the regulations for short-term discharges.

AOX variability

The variability factors for the AOX discharges of all the kraft mills included in Table I are shown in **Fig. 3.** The x-axis shows the corresponding long-term average AOX discharge, expressed as kg/metric ton bleached pulp. Both VF4 and VF30 are shown, since there were insufficient data available to calculate VF30 for some mills. The mills concerned had either ASB effluent treatment or primary treatment only, as indicated in Table I.

It is apparent that discharges of AOX exhibit less variability than the traditional pollutants discussed previously. The variability factors are all remarkably constant, despite the range of AOX discharges and the differences among the mills. Three have extensive AOX control, Cornwall is low for no clear reason, and other mills were in the early stages of AOX-control programs.

III. Summary of variability factors and average discharges

	BOD BAT ref.	*BOD* EPA	*BOD* E. Canada	*TSS* BAT ref.	*TSS* EPA	*TSS* E. Canada	*AOX* BAT ref.
VF1	3.0	3.5	2.5	2.8	3.6	2.5	1.7
VF30	1.4	1.9	1.5	1.3	1.9	1.5	1.2
LTA mg/L	27			15			12
LTA kg/t	1.4	3.6		2.4	7.5		1.1

The definitions of VF1 and VF30 differ somewhat, but are synonymous for most practical purposes.
"BAT ref." above is the average of the data shown for the BAT reference mills discussed herein.
The value shown for EPA LTA is the average for market kraft and integrated kraft/fine paper categories.
EPA = U.S. Environmental Protection Agency. E. Canada = Environment Canada

Seasonal effects

The 30-day moving averages of BOD_5 and TSS concentrations in the treated effluents from three ASBs operating in extremely cold climates are shown in **Figs. 4–6.** In each case, cold weather prevails from November until April. There was no statistical analysis of the temperature effects, but experienced readers will notice that the degradation in cold weather is modest.

The most visible degradation of treatment plant performance in winter is at Terrace Bay. The winter BOD_5 is approximately double the summer concentration, but even then, the effluent quality in winter is excellent.

Conclusions

The variability factors determined for all of the BAT reference mills identified in Table I are compared in **Table III** with those determined by the U.S. EPA and Environment Canada.

BOD and TSS

Several mills discharging effluents containing very low concentrations of BOD_5 and TSS have demonstrated that the variability of BOD_5 and TSS discharges is generally similar to or lower than that found by the EPA in the early 1980s. The average effluent discharge quality of the systems reported herein is much better than was normal at that time.

Well-run activated-sludge systems supported by good spill control are more stable than ASBs with respect to BOD_5 and TSS discharges.

The ASBs with low BOD_5 discharges operating in cold climates demonstrated only modest degradation of performance in winter.

AOX

The variability of AOX discharges is less than for BOD_5 and TSS, and is independent of whether effective AOX control measures are implemented or not.

These conclusions are valid whether variability is considered on the basis of daily loadings or on the basis of daily average concentrations of BOD_5, TSS, or AOX.

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Documents from the Ontario Ministry of the Environment are available from the Ministry's Public Information Office in Toronto at (416) 323–4321 or by FAX at (416) 323–4564.

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