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A COMPREHENSIVE COMPARISON OF CANADIAN AND U.S. PULP AND PAPER MILL AIR EMISSION DATA

SPECIAL REPORT 05-03

NOVEMBER 2005

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Acknowledgments

This report was prepared by Dr. Arun V. Someshwar, Principal Research Engineer at the NCASI Southern Regional Center. Dr. John E. Pinkerton (Vice President, Air Quality) provided valuable review of the report contents. Susan Kirkland assisted in the report preparation.

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National Council for Air and Stream Improvement, Inc. (NCASI). 2005. *A comprehensive comparison of Canadian and U.S. pulp and paper mill air emission data*. Special Report No. 05-03. Research Triangle Park, N.C.: National Council for Air and Stream Improvement, Inc.

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PRESIDENT'S NOTE

This report presents a detailed comparison of air emission data generated at Canadian pulp and paper mill facilities during the recent 20-mill study conducted through the Forest Products Association of Canada (FPAC) with similar data generated in the U.S. over the past decade or so. Included in the comparison are emissions for certain key speciated volatile organic compounds (including methanol, acetaldehyde, methyl ethyl ketone, and formaldehyde) from a range of pulp and paper mill sources. The individual mill source emissions and their median for the Canadian mills are compared with median emissions for the corresponding U.S. mill sources and also with the median and range for the combined Canadian-U.S. data sets.

Because Canadian and U.S. pulp and paper mills use similar production processes and because many emission sampling methods are nearly identical in the two countries, assembling a single comprehensive set of North American emissions data from the U.S. data set and the FPAC 20-mill study data set would enhance the consistency of emission estimates made in the two countries and would allow use of data that may not otherwise be available to either country. However, synthesis of these two data sets requires an analysis to demonstrate that the two are in fact compatible and that there are no underlying fundamental differences between Canadian and U.S. pulp mill operations that would prohibit combining them.

The comparison for select volatile organic compounds (VOCs) showed that most of the data in the two groups were comparable in that the medians were similar and much of the Canadian data fell within the range for the U.S. data. As such, combining the two data sets into one robust data set makes much sense. Criteria air contaminant emissions from Canadian and U.S. unit operations were also comparable. Trace metal emissions appeared to be similar for comparable unit operations within the two countries. However, limited evidence pointed to somewhat higher emissions of phosphorus and manganese from Canadian unit operations.

Overall, for the substances and process units examined in this report, the Canadian 20-mill study results almost always fell within the range observed in the U.S. data set. Furthermore, the median of the combined data set was usually quite close to the median of the U.S. data set. The data comparison suggests there are no fundamental differences between the Canadian and U.S. emissions data sets that were reviewed for this analysis, and thus supports their combination into one overall data set for these substances.

Ronald A. Yeske

November 2005

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MOT DU PRÉSIDENT

Ce rapport présente une comparaison détaillée entre les données d'émissions générées par les fabriques de pâtes et papiers canadiennes obtenues lors de la récente étude portant sur 20 fabriques, préparée par l'Association des produits forestiers du Canada (APFC) et des données similaires générées par des fabriques américaines depuis la dernière décennie environ. Les auteurs ont inclus dans la comparaison, les émissions de certains composés organiques volatils spécifiques clés (dont le méthanol, l'acétaldéhyde, le méthyléthylcétone et le formaldéhyde) à partir d'un éventail de sources qui se trouvent dans les fabriques de pâtes et papiers. Les sources d'émissions des fabriques canadiennes pris individuellement et leurs médianes sont comparées avec les émissions médianes des sources de fabriques américaines de même type. De plus, les médianes et intervalles de l'ensemble de données canadiennes et américaines sont comparés.

Étant donné que les fabriques de pâtes et papiers canadiennes et américaines utilisent des procédés de production similaires et que plusieurs des méthodes d'échantillonnage des émissions sont presque identiques dans les deux pays, l'assemblage d'un ensemble unique et complet de données d'émissions nord américaines à partir de l'ensemble de données américaines et celui de l'étude portant sur les 20 fabriques de l'APFC permettrait d'améliorer la consistance des estimés d'émissions produits dans les deux pays. Cela permettrait également d'utiliser des données qui autrement pourraient ne pas être disponibles dans un ou l'autre des pays. Toutefois la synthèse de ces deux ensembles de données nécessite une analyse pour démontrer qu'ils sont en fait compatibles et qu'il n'existe pas de différences fondamentales entre les opérations des fabriques de pâtes canadiennes et américaines, différences qui empêcheraient la combinaison des deux ensembles.

La comparaison des composés organiques volatils (COV) retenus a démontré que la plupart des données dans les deux groupes étaient comparables car les médianes étaient similaires et de nombreuses données canadiennes se situaient dans l'intervalle des données américaines. Ainsi, combiner les deux ensembles de données dans un ensemble de données robuste tombe sous le sens. Les émissions des principaux contaminants atmosphériques des opérations unitaires des fabriques canadiennes et américaines étaient également comparables. Les émissions des métaux à l'état de traces semblaient similaires pour les opérations unitaires comparables dans les deux pays. Toutefois, certaines conclusions ont démontré que des émissions de phosphore et de manganèse un peu plus élevées étaient générées par les opérations unitaires canadiennes.

Dans l'ensemble, pour les substances et les unités de procédé examinées dans ce rapport, les résultats de l'étude canadienne portant sur les 20 fabriques se situaient, pour la plupart, toujours dans l'intervalle observé dans l'ensemble de données américaines. De plus, la médiane de l'ensemble de données combinées se trouvait habituellement assez près de la médiane de l'ensemble de données américaines. Cette comparaison de données nous porte à croire qu'il n'y a pas de différences fondamentales entre les ensembles de données d'émission canadiennes et américaines qui ont fait l'objet d'une revue dans cette analyse. Cette observation montre bien que la combinaison de données portant sur ces substances, dans un ensemble global, est adéquate.

Ron Yeske

Ronald A. Yeske

Novembre 2005

A COMPREHENSIVE COMPARISON OF CANADIAN AND U.S. PULP AND PAPER MILL AIR EMISSION DATA

SPECIAL REPORT NO. 05-03
NOVEMBER 2005

ABSTRACT

This report presents a detailed comparison of air emission data generated at Canadian pulp and paper mill facilities during the recent Forest Products Association of Canada's 20-mill study with similar data generated in the U.S. over the past decade or so. Included in the comparison are emissions for certain key speciated volatile organic compounds (including methanol, acetaldehyde, methyl ethyl ketone, and formaldehyde) from a range of pulp and paper mill sources. These sources include vacuum drum type brownstock washers, kraft bleach plants, oxygen delignification systems, direct contact evaporator (DCE) and non-direct contact evaporator (NDCE) kraft recovery furnaces, smelt dissolving tanks, lime kilns, thermomechanical pulping (TMP) and groundwood pulping operations, and paper machines processing mainly mechanical pulp. The individual mill source emissions and their medians for the Canadian mills were compared with median emissions for the corresponding U.S. mill sources and also with the median and range for the combined Canadian-U.S. data sets. Outliers arising from application of statistical treatment procedures to the combined data sets were identified. Besides VOCs, the comparison included criteria air pollutants such as total particulate matter (TPM), PM_{10}, $PM_{2.5}$, CO, SO_2 and NO_x for DCE and NDCE furnaces; total reduced sulphur (TRS) for NDCE furnaces; TPM and TRS for smelt dissolving tanks; TPM, PM_{10}, $PM_{2.5}$, SO_2 and TRS for lime kilns; SO_2, NO_x, CO and TRS for thermal oxidizers; TPM, SO_2 and NO_x for sulphite recovery furnaces; and trace metals for DCE/NDCE recovery furnaces, smelt dissolving tanks and lime kilns.

The comparison for select VOCs showed that most of the data in the two groups were comparable in that the medians were similar and much of the Canadian data fell within the range for the U.S. data. As such, combining the two data sets into one robust data set makes much sense. Criteria air contaminant emissions from Canadian and U.S. unit operations were also comparable. Trace metal emissions appeared to be similar for comparable unit operations within the two countries. However, limited evidence pointed to somewhat higher emissions of phosphorus and manganese from Canadian unit operations. In some cases, the extent of data available either in the U.S. or Canadian data sets was small; thus, a proper comparison could not be made.

KEYWORDS

air emissions, Canada, criteria air contaminants, criteria air pollutants, groundwood, kraft, median, outlier, range, sulfite, sulphite, thermo-mechanical pulping, trace metals, TRS, unit operations, U.S., VOCs

RELATED NCASI PUBLICATIONS

Technical Bulletin No. 884 (2004). *Compilation of criteria air pollutant emissions data for sources at pulp and paper mills including boilers.*

Technical Bulletin No. 858 (2003). *Compilation of 'air toxic' and total hydrocarbon emissions data for sources at kraft, sulphite and non-chemical pulp mills – An update.*

Technical Bulletin No. 849 (2002). *Compilation of speciated reduced sulfur compound and total reduced sulfur emissions data for kraft mill sources*.

NCASI methods manual. 1999.

UNE COMPARAISON DÉTAILLÉE DES DONNÉES D'ÉMISSIONS DE FABRIQUES DE PÂTES ET PAPIERS CANADIENNES ET AMÉRICAINES

RAPPORT SPÉCIAL NO.05-03
NOVEMBRE 2005

RÉSUMÉ

Ce rapport présente une comparaison détaillée entre les données d'émissions générées par les fabriques de pâtes et papiers canadiennes obtenues lors de la récente étude portant sur 20 fabriques, préparée par l'Association des produits forestiers du Canada (APFC) et des données similaires générées par des fabriques américaines depuis la dernière décennie environ. Les auteurs ont inclus dans la comparaison, les émissions de certains composés organiques volatils spécifiques (dont le méthanol, l'acétaldéhyde, le méthyléthylcétone et le formaldéhyde) à partir d'un éventail de sources qui se trouvent dans les fabriques de pâtes et papiers. Les sources à l'étude sont les suivantes : les piles laveuses de pâte écrue, les usines de blanchiment de pâte kraft, les systèmes de délignification à l'oxygène, chaudières de récupération kraft avec évaporateur à contact direct (DCE) et avec évaporateur à contact indirect (NDCE), les réservoirs de dissolution, les fours à chaux, les procédés de réduction en pâte par voie thermomécanique (PTM) et par voie mécanique de même que les machines à papier traitant la pâte mécanique principalement. Les sources d'émissions des fabriques canadiennes pris individuellement et leurs médianes sont comparées avec les émissions médianes des sources de fabriques américaines de même type. De plus, les médianes et intervalles de l'ensemble de données canadiennes et américaines sont comparés. On a identifié les valeurs aberrantes qui surviennent suite à l'application des procédures de traitement statistique sur les ensembles de données combinées. En plus des COV, la comparaison incluait les principaux contaminants atmosphériques, tels que les particules totales (TPM), les PM_{10}, les $PM_{2,5}$, le CO, le SO_2 et les NO_x pour les chaudières DCE et NDCE, les composés de soufre réduit totaux (SRT) pour les chaudières NDCE, les TPM et les SRT pour les réservoirs de dissolution, les TPM, PM_{10}, $PM_{2,5}$, le SO_2 et les SRT pour les fours à chaux, le SO_2, les NO_x, le CO et les SRT pour les systèmes d'oxydation thermique, les TPM, le SO_2 et les NO_x pour les chaudières de récupération du bisulfite et les métaux à l'état de traces pour les chaudières DCE/NDCE, les réservoirs de dissolution et les fours à chaux.

La comparaison des COV retenus a démontré que la plupart des données dans les deux groupes étaient comparables car les médianes étaient similaires et de nombreuses données canadiennes se situaient dans l'intervalle des données américaines. Ainsi, combiner les deux ensembles de données dans un ensemble de données robuste tombe sous le sens. Les émissions des principaux contaminants atmosphériques des opérations unitaires des fabriques canadiennes et américaines étaient également comparables. Les émissions des métaux à l'état de traces semblaient similaires pour les opérations unitaires comparables dans les deux pays. Toutefois, certaines conclusions ont démontré que des émissions de phosphore et de manganèse un peu plus élevées étaient générées par les opérations unitaires canadiennes. Dans certains cas, le nombre de données disponibles dans un ou l'autre des ensembles de données américaines ou canadiennes était petit, ce qui empêchait les auteurs d'effectuer une comparaison acceptable.

MOTS CLÉS

Émissions atmosphériques, Canada, principaux contaminants atmosphériques, pâte mécanique, kraft, médiane, valeur aberrante, intervalle, bisulfite, mise en pâte par voie thermomécanique, métaux à l'état de traces, SRT, opérations unitaires, États-Unis, COV

AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

Bulletin technique no. 884 (2004). *Compilation of criteria air pollutant emissions data for sources at pulp and paper mills including boilers.*

Bulletin technique no. 858 (2003). *Compilation of 'air toxic' and total hydrocarbon emissions data for sources at kraft, sulphite and non-chemical pulp mills – An update.*

Bulletin technique no. 849 (2002). *Compilation of speciated reduced sulfur compound and total reduced sulfur emissions data for kraft mill sources*.

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CONTENTS

APPENDICES

FIGURES

A COMPREHENSIVE COMPARISON OF CANADIAN AND U.S. PULP AND PAPER MILL AIR EMISSION DATA

1.0 INTRODUCTION

Over the past two decades, pulp and paper mills in the U.S. generated a significant amount of emission data that included several so-called air toxics, many of which were designated as Hazardous Air Pollutants (HAPs) in the 1990 Clean Air Act Amendments. These data were typically obtained to address Environmental Protection Agency rulemaking initiatives. For example, during the mid-1990s, the U.S. EPA was developing its MACT (Maximum Allowable Control Technology) regulations for the pulp and paper industry and a significant amount of air emissions testing was carried out by NCASI and individual companies to help formulate these regulations. Emission testing for reduced sulphur compounds and criteria air contaminants (CACs) such as carbon monoxide, oxides of nitrogen, particulate matter (total, PM_{10}, and $PM_{2.5}$), and sulphur dioxide is routinely conducted by many U.S. pulp and paper mills. Often companies will share these results with NCASI for use in developing emission factors.

During 2001 and 2002, the Forest Products Association of Canada (FPAC), in consultation with Environment Canada (EC), coordinated a comprehensive emission testing program at 20 Canadian pulp and paper mills. The FPAC 20-mill study included testing for close to 40 organic compounds, 36 metals, reduced sulphur compounds, and various CACs. In 2003, a series of four reports (FPAC 2003a, 2003b, 2003c, 2003d) were prepared for the Environment Section of FPAC. The first report was an overall summary outlining objectives, scope, validity and application of results, compilation of results, and recommendations (FPAC 2003a). The second included brief summaries of mills and sources tested and data obtained at each mill site (FPAC 2003b). The third was comprised of a Quality Assurance Program Plan followed for this study (FPAC 2003c). The fourth dealt with a brief analysis of the unvalidated data from 4 of the 20 mills involved (FPAC 2003d).

NCASI recently completed a detailed quality assurance and quality control (QA/QC) analysis of most of the speciated VOC data generated during the FPAC 20-mill study. The sampling was conducted according to an NCASI method for speciated VOC measurement (IM/CAN/WP-99.01) (NCASI 1999). A final report was submitted to FPAC in May of 2005 (NCASI 2005a). This report included a summary of the CAC and reduced sulphur compound (RSC) data generated during the FPAC study, and presented brief comparisons of the speciated VOC, CAC and RSC emission data generated in the FPAC study with similar data existing in NCASI's database for primarily U.S. pulp and paper mills.

From time to time, questions arise as to whether emissions of various air toxics, CACs, and RSCs from similarly designed pulp and paper mill operations in Canada and the U.S. are comparable in magnitude. The questions arise due to a) differences in geography that affect available wood species and sources of water at a mill, b) potential differences in pulping and papermaking operations, c) differences in emission control technologies, and d) differences in test methods used for air emissions measurement in the two countries.

Conventional wisdom suggests that the source of water would have no impact on pulp mill air toxic emissions per se since the natural river or underground waters used by mills have very little organics and/or trace metals in them. The type of wood species used to make pulp would perhaps be expected to affect generation of certain terpene-like compounds, especially during delignification of wood and subsequent washing of the pulp. However, actual emissions of these terpene-like compounds are governed by other factors.

In chemical pulping and recovery operations (kraft, sulphite, semi-chemical), the gases generated from delignification are made to pass through condensers and blow tanks, and the uncondensed gases, called noncondensible gases or NCGs, are normally incinerated or scrubbed, leading to minimal atmospheric emissions. For the more oxygenated and non-terpene-like compounds such as methanol, formaldehyde, acetaldehyde, methyl ethyl ketone, etc., the amount formed during delignification and recovery is not related to wood species, with the possible exception of methanol. There is limited evidence that hardwoods produce more methanol than softwoods for an equivalent grade of pulp. However, the differences between the type of pulp being produced, namely bleached, linerboard-grade unbleached, or bleachable grade unbleached, have a much more pronounced effect on methanol generation (Zhu et al. 2000). Historically, the air emissions of non-terpene-like compounds from pulp washing, bleaching, papermaking, and chemical recovery operations have been known to be related to either the level of these compounds in water used in such operations, or to reactions between the cooking or bleaching chemicals with the wood lignin, or to the effect of heat during combustion of the spent chemical liquor and regeneration of lime, or to subsequent regeneration of cooking chemicals from the smelt and reburned lime.

In mechanical pulping operations, the NCGs are typically vented to the atmosphere; thus, any terpene-like compounds generated during pulping can be emitted. The non-terpene-like compounds are generally expected to be present only in very small quantities in NCGs vented from mechanical pulping operations, since these type of compounds are generated mainly from chemical reactions with the lignin and not from simple applications of heat and/or pressure during pulping.

Processes used to make pulp and paper products and technologies used to control air emissions from these processes are generally believed to be similar in Canada and the U.S. However, emissions may not always be similar because regulations governing the emissions of various compounds are not identical in the two countries. For example, kraft recovery furnaces may be operated differently in the U.S. and Canada relative to how the liquor and combustion air distribution systems are designed with respect to minimizing certain pollutants like TRS, SO_2, and NO_x.

A difference in the measurement method used to sample for the speciated organics in process vents at U.S. and Canadian pulp mills does, however, exist. The NCASI Method (IM/CAN/WP-99.01) used in the FPAC 20-mill study was previously used by NCASI only for organic emissions testing at wood products mills. It uses a set of impingers to first collect up to nine water soluble organic compounds including methanol, 2-butanone (MEK), acetaldehyde, and formaldehyde and then capture the undissolved water soluble and insoluble compounds (such as benzene, toluene, and terpenes) in a canister. The water from the impingers is analyzed by direct injection into a gas chromatograph equipped with a flame ionization detector (GC/FID). For terpenes, a gas sample from the canister is injected into a GC/FID for analysis. For all other organic compounds, another gas sample is passed through a cryogenic preconcentrator and then injected into a gas chromatograph equipped with a mass selective detector (GC/MSD).

In contrast, most of the organic emissions testing at pulp and paper mills in the U.S. was carried out using either the heated canister method or the dilution probe/ambient temperature canister method, both different from NCASI Method IM/CAN/WP-99.01. In the heated canister method, sample gases are collected in heated canisters and the gases are then analyzed on a GC/FID using either a whole gas sample or cryogenically concentrated sample (NCASI 2003a). A mass selective detector is used occasionally to confirm the compounds identified from gas chromatographic analysis. In the dilution probe/ambient temperature canister method, an in-stack dilution probe is used to bring the stack gas moisture content below the dew point at ambient temperature. The diluted gas is collected in a stainless steel container, cryogenically preconcentrated, and analyzed on a GC/mass spectrometer (GC/MS) for speciation and GC/FID for total VOC analysis.

If the U.S. (NCASI) and Canadian (FPAC) data sets were found to be comparable, it would make sense to combine them to obtain a single set that would be more robust than either of the two individually. Also, once a case is made that similar emissions are expected from similar unit operations in the two countries, there is an obvious advantage to using data obtained in one country for a given unit operation in the second country, when such data do not exist for that particular operation in the second country. This report, therefore, examines in some detail the comparability of speciated VOC, CAC, RSC and trace metal emissions from a range of Canadian and U.S. pulp and paper mill unit operations.

2.0 SCOPE

The comparison of the Canadian data set to the U.S. data set involved several steps. First, for speciated VOCs, the individual and average source emissions for the Canadian mills were compared with either individual or average emissions for similar sources tested in the U.S. Next, for speciated VOCs, the emissions for the Canadian mills were compared with the average and range (minimum and maximum) of source emissions for the combined U.S.-Canada data set. For CACs, the individual source emissions for the Canadian mills were compared with either individual or average emissions for similar sources in the U.S. When comparing population averages, either the median or the mean may be used. The median was chosen for comparing speciated VOCs and CACs since it is known to be relatively unaffected by data in the extremes (high and low). The median of the combined data set was obtained after the data set was subject to statistical data treatment procedures. These procedures rejected two types of data: a) data deemed to be “outliers,” and b) data corresponding to non-detects (NDs) with detection limits (DLs) greater than twice the highest detected observation. Similar procedures were applied to the large body of data for U.S. mills (NCASI 2003a). The outliers among the individual source emissions for the Canadian mills are identified in the current report. When comparing trace metal emissions from kraft recovery sources, the mean value for the Canadian units was compared with the maximum, minimum and mean for the U.S. units, since the number of Canadian units tested was typically small.

When considering the combined data sets it could also happen that certain data points for the U.S. mills, which were previously excluded for one of the two reasons given above, could now be included in the combined set as the original reasons become invalid. It should be noted that these exclusions or inclusions have no bearing on the validity of the specific mill’s emission data that were either excluded or included. Rather, they are statistical outcomes of data treatment procedures designed to yield population averages that are unaffected by outliers or NDs with inappropriately high DLs. The individual mill data may indeed be valid for other non-comparative purposes, such as for estimating the particular mill’s own emissions.

Certain data generated during the FPAC study are not included in this comparison. These include: a) CAC and air toxic emissions from boilers; b) emissions from fugitive sources such as wastewater treatment plants (WWTPs) and wood residue piles; c) emissions from wood residue transport systems and other miscellaneous sources; d) limited emissions for dioxins and furans (PCDD/Fs) and polycyclic aromatic hydrocarbons (PAHs); and e) limited emissions for other air toxics such as sulphuric acid, hydrochloric acid, and ammonia.

Emissions from boilers were not included in the comparison since most pulp mill boilers fire more than one fuel and, as such, the CAC and air toxic emissions from such boilers would be boiler-specific and incapable of being lumped into one category for comparison. For boilers firing 100% coal, fuel oil, or natural gas, NCASI generally relies on EPA’s AP-42 emission factor document (USEPA 1998) for obtaining estimates of average CAC and air toxic emissions. For 100% wood combustion, emissions summarized in NCASI reports (NCASI 2003a, 2004a), which represent a combination of data available in EPA's AP-42 background documents and NCASI's own database for wood combustion, after being subject to appropriate data treatment procedures to identify outliers and high NDs, were used. NCASI has no field test data on fugitive air emissions from WWTPs and bark/chip storage piles; thus, a comparison is not feasible. However, NCASI also has serious reservations with the measurement techniques used, including those in the FPAC study, for estimating emissions from such sources. Emissions from wood transport cyclones and several other miscellaneous source vents measured in the FPAC study are not available for similar U.S. sources; thus, a comparison cannot be made. The emissions of PCDD/Fs, PAHs, H_2SO_4, HCl and NH_3 from select sources in the FPAC study are not compared with U.S. data from similar sources as they are too sparse relative to the data available elsewhere in NCASI reports and published literature.

3.0 SUMMARY OF FPAC 20-MILL STUDY DATA

As previously mentioned, NCASI conducted a rigorous QA/QC evaluation of the speciated VOC emission data generated during the 20-mill FPAC study and the resulting quality assured data were summarized in a report submitted to FPAC (NCASI 2005a). There were several reservations expressed in that report with regard to the quality of a significant fraction of the data that NCASI originally received for the QA/QC evaluation. They included the following: a) inadequate run spike recoveries; b) frequent exceedances in sample storage times (prior to analysis) beyond that specified in the sampling method; c) lack of train spikes and field duplicates; d) inconsistent sampling times for the impinger and canister portions of the sampling train; e) unusually high detection limits for impinger samples taken at a majority of the mills; and f) assuming zero value for all non-detect (ND) concentrations when estimating total source vent concentrations and emission rates.

The first four reservations (a through d) were not rectified in the QA/QC evaluation. The fifth reservation, unusually high detection limits (DLs) for impinger samples used in several mill reports, was rectified by replacing with lower DLs comparable to work done by NCASI in the U.S. using this method, after additional information was provided by the Canadian laboratories that undertook the analyses. Finally, instead of assuming zero values for all NDs, the lowered DLs for impinger samples were applied to estimate emissions for sources with single or multiple vents using ½ DL.

In the end, much of the data were deemed suitable for the purposes of being subject to the final screening step by NCASI. This step involved the application of rigorous statistical treatment procedures to the data, similar to that done to a much larger set of similar data for U.S. pulp and paper mills and published in NCASI Technical Bulletin No. 858 (NCASI 2003a). In the case of most sources tested, this final screening step was applied after combining the Canadian data with comparable U.S. data, when the latter were available. In some instances, since only Canadian sources were tested, these data alone were subject to the screening analysis. In simple terms, the data treatment procedures developed by NCASI include the following: a) rejection of ND data when the detection limit was greater than twice the highest detected concentration for a given source; b) rejection of statistical outliers based upon application of either the Dixon or Rosner's test for determining outliers (USEPA 2000); c) determination of the "trimmed mean" in the case of data sets with between 15% and 50% NDs (USEPA 2000); and d) application of the NORPLOT or SDln methods for determination of statistically-derived medians of "heavily censored" data sets, i.e., data sets with greater than 50% NDs (NCASI 2003a).

Tables A1 to A5 of Appendix A summarize all the speciated VOC emission data generated for pulp and paper mill operations during the 20-mill FPAC study. A total of 36 organic compounds or categories of organic compounds are listed in these tables. These include the eight water-soluble compounds captured predominantly in the impinger portion of the NCASI sampling train, namely acetaldehyde, acrolein, 2-butanone (methyl ethyl ketone), formaldehyde, methanol, methyl isobutyl ketone, phenol, and propionaldehyde.

Table A1 summarizes the speciated VOC emissions from several major kraft pulp mill sources, including black liquor oxidation systems, bleach plants, vacuum drum type and diffusion type brownstock washers, deckers, deknotters, lime kilns, thermal oxidizers, oxygen delignification systems, bleached paper machines and pulp dryers, DCE and non-DCE recovery furnaces, slakers, causticizers, and smelt dissolving tanks. Table A2 summarizes speciated VOC emissions from several miscellaneous kraft pulp mill sources, including weak and strong black liquor storage tanks, mud filter hood exhausts, dregs filter hood exhausts, Kamyr chip bins, sludge press and blend tanks, and miscellaneous waste treatment system vents. Table A3 summarizes the speciated VOC emissions from sulphite pulp mill sources, including recovery furnaces, pulping and recovery area sources and bleach plants. Table A4 summarizes the speciated VOC emissions from several non-chemical pulp mill sources, including thermomechanical, groundwood and deinking pulping area sources, virgin mechanical and chemical pulp furnish paper machines, and a BCTMP pulp dryer. Finally, Table A5 summarizes the speciated VOC emissions from several miscellaneous pulp mill sources, including cooling towers, ClO_2 generator scrubbers, and chip/bark handling systems and fugitive emission fluxes from chip and bark piles.

Several wastewater treatment plant (WWTP) sources were tested during the 20-mill FPAC study. However, NCASI has serious concerns regarding the methods employed in obtaining estimates for area sources, especially pulp mill WWTP area sources that are designed to have a high degree of turbulence in parts of the system. As such, these emissions were not subject to a QA/QC analysis by NCASI and are therefore not reproduced here.

Table B1 in Appendix B summarizes most of the criteria air contaminant (CAC) emission data generated for various combustion and non-combustion sources during the 20-mill FPAC study. In most cases, standard measurement methods were utilized for measurement of the CACs, methods that have been validated either in the U.S. or in Canada. The unit operations tested included boilers burning coal, oil, gas and wood residues exclusively, combination wood-oil, wood-gas, wood-coal, and wood-sludge boilers, one thermal oxidizer burning concentrated NCGs, DCE and non-DCE recovery furnaces, smelt dissolving tanks, lime kilns and sulphite recovery furnaces. These data were combined with pre-existing CAC data in NCASI's database and the combined data summarized in NCASI Technical Bulletin No. 884 (NCASI 2004a). It should be noted, however, that for estimating emissions of CACs from boilers, NCASI generally prefers to use the data provided in EPA's AP-42 Emission Factor documents for coal, oil and gas combustion, and a combination of EPA's AP-42 document and NCASI's own database for wood and wood residue combustion. This is because NCASI considers the significantly larger fossil fuel combustion database within AP-42 as an appropriate source for these emission factors. This is not the case for emissions from other pulp and paper industry-related operations, including wood and wood residue combustion, where NCASI's database is more reflective of the emissions from pulp and paper mill operations. This approach is, for example, adopted by NCASI in the *NPRI Handbook for Pulp and Paper Facilities* for estimating generic boiler CAC emissions.

Table C1 in Appendix C summarizes all the reduced sulphur compound and total reduced sulphur (TRS) emission data generated for various combustion and non-combustion sources during the 20-mill FPAC study. The unit operations tested included one bleach plant, one brownstock washing system, five lime kilns, three non-contact recovery furnaces, four smelt dissolving tanks, one strong black liquor storage tank, one tall oil scrubber, one thermal oxidizer, one chip bin, two causticizing units, and one lime slaker. Just as for speciated VOCs, for reasons outlined above, the WWTP source emissions of reduced sulphur compounds and TRS are not included here.

Tables D1 through D4 in Appendix D summarize trace and heavy metal emissions generated for various combustion sources during the 20-mill FPAC study. The sources include two direct contact evaporator (DCE) and three non-direct contact evaporator (NDCE) kraft recovery furnaces, five smelt dissolving tanks, and three lime kilns [one with an electrostatic precipitator (ESP) and two with wet scrubbers].

4.0 COMPARISON OF FPAC 20-MILL STUDY DATA WITH U.S. DATA

NCASI Technical Bulletin No. 858 (NCASI 2003a) summarizes emissions of various air toxics, including speciated VOCs and trace metals from most unit operations at kraft, sulphite and non-chemical pulp mills in the United States. NCASI Technical Bulletin No. 849 (NCASI 2002a) summarizes emissions of speciated reduced sulphur compounds and TRS from various unit operations at kraft pulp mills in the United States. Finally, NCASI Technical Bulletin No. 884 (NCASI 2004a) summarizes emissions of various criteria air pollutants, including carbon monoxide, oxides of nitrogen (NO_x), particulate matter (total, PM_{10}, and $PM_{2.5}$), and sulphur dioxide (SO_2), from most relevant unit operations including boilers at pulp and paper mills in the United States. In this section, much of the data generated during the 20-mill FPAC study are compared with those presented in the NCASI reports which comprise essentially all U.S. data. The comparison is first made for speciated VOCs, then for CACs, then for reduced sulphur compounds, and finally for certain trace metals.

It should be noted that in most cases for air emission data generated during the 20-mill FPAC study, attendant process information that could have shed further light as to why certain emissions were high or low was not available. Such process information typically includes factors such as a) a description of operations during the time of testing (whether normal or not), b) the quality of the wash or process water used in a given operation (e.g., clean or dirty condensate), and c) detailed process flow diagrams to show how the operation was configured with respect to other operations, etc. Thus the following comparison necessarily focuses on the magnitude of the averages in the two data sets and not on why certain source emissions were high or low.

4.1 Comparison of FPAC 20-Mill Study Data with U.S. Data – Speciated VOCs

This section compares certain key speciated VOC emissions measured during the FPAC 20-mill study for a given unit operation with averages reported in NCASI Technical Bulletin No. 858 (NCASI 2003a) for the same unit operation in the U.S. The individual source and median emissions for the Canadian mills are compared with individual or median emissions for the U.S. sources. Further, the Canadian and U.S. data are compared with range and median emissions for the combined U.S. and Canadian data sets. ***It should be noted that often, applying the statistical outlier test to the combined data set may result in greater or fewer data points in the combined set compared with the sum of data points in the two individual data sets. The number of data points in the combined set is greater when certain data points in the U.S. data set that were earlier rejected from average determinations now become included in the combined data set. They become fewer when certain data points in the FPAC data set get rejected from the combined data set. These rejections come from applying the data treatment procedures to the data which include the identification of statistical outliers and "non-detects with detection limits greater than twice the highest detected observation."*** In other words, if the Canadian data set had 5 data points, and the U.S. data set had 21 data points, the combined set need not have 5 + 21 (i.e., 26) data points. It could be lower or greater than 26.

4.1.1 *Kraft Vacuum Drum Brownstock Washers*

Brownstock washing systems emit gases containing reduced sulphur compounds and VOCs, including methanol, acetaldehyde, and MEK. The emissions from different types of washers depend on the vent gas flow rate, quality of shower water and liquor properties. For vacuum drum type brownstock washers (VDWs), the quality of the last stage shower water is likely the key factor in determining methanol emissions (NCASI 2003a). No information was available on the last stage shower water for the FPAC testing. Vacuum drum washer systems have the highest air flow rates and highest emissions. Emissions from other types of washer systems are generally much lower, mainly due to the low gas flow rates. Pressurized washing systems only emit gases from their filtrate tanks.

Acetaldehyde, 2-butanone (MEK), formaldehyde, methanol, and propionaldehyde are five VOCs emitted from kraft VDWs that are frequently tested for. Figure 4.1 compares the median and individual acetaldehyde emissions for seven Canadian kraft mill VDWs (all 7 detects) with the median emissions for 20 such U.S. washers (19 detects). The Canadian washer emissions are also compared with median and range of acetaldehyde emissions for the combined set of 27 washers (26 detects). As seen in Figure 4.1, the median for acetaldehyde emissions from the seven Canadian washers was somewhat smaller than the median for emissions from the 20 U.S. washers. However, the Canadian data fell within the range of the U.S. data, implying the two data sets were quite comparable.

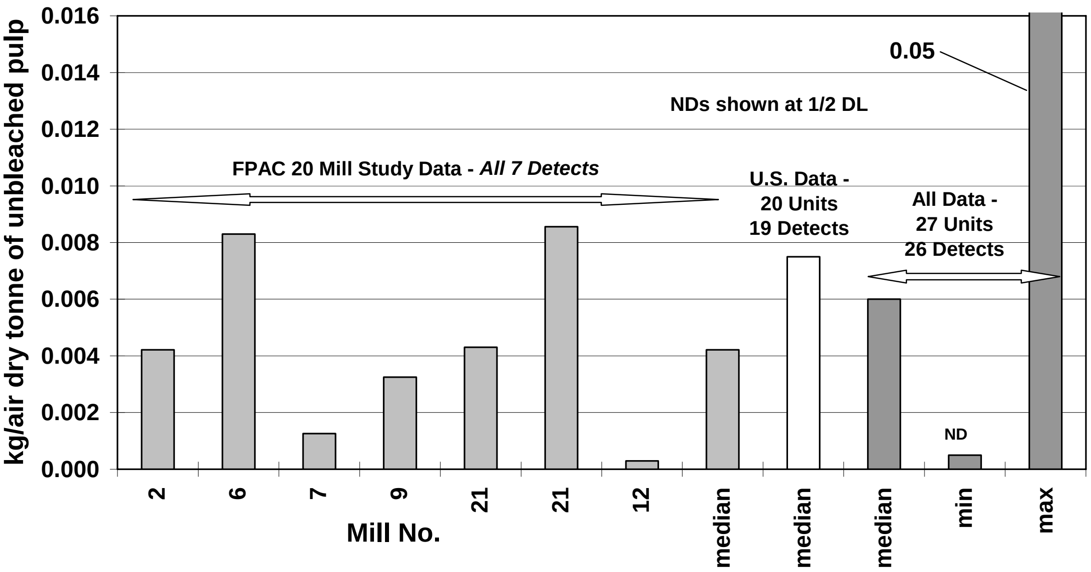


Figure 4.1 Comparison of Acetaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill Vacuum Drum Brownstock Washers

Figure 4.2 compares the median and individual 2-butanone (MEK) emissions for seven Canadian kraft mill VDWs (5 detects) with the median emissions for 29 such U.S. washers (20 detects). The Canadian washer emissions are also compared with median and range of MEK emissions for the combined set of 36 washers (25 detects). Once again, Figure 4.2 shows that the median MEK emissions for the seven Canadian washers were somewhat lower than the median emissions for 29 U.S. washers, but the Canadian data fell well within the range of the data for the U.S. washers, implying the two data sets were quite comparable.

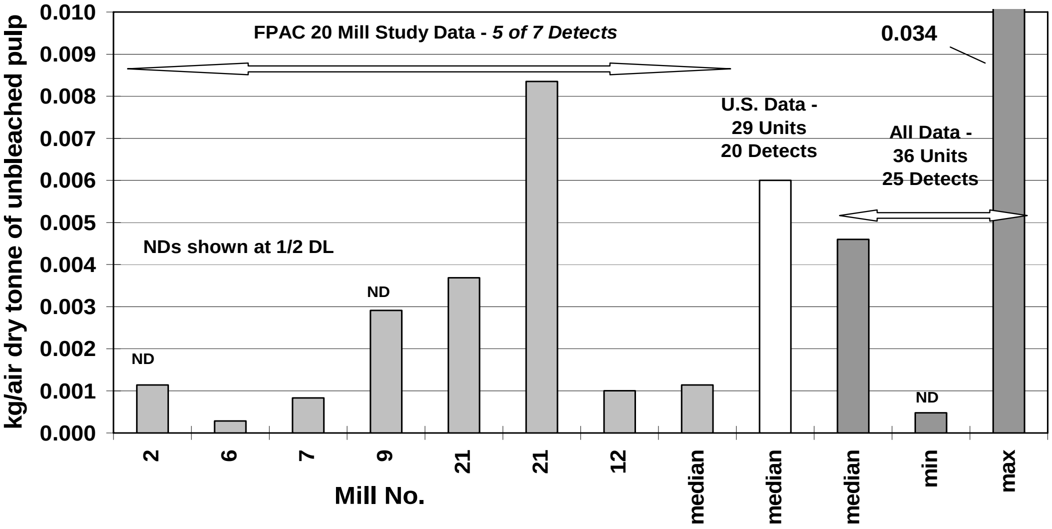


Figure 4.2 Comparison of 2-Butanone (MEK) Emissions from Canadian and U.S. Kraft Pulp Mill Vacuum Drum Brownstock Washers

Figure 4.3 compares the median and individual formaldehyde emissions for seven Canadian kraft mill VDWs (4 detects) with the median emissions for 13 such U.S. washers (10 detects). The Canadian washer emissions are also compared with median and range of formaldehyde (HCHO) emissions for the combined set, which now has 21 washers (15 detects). One measurement in the U.S. data set of 0.0105 kg/ADTUBP, considered earlier to be an outlier, is now included in the combined data set after it was determined it was not an outlier any more. As seen in Figure 4.3, the Mill 6 Canadian washer had the highest HCHO emissions of 0.015 kg/ADTUBP among all 21 washers in the combined set, nearly 43% higher than the highest U.S. emission. The reason for this is unclear. However, this did not appear to affect the median emissions for both the Canadian and combined data sets, which are comparable. The rest of the Canadian washer emissions generally fall within the range for the U.S. washers. Some of the U.S. measurement tests (those conducted by NCASI) and all of the Canadian measurement tests for HCHO utilized an impinger method with colorimetric analysis of the reaction product between HCHO and acetylacetone. Other tests conducted in the U.S. for HCHO utilized the "RTI Draft Method for Aldehydes and Ketones." In this method, the HCHO is captured in impingers containing 2,4-dinitrophenylhydrazine (DNPH) in acidified acetonitrile and analyzed on a high performance liquid chromatograph (HPLC) equipped with an ultraviolet detector.

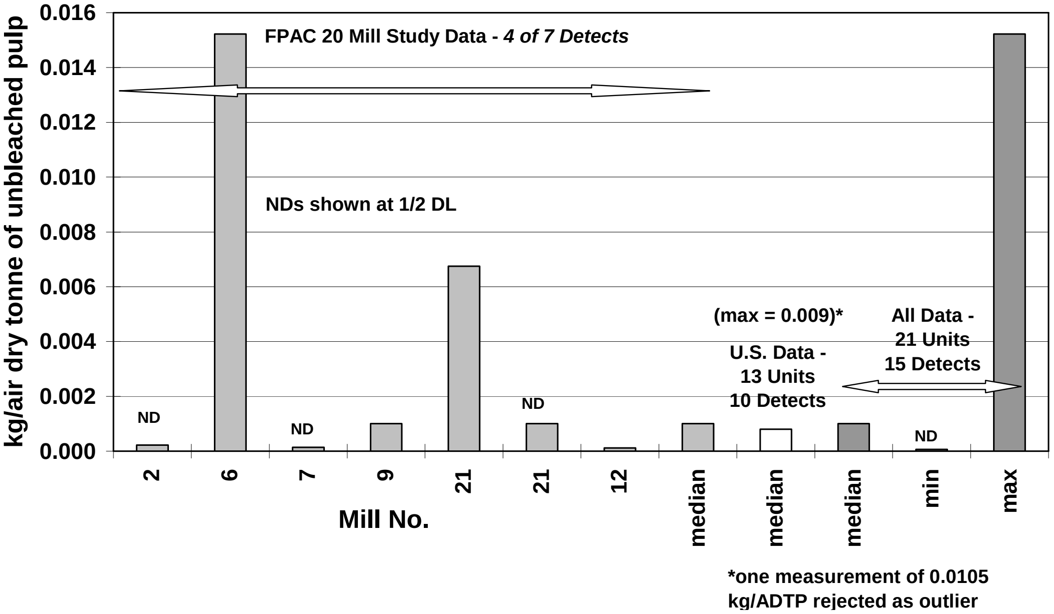


Figure 4.3 Comparison of Formaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill Vacuum Drum Brownstock Washers

Figure 4.4 compares the median and individual methanol emissions for seven Canadian kraft mill VDWs (all 7 detects) with the median emissions for 32 such U.S. washers (all 32 detects). The Canadian washer emissions are also compared with median and range of methanol emissions for the combined set, which has 38 washers (all detects). The Mill 6 Canadian washer had rather high methanol emissions (1.85 kg/ADTUBP) compared with the rest, which for the purposes of determining averages of the combined data set, was rejected based upon application of the Rosner test for statistical outliers (NCASI 2003a). A similar high methanol emission rate (2.1 kg/ADTUBP) was rejected as an outlier from the U.S. data set. Note that both data points had little to no impact on the median emissions. However, they may have been valid measurements and are identified here as outliers for informational purposes only. As seen in Figure 4.4, based on the median and range for kraft mill VDW methanol emissions, the two data sets are quite comparable.

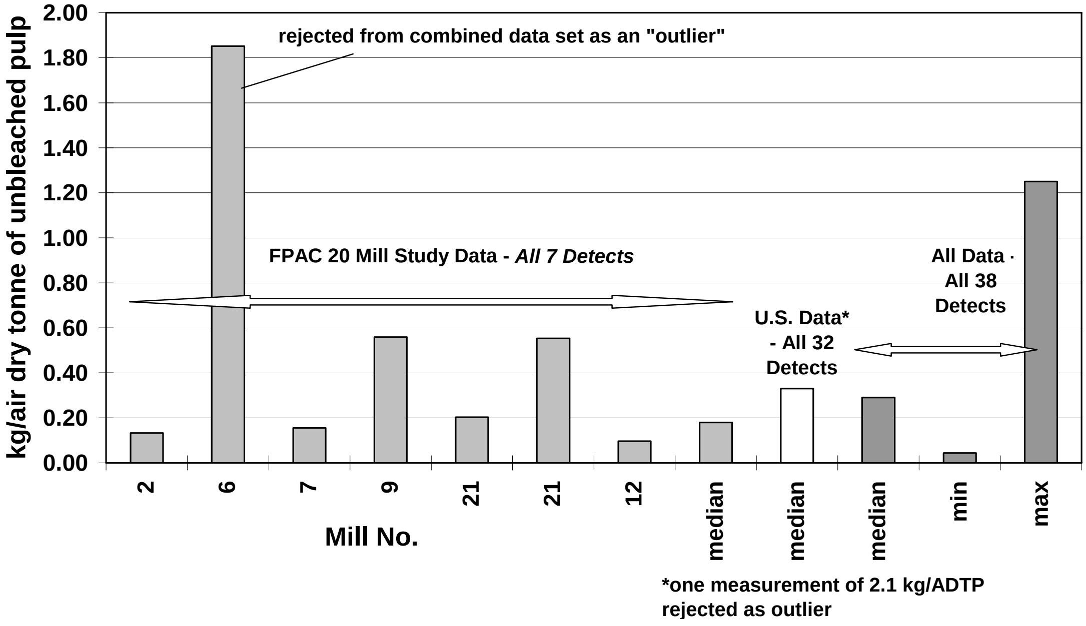


Figure 4.4 Comparison of Methanol Emissions from Canadian and U.S. Kraft Pulp Mill Vacuum Drum Brownstock Washers

Finally, Figure 4. 5 compares the median and individual propionaldehyde emissions for seven Canadian kraft mill VDWs (all 7 detects) with the median emissions for seven such U.S. washers (5 detects). The Canadian washer emissions are also compared with median and range of propionaldehyde emissions for the combined set, which has 13 washers. Propionaldehyde emissions from one of two washers at Mill 21 were non-detect with half the detection limit (DL) being greater than the highest detected concentration among all washers. This data point was rejected before estimating averages for the combined data set. As seen in Figure 4.5, the two data sets are quite comparable for propionaldehyde emissions.

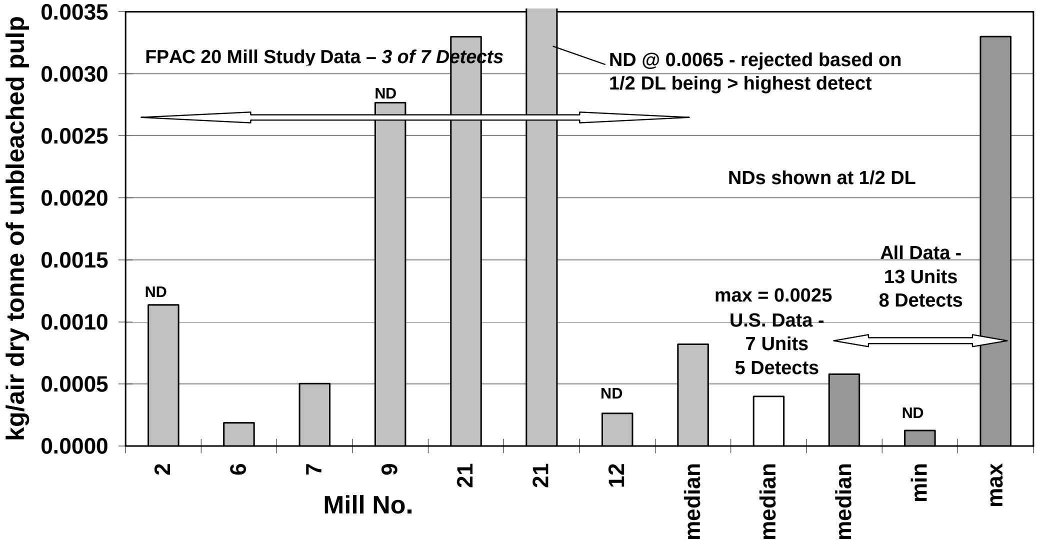


Figure 4.5 Comparison of Propionaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill Vacuum Drum Brownstock Washers

Summary for Kraft Vacuum Drum Brownstock Washers – Based on a comparison of median and range emissions for five key VOCs (including methanol)from kraft mill vacuum drum washers, it would appear that the Canadian and U.S. data sets are reasonably comparable to each other so that they could be effectively combined to yield one robust data set.

4.1.2 *Kraft Pulp Mill Bleach Plants*

The composition and quantity of emissions from bleaching operations are affected by the bleach plant configuration and operating conditions. Factors such as chemical usage, bleaching stage temperature, pH, type of pulp washer, efficiency of pulp washing between stages can affect emissions. Chlorine and chlorine dioxide emissions are normally controlled by vent gas scrubbers, although uncontrolled emissions can be reduced through various process controls and manipulation of operating conditions. Formation of other compounds of environmental concern generated in kraft pulp bleaching (e.g., chloroform) are also minimized by implementation of various pulp mill or bleach plant operating practices rather than end-of-pipe control devices. Only trace quantities of speciated organics are emitted by kraft bleach plants. Chlorine dioxide and carbon monoxide are now the substances of most interest for bleach plants that employ 100% ClO_2 substitution.

Regarding VOCs, acetaldehyde, 2-butanone (MEK), chloroform, formaldehyde, and methanol are the five most frequently tested for compounds at kraft mill bleach plants. Prior to MACT implementation in the U.S., an NCASI survey of organic HAP emissions from kraft bleach plants showed that methanol and chloroform comprised over 90% of the total HAPs measured. With widespread implementation of ECF bleaching (100% ClO_2 substitution), the emissions of chloroform have dropped to very low levels. Emissions of methanol and other organics following bleach plant scrubbers depend on the concentrations in the scrubbing solution used in the scrubbers, and also the level of these organics carried forward to the bleach plant from the brownstock washing operations.

Figure 4.6 compares the median and individual acetaldehyde emissions for six Canadian kraft mill bleach plants (all 6 detects) with median emissions for 32 such U.S. bleach plants (24 detects). The Canadian bleach plant emissions are also compared with median and range of acetaldehyde emissions for the combined set of 37 bleach plants (29 detects). One measurement in the U.S. data set of 0.008 kg/ADTBP was determined to be an outlier when the two data sets were combined. It is seen from Figure 4.6 that the two data sets are very much comparable.

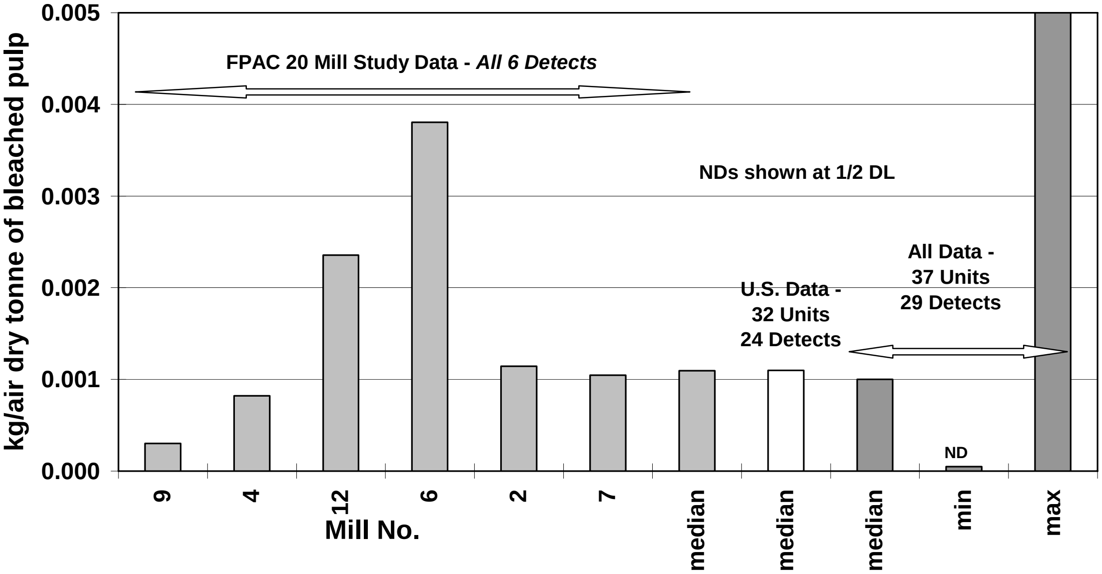


Figure 4.6 Comparison of Acetaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill Bleach Plants

Figure 4.7 compares the median and individual 2-butanone (MEK) emissions for six Canadian kraft mill bleach plants (all 6 non-detects) with median emissions for 43 such U.S. bleach plants (23 detects). The Canadian bleach plant emissions are also compared with median and range of MEK emissions for the combined set, which now has 51 bleach plants (24 detects). MEK emissions from two bleach plants, rejected earlier in the U.S. data set, are now included in the combined set. As seen in Figure 4.7, the two data sets are quite comparable, although all measurements in the Canadian set were NDs which makes any comparison difficult. However, it is also seen that the combined data set has a much lower median than the median for the U.S. data set. This is so since the combined data set had >50% NDs (highly "censored"), while the U.S. data set had less than 50% NDs. Special techniques, such as the Multiple-Limit Regression on Order Statistics (MLROS) technique (Helsel and Cohn 1988), are generally used to obtain averages of highly censored data sets. These techniques invariably result in much lower population averages than those that derive averages arithmetically (which, however, require less than 50% NDs).

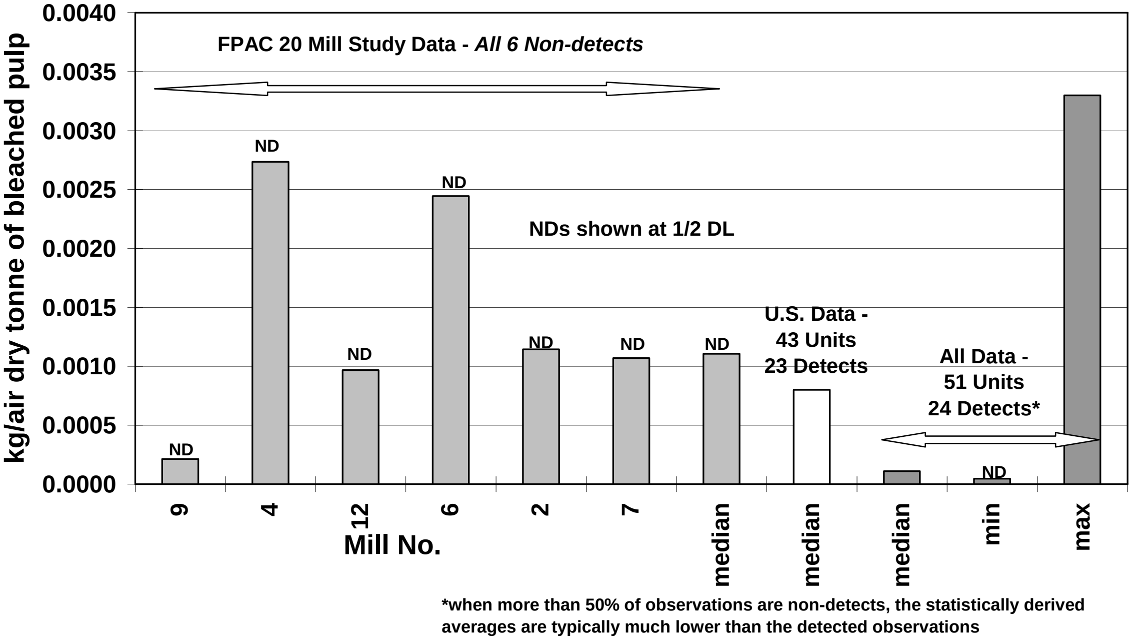


Figure 4.7 Comparison of 2-Butanone (MEK) Emissions from Canadian and U.S. Kraft Pulp Mill Bleach Plants

Figure 4.8 compares the median and individual chloroform emissions for six Canadian kraft mill bleach plants (all 6 detects) with median emissions for 100% ClO_2 substitution mills (ECF) in the U.S. Five of the Canadian mills reportedly employed ECF bleaching, while the sixth (Mill 7) used some chlorine with ClO_2. The range of chloroform emissions from 100% ECF mills in the U.S. is ND to 0.01 kg/ADTBP (NCASI 2003a). The Canadian bleach plant emissions of $CHCl_3$ fall well within this range.

Figure 4.9 compares the median and individual formaldehyde emissions for six Canadian kraft mill bleach plants (5 detects) with median emissions for 19 such U.S. bleach plants (14 detects). The Canadian bleach plant emissions are also compared with median and range of HCHO emissions for the combined set, which now has 26 bleach plants (20 detects). Two data points rejected earlier in the U.S. data set (0.00105 and 0.00145 kg/ADTBP) are now included in the combined data set (no longer outliers). However, the Mill 6 Canadian bleach plant HCHO emission of 0.0057 kg/ADTUBP was determined to be an outlier in the combined set. Two other data points in the U.S. data set (0.017 and 0.030 kg/ADTUBP) that were earlier rejected as outliers remained outliers. Note that the medians of both the U.S. and combined data sets were fairly unaffected by these higher values. Based on a comparison of median and range for the two data sets, Figure 4.9 shows that HCHO emissions were quite comparable.

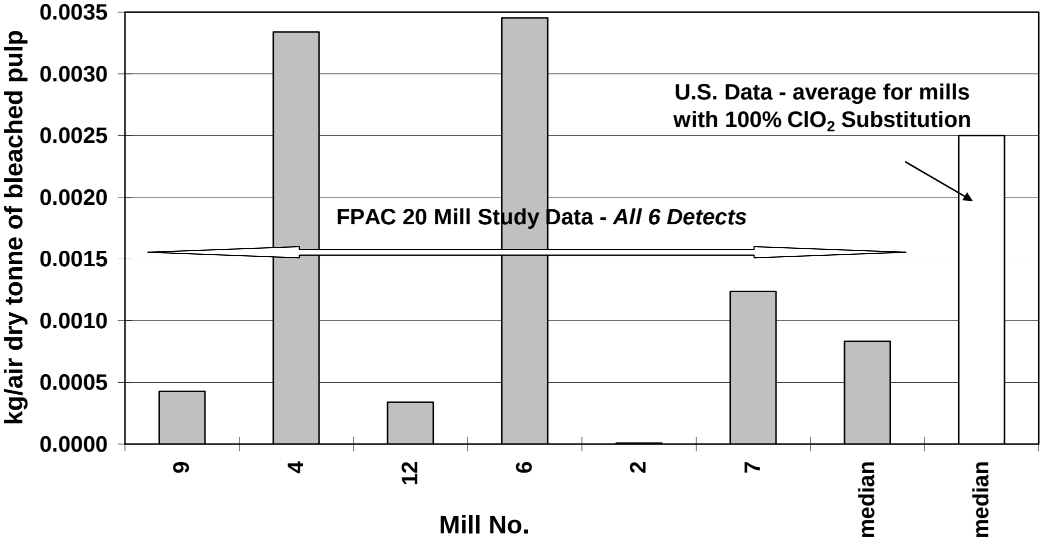
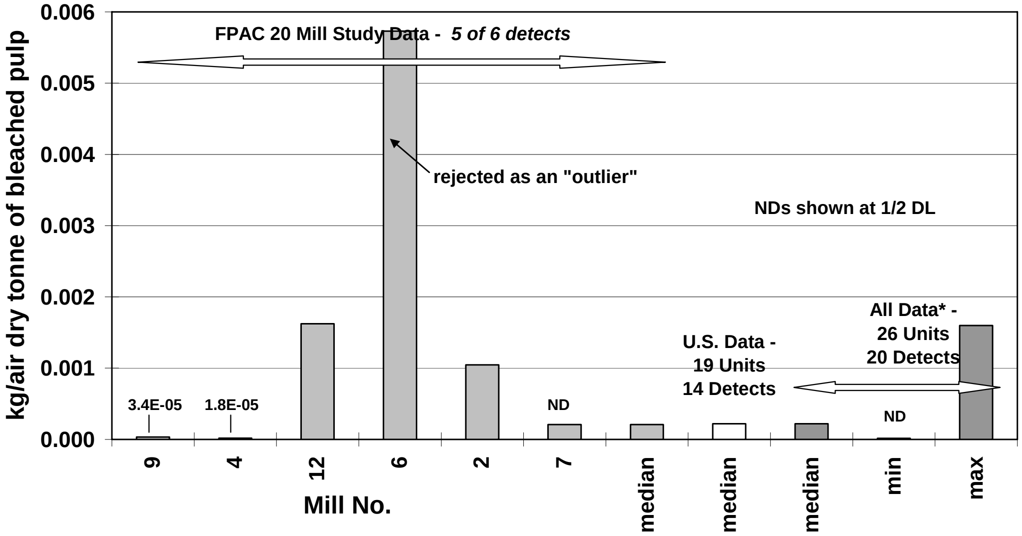


Figure 4.8 Comparison of Chloroform Emissions from Canadian and U.S. Kraft Pulp Mill Bleach Plants



*Two mill emissions rejected earlier in the U.S. set now included in combined data set

Figure 4.9 Comparison of Formaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill Bleach Plants

Finally, Figure 4.10 compares the median and individual methanol emissions for six Canadian kraft mill bleach plants (all 6 detects) with median emissions for 50 such U.S. bleach plants (all 50 detects). The Canadian bleach plant emissions are also compared with median and range of methanol emissions for the combined set of 56 bleach plants (all 56 detects). Two data points rejected earlier in the U.S. data set (1.9 and 0.41 kg/ADTBP) were once again determined to be outliers in the combined data set. As previously mentioned, methanol is perhaps the key VOC emission from kraft mill bleach plants today. Figure 4.10 shows that the two data sets are very much comparable for methanol emissions.

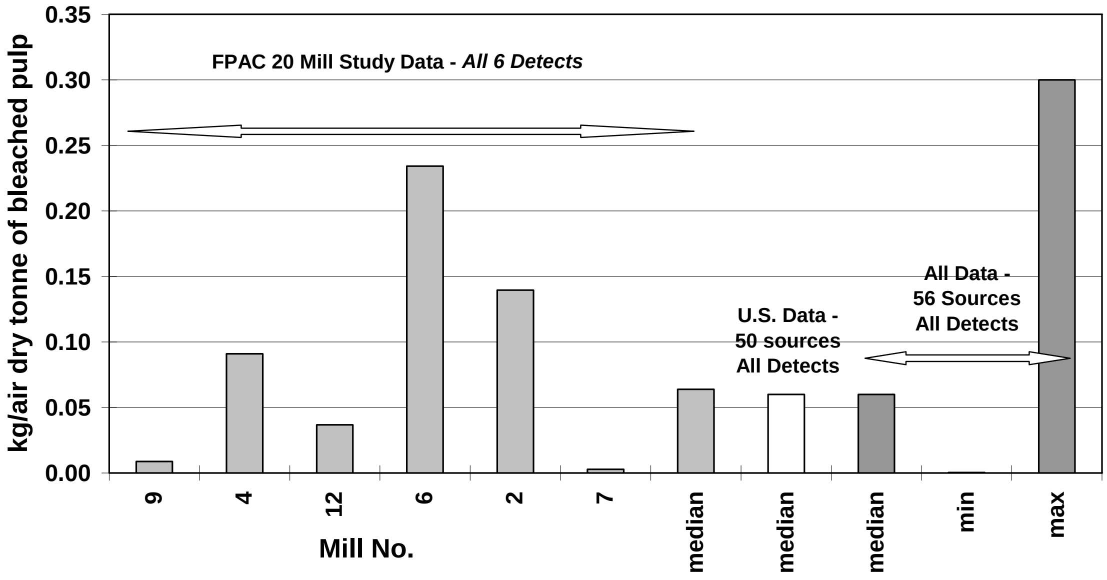


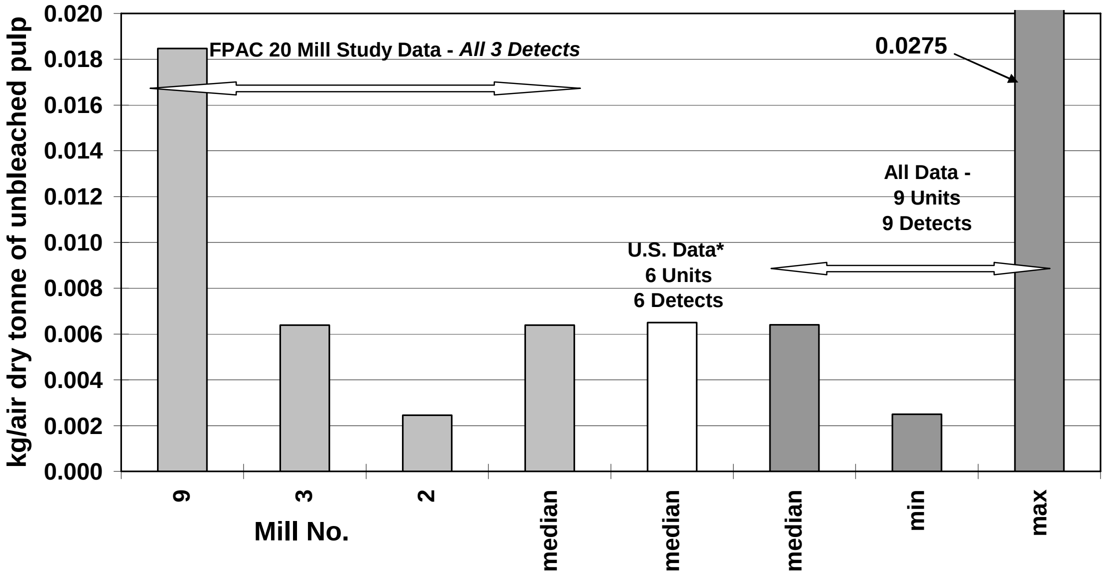
Figure 4.10 Comparison of Methanol Emissions from Canadian and U.S. Kraft Pulp Mill Bleach Plants

Summary for Kraft Pulp Mill Bleach Plants – Methanol is the main VOC emitted by kraft mill bleach plants with ECF bleaching. Methanol emissions from Canadian and U.S. bleach plants compared quite favorably. From this and a comparison of emissions of four other key VOCs from kraft mill bleach plants, it would appear that the Canadian and U.S. data sets are reasonably comparable to each other so that they could be effectively combined into one robust data set.

4.1.3 *Kraft Pulp Mill Oxygen Delignification Systems*

In an oxygen delignification system, volatile organic compounds present in the incoming pulp slurry, oxidized white liquor, and washer shower water can be released in blow tank, washer hood, washer filtrate tank, and pulp storage tank vent gases. The amounts of these compounds present in the various process liquids will depend upon the water reuse practices of the mill, particularly if condensates are used on the post-oxygen washers. Releases of volatile organic compounds from washer systems are also a function of the extent to which exhaust air and process liquids are in contact, which in turn depends upon equipment design and ventilation practices. Studies have shown that methanol is the dominant organic compound found in all of these vent gases (NCASI 1994a), with considerably lesser amounts of acetone, acetaldehyde and methyl ethyl ketone (MEK).

Acetaldehyde, 2-butanone (MEK), formaldehyde, and methanol are four VOCs emitted by kraft pulp mill oxygen delignification systems that are frequently tested for. Figure 4.11 compares the median and individual acetaldehyde emissions for three Canadian kraft mill O_2 delignification systems (all 3 detects) with median emissions for six such U.S. O_2 delignification systems (all 6 detects). The Canadian O_2 delignification system emissions are also compared with median and range of acetaldehyde emissions for the combined set of nine O_2 delignification systems (all 9 detects). As seen in Figure 4.11, the two data sets are quite comparable.



*one mill's emission of 0.08 kg/ ADTUBP rejected as an outlier

Figure 4.11 Comparison of Acetaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill Oxygen Delignification System Vents

Figure 4.12 compares the median and individual 2-butanone (MEK) emissions for three different Canadian kraft mill O_2 delignification systems (all 3 detects) with median emissions for 10 such U.S. O_2 delignification systems (all 10 detects). The Canadian O_2 delignification system emissions are also compared with median and range of MEK emissions for the combined set, which consists of only 12 O_2 delignification systems (all 12 detects). The Mill 9 Canadian O_2 delignification system had the highest MEK emissions (0.0195 kg/ADTUBP) compared to the rest of the 12 systems. For determining averages of the combined data set, this data point was rejected based upon application of the Dixon test for statistical outliers (NCASI 2003a). Note, however, that the median of the combined set would have been unchanged without rejecting this data point.

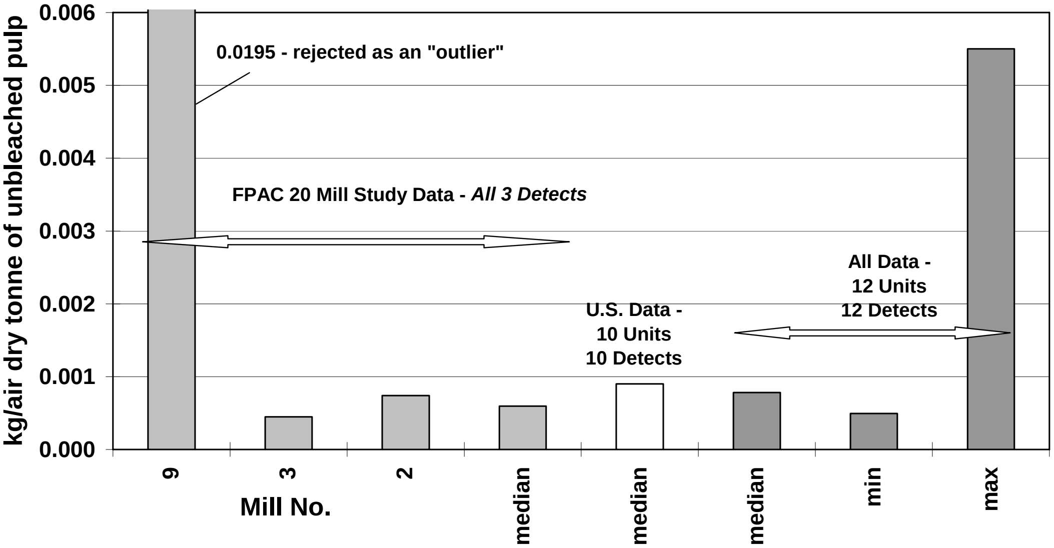


Figure 4.12 Comparison of 2-Butanone (MEK) Emissions from Canadian and U.S. Kraft Pulp Mill Oxygen Delignification System Vents

Figure 4.13 compares the median and individual formaldehyde emissions for three different Canadian kraft mill O_2 delignification systems (all 3 detects) with median emissions for seven such U.S. O_2 delignification systems (6 detects). The Canadian O_2 delignification system emissions are also compared with median and range of HCHO emissions for the combined set of 10 O_2 delignification systems (9 detects). As seen in Figure 4.13, the median for the three Canadian mills is comparable to that for the U.S. and combined data sets.

Finally, Figure 4.14 compares the median and individual methanol emissions for three Canadian kraft mill O_2 delignification systems (all 3 detects) with median emissions for seven such U.S. O_2 delignification systems (all 7 detects). The Canadian O_2 delignification system emissions are also compared with median and range of methanol emissions for the combined set of 10 O_2 delignification systems (all 10 detects). Median methanol emissions for the three Canadian O_2 delignification systems appear to be somewhat smaller than the median emissions for the 10 U.S. systems. However, overall, it can be seen from Figure 4.14 that the Canadian data fall within the range for the U.S. data, implying that the two data sets were quite comparable.

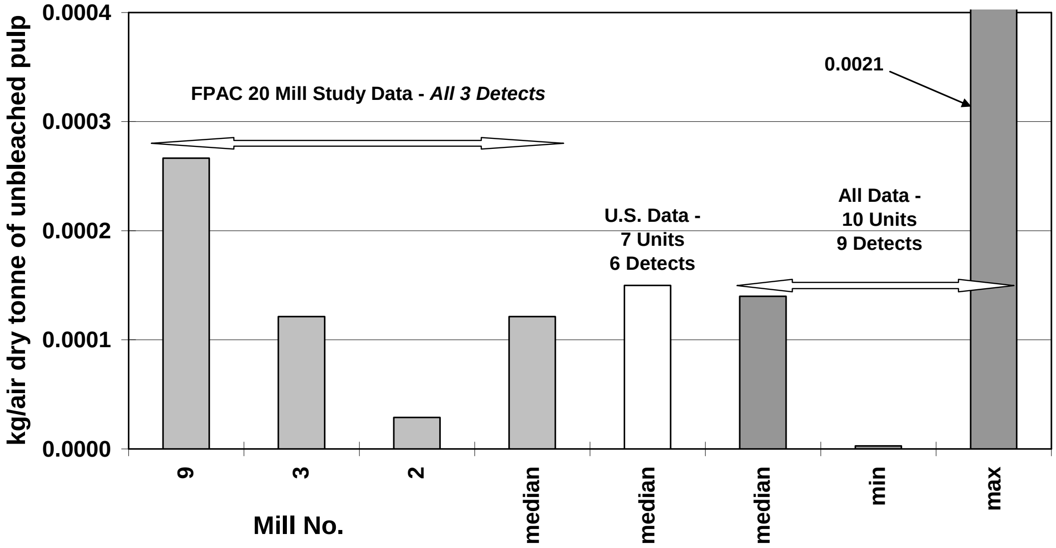


Figure 4.13 Comparison of Formaldehyde Emissions from
Canadian and U.S. Kraft Pulp Mill Oxygen Delignification System Vents

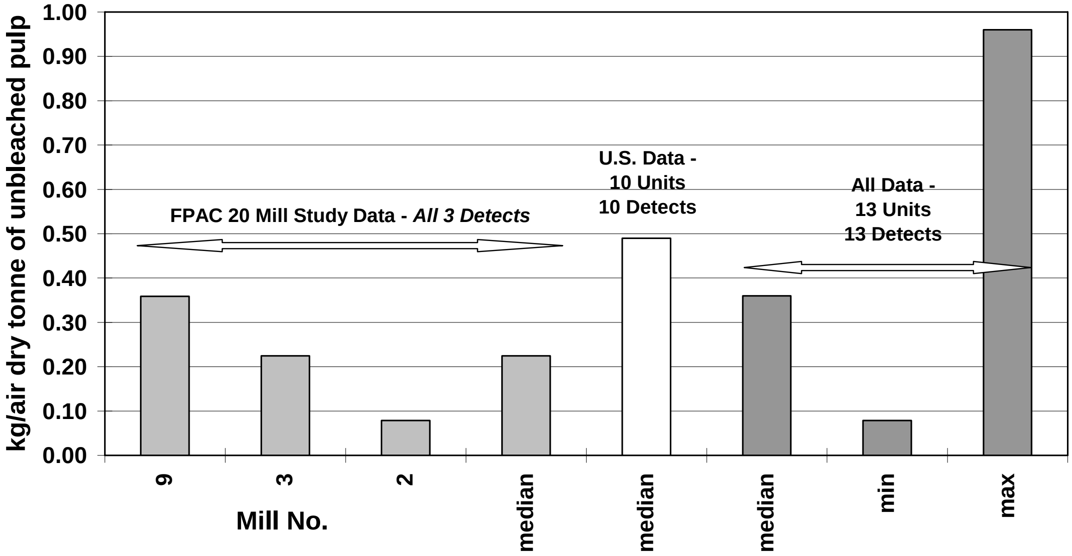


Figure 4.14 Comparison of Methanol Emissions from
Canadian and U.S. Kraft Pulp Mill Oxygen Delignification System Vents

Summary for Kraft Pulp Mill Oxygen Delignification System Vents – As noted earlier, methanol is the main VOC emission from kraft mill oxygen delignification system vents. Methanol emissions from Canadian and U.S. kraft mill oxygen delignification system vents compared quite favorably, although the Canadian data set was rather small to make a proper comparison. From this and a comparison of emissions of three other key VOCs from kraft mill oxygen delignification system vents, it would appear that the Canadian and U.S. data sets are reasonably comparable so they can be combined into one data set.

4.1.4 *Kraft Pulp Mill Direct Contact Recovery Furnaces*

Volatile organic compounds, except perhaps methanol, are emitted in small amounts from recovery furnaces. The source of these compounds may be incomplete combustion or the liquor itself when it comes into contact with combustion gases. The most obvious contact between liquor and flue gas is in a direct contact evaporator (DCE), where methanol and other volatiles can be transferred from the liquor to the flue gas. Less obvious contact occurs in the bottom of electrostatic precipitators where black liquor is used to collect the captured ash, and in furnaces that use liquor to transfer ash removed from the upper furnace areas to the salt cake mix tank. An early NCASI study (NCASI 1981) showed that a) total VOC emissions from kraft recovery furnaces could not be correlated to the black liquor firing rate or excess air usage, and b) VOC emissions from NDCE furnaces correlated with CO emissions, although the significance of this was not well understood.

Acetaldehyde, benzene, 2-butanone (MEK), formaldehyde, and methanol are five VOCs emitted by kraft DCE recovery furnaces that are frequently tested for. Figure 4.15 compares the median and individual acetaldehyde emissions for three Canadian kraft mill DCE recovery furnaces (only 1 detect) with median emissions for eight such U.S. DCE recovery furnaces (6 detects). The Canadian DCE recovery furnace emissions are also compared with median and range of acetaldehyde emissions for the combined set of 11 DCE recovery furnaces (7 detects). As seen in Figure 4.15, the two data sets are reasonably comparable.

Figure 4.16 compares the median and individual benzene emissions for three different Canadian kraft mill DCE recovery furnaces (all 3 detects) with median emissions for 18 such U.S. DCE recovery furnaces (9 detects). The Canadian DCE recovery furnace emissions are also compared with median and range of benzene emissions for the combined set of 21 DCE recovery furnaces (12 detects). As seen in Figure 4.16, the benzene emissions from the three Canadian furnaces were somewhat smaller than the median value for their U.S. counterparts, but overall, these data fell within the range for the U.S. data, implying the two data sets were comparable.

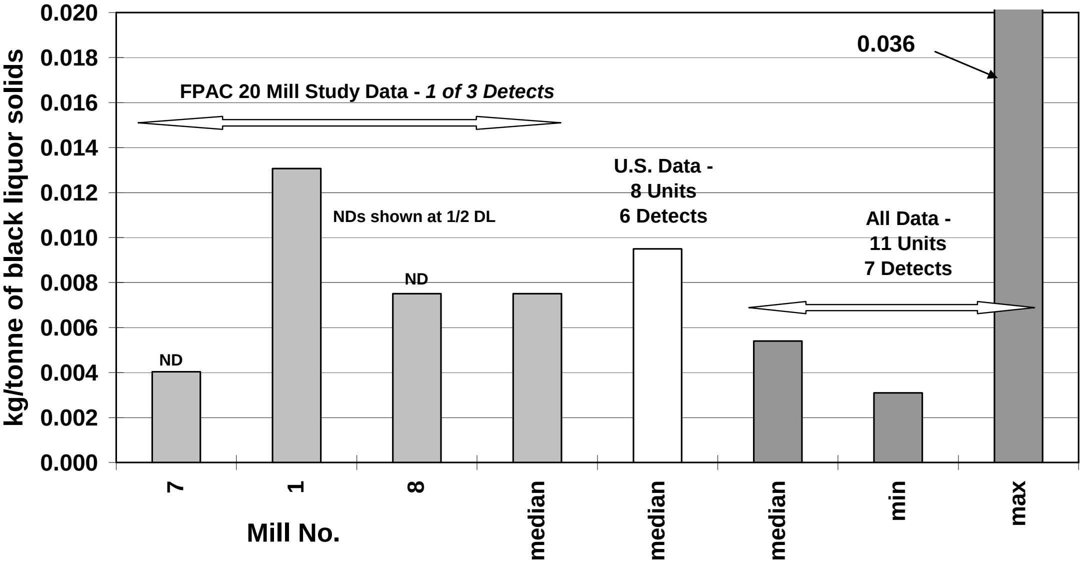


Figure 4.15 Comparison of Acetaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill DCE Recovery Furnaces

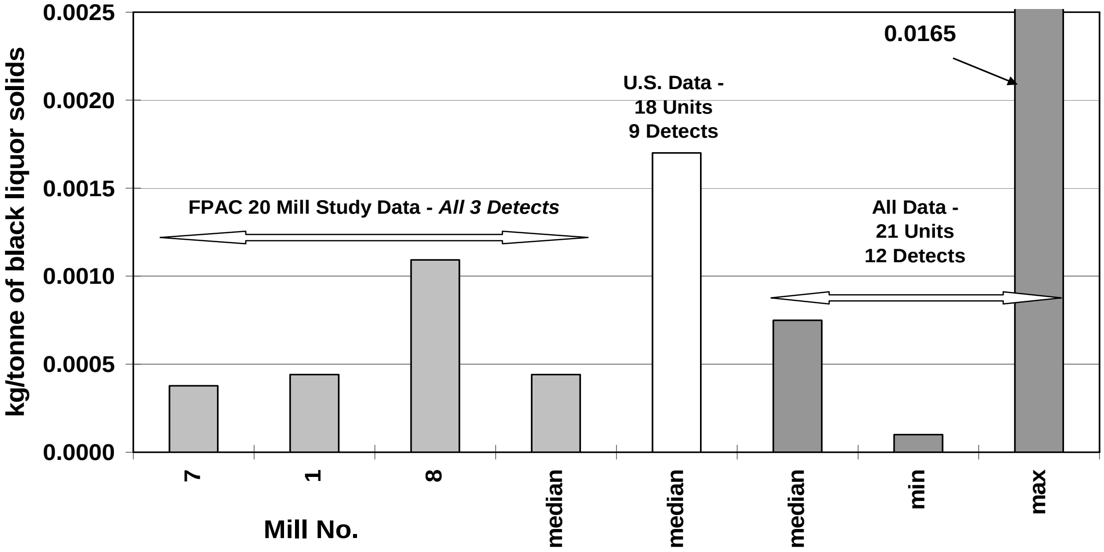


Figure 4.16 Comparison of Benzene Emissions from Canadian and U.S. Kraft Pulp Mill DCE Recovery Furnaces

Figure 4.17 compares the median and individual 2-butanone (MEK) emissions for three Canadian kraft mill DCE recovery furnaces (all 3 non-detects) with median emissions for 18 such U.S. DCE recovery furnaces (9 detects). The Canadian DCE recovery furnace emissions are also compared with median and range of MEK emissions for the combined set of 21 DCE recovery furnaces (9 detects). It is difficult to make a comparison between MEK emissions from Canadian and U.S. DCE furnaces since all three Canadian furnaces yielded non-detects. Further, Figure 4.18 shows that the U.S. data set had 50% NDs, while the combined U.S.-Canada set had over 50% NDs, and thus the median for the latter was much lower for reasons explained before.

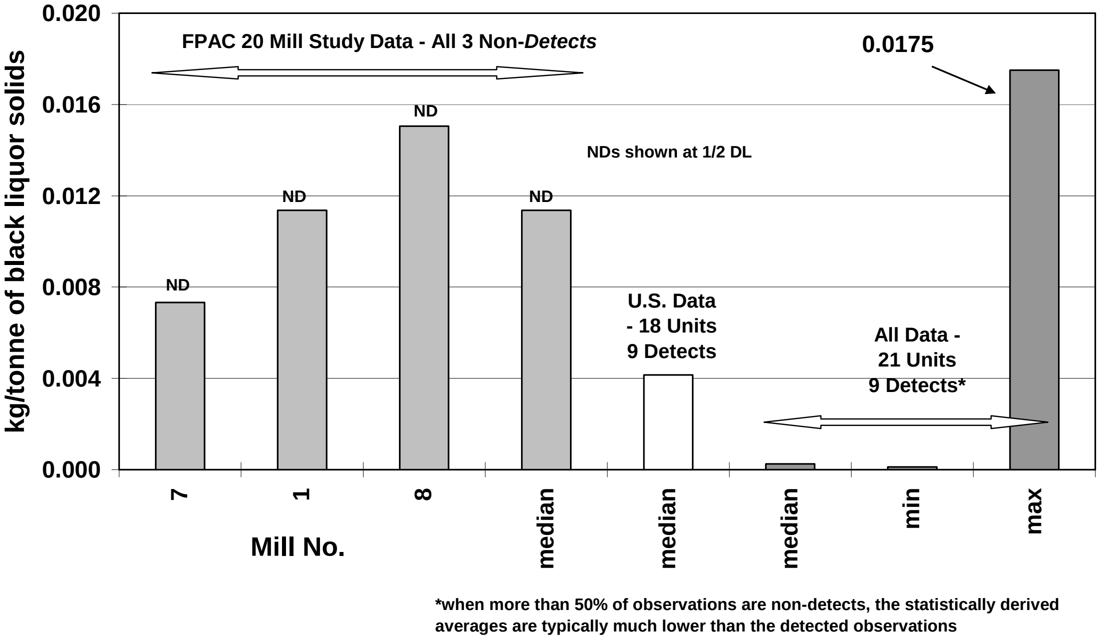


Figure 4.17 Comparison of 2-Butanone (MEK) Emissions from Canadian and U.S. Kraft Pulp Mill DCE Recovery Furnaces

Figure 4.18 compares the median and individual formaldehyde emissions for three Canadian kraft mill DCE recovery furnaces (2 detects) with median emissions for seven such U.S. DCE recovery furnaces (3 detects). The Canadian DCE recovery furnace emissions are also compared with median and range of formaldehyde emissions for the combined set of eight DCE recovery furnaces (3 detects). Two of the three Canadian DCE recovery furnaces (Mill 1 and Mill 8) had rather high HCHO emissions (0.088 and 0.029 kg/TBLS) compared with the rest. The maximum among the remaining 8 furnaces was 0.0048 kg/TBLS. These two data points were rejected from average determinations based upon application of the Dixon test for statistical outliers to the combined data set (NCASI 2003a). These data points were also flagged as suspect in an FPAC report (FPAC 2003b) “based on significant variance from industry norms for Canada and the U.S., both in magnitude and relative magnitude with other substances normally tested at the same time.” High levels of HCHO emissions from DCE recovery furnaces are likely indicative of inefficient combustion, due for example to an “overloaded” condition. However, there was no other emission information available, such as measurement of concurrent CO or total VOCs, to suggest that this was the problem. There are insufficient data for assessing whether the HCHO emissions from Canadian DCE furnaces were indeed different from HCHO emissions from similar U.S. furnaces.

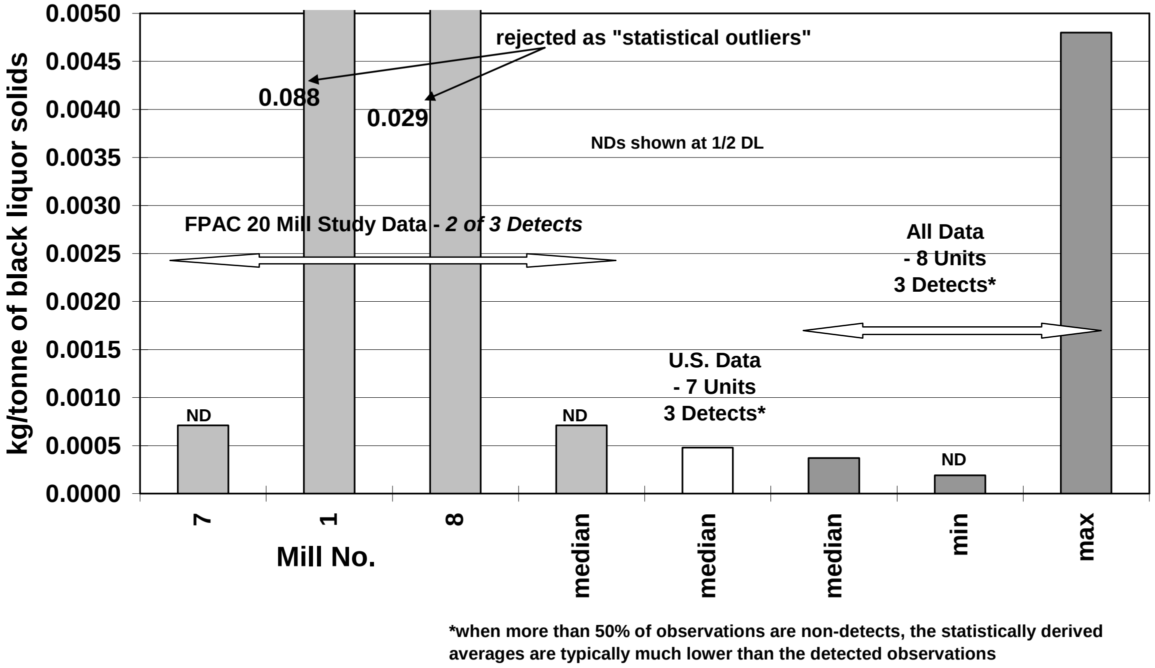


Figure 4.18 Comparison of Formaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill DCE Recovery Furnaces

Finally, Figure 4.19 compares the median and individual methanol emissions for three Canadian kraft mill DCE recovery furnaces (all detects) with median emissions for 23 such U.S. DCE recovery furnaces (all detects). The Canadian DCE recovery furnace emissions are also compared with median and range of methanol emissions for the combined set of 26 DCE recovery furnaces (all detects). As seen in Figure 4.19, the methanol emissions from the three Canadian furnaces were quite a bit smaller than the median value for their U.S. counterparts, but overall, the Canadian data fell within the range of the U.S. and combined data sets, implying the two data sets were comparable.

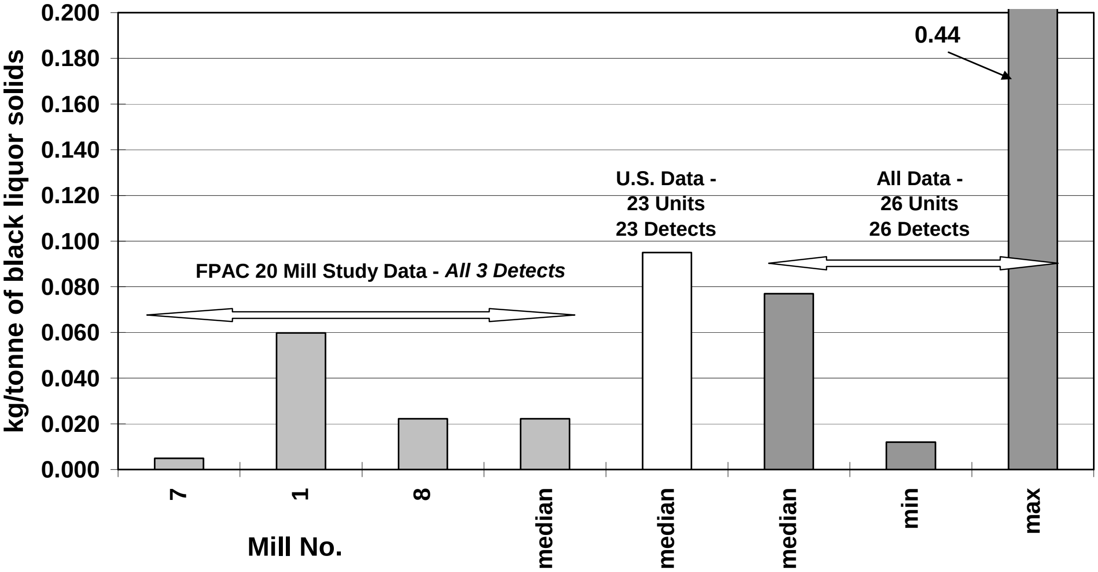


Figure 4.19 Comparison of Methanol Emissions from Canadian and U.S. Kraft Pulp Mill DCE Recovery Furnaces

Summary for Kraft Pulp Mill Direct Contact Evaporator Recovery Furnaces – Compared with non-DCE furnaces, DCE furnaces are an older design of recovery furnace operation both in the U.S. and in Canada. As such, the number of these furnaces still operating is declining. Only three DCE furnaces were tested for speciated VOCs during the FPAC study. Thus, the comparison with the U.S. data set should be viewed with caution. Nevertheless, based on a comparison of median and range emissions for five key VOCs (including methanol) from kraft DCE recovery furnaces, it would appear that the Canadian and U.S. data sets are reasonably comparable to each other so that they could be effectively combined to yield one robust data set. Formaldehyde emissions from two of three Canadian DCE furnaces tested were higher than normal. However, emissions of other organics which also result primarily from incomplete combustion and/or stripping of liquor in the direct contact evaporator were comparable in the two data sets.

4.1.5 *Kraft Pulp Mill Non-Direct Contact Recovery Furnaces*

As for DCE furnaces, acetaldehyde, benzene, 2-butanone (MEK), formaldehyde, and methanol are five VOCs emitted by kraft NDCE recovery furnaces that are frequently tested for. Figure 4.20 compares the median and individual acetaldehyde emissions for nine Canadian kraft mill NDCE recovery furnaces (5 detects) with median emissions for 14 such U.S. DCE furnaces (5 detects). The Canadian NDCE recovery furnace emissions are also compared with median and range of acetaldehyde emissions for the combined set of 23 NDCE recovery furnaces (10 detects). As seen in Figure 4.20, the acetaldehyde emissions for the Canadian furnaces were uniformly higher than the median estimated for the 14 U.S. furnaces but they also fell within the range for the U.S furnaces. However, it is also seen that the U.S. and combined data sets both had over 50% NDs, which requires the estimation of statistical averages for heavily censored data sets. As previously explained, such averaging techniques typically yield much lower averages compared with arithmetic averages that are derived for data sets with less than 50% NDs. In general, the acetaldehyde emissions from the Canadian furnaces fell within the range measured for the U.S furnaces.

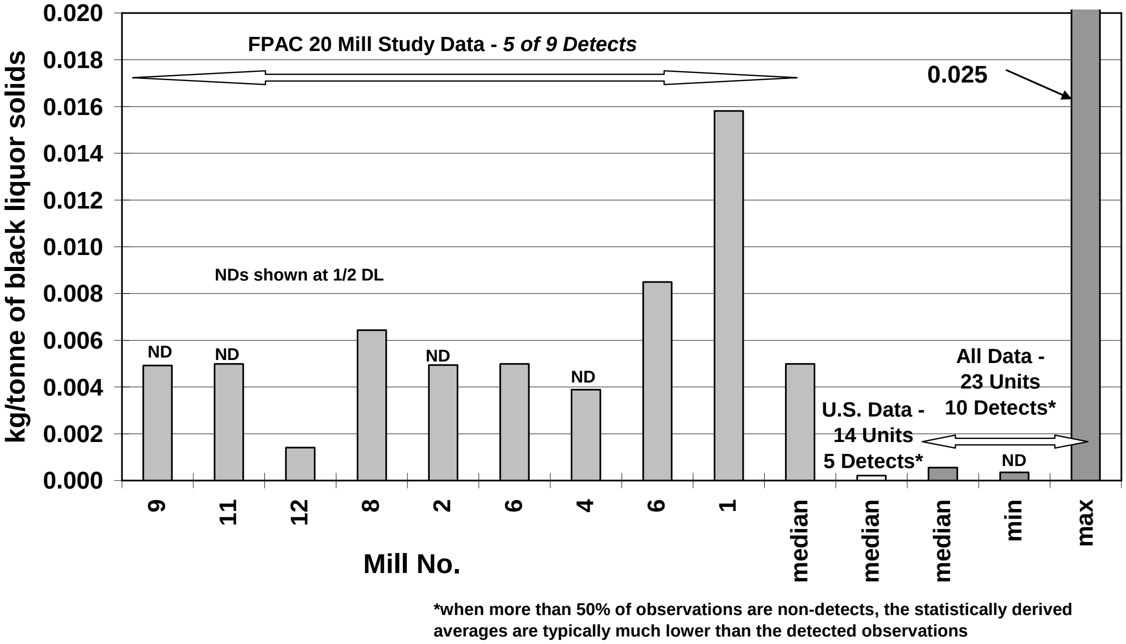


Figure 4.20 Comparison of Acetaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill NDCE Recovery Furnaces

Figure 4.21 compares the median and individual benzene emissions for nine Canadian kraft mill NDCE recovery furnaces (8 detects) with median emissions for 13 such U.S. NDCE furnaces (5 detects). The Canadian NDCE recovery furnace emissions are also compared with median and range of benzene emissions for the combined set of 20 NDCE recovery furnaces (13 detects). Two data points in the original U. S. data set, both NDs, which were included when estimating a statistical median (over 50% NDs) for the U.S data set, are now rejected while estimating an arithmetic median (under 50% NDs) for the combined data set. These rejected ND observations had detection limits that were more than twice the highest detected concentration. As seen in Figure 4.21, the individual furnace emissions of benzene for the Canadian mills fell within the range for the 13 U.S. furnaces, while the median emissions are not comparable for reasons explained above.

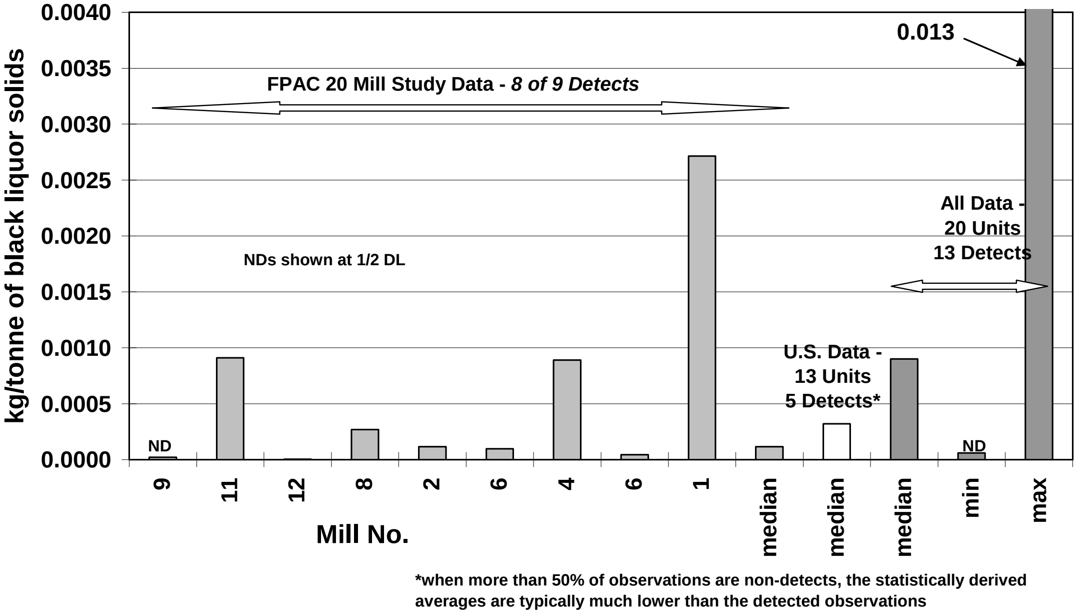
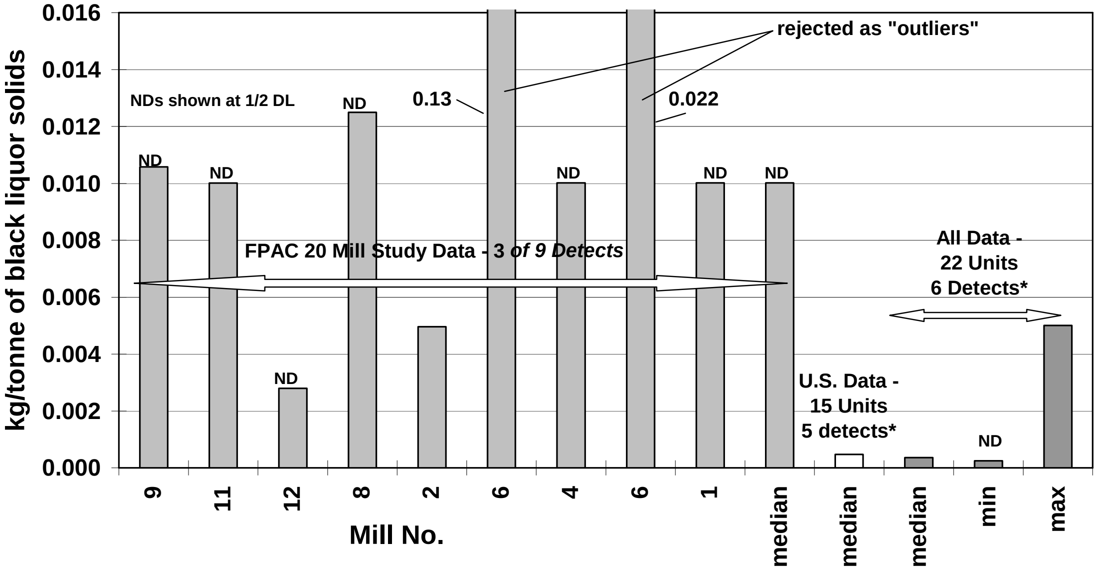


Figure 4.21 Comparison of Benzene Emissions from Canadian and U.S. Kraft Pulp Mill NDCE Recovery Furnaces

Figure 4.22 compares the median and individual MEK emissions for nine Canadian kraft mill NDCE recovery furnaces (3 of 9 detects) with median emissions for 15 such U.S. NDCE furnaces (5 detects). The Canadian NDCE recovery furnace emissions are also compared with median and range of MEK emissions for the combined set of 22 NDCE recovery furnaces (only 6 detects). Two of the three Canadian NDCE recovery furnaces (both at Mill 6) that had detects for MEK also had rather high emissions compared with the rest of the 22 furnaces (0.022 and 0.13 kg/TBLS). These two data points were rejected from estimation of averages after applying the Dixon test for statistical outliers (NCASI 2003a). Excluding these two data points, only one of the remaining seven Canadian furnaces had detectable levels of MEK. Thus, any comparison with the data for U.S. furnaces is difficult to make. Also, the U.S. and combined U.S.-Canadian data sets had over 50% NDs, thus requiring the estimation of statistical averages.



*when more than 50% of observations are non-detects, the statistically derived averages are typically much lower than the detected observations

Figure 4.22 Comparison of 2-Butanone (MEK) Emissions from Canadian and U.S. Kraft Pulp Mill NDCE Recovery Furnaces

Figure 4.23 compares the median and individual formaldehyde emissions for nine Canadian kraft mill NDCE recovery furnaces (7 detects) with median emissions for nine such U.S. NDCE furnaces (5 detects). The Canadian NDCE recovery furnace emissions are also compared with median and range of formaldehyde emissions for the combined set, which now consisted of 19 NDCE recovery furnaces (13 detects). One data point in the original U.S data set (maximum of 0.041 kg/TBLS), which was considered an outlier, is now deemed not an outlier in the combined data set with the addition of the Canadian data. As seen in Figure 4.23, unlike for DCE furnaces, the HCHO emissions for the Canadian NDCE furnaces fall within the range measured for the U.S furnaces. Also, the median for the combined data set is mostly unchanged by the addition of the data for the nine Canadian furnaces. Thus, the two data sets are quite comparable.

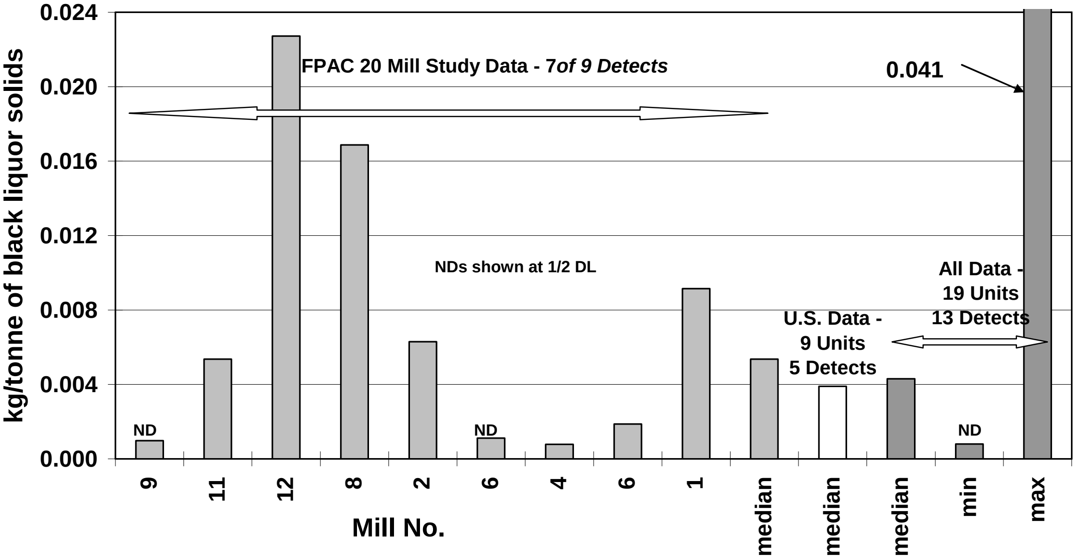


Figure 4.23 Comparison of Formaldehyde Emissions from Canadian and U.S. Kraft Pulp Mill NDCE Recovery Furnaces

Finally, Figure 4.24 compares the median and individual methanol emissions for nine Canadian kraft mill NDCE recovery furnaces (3 detects) with median emissions for 17 such U.S. NDCE recovery furnaces (12 detects). The Canadian NDCE recovery furnace emissions are also compared with median and range of methanol emissions for the combined set of 26 NDCE recovery furnaces (15 detects). As seen in Figure 4.24, while the methanol emissions from Canadian NDCE furnaces fell within the range for the U.S. NDCE furnaces, they were generally lower than the median for the same. It is not clear why this was the case. Methanol is generally not associated with emissions from liquor combustion per se. One reason methanol may be emitted from NDCE furnaces is a post-combustion phenomenon related to the stripping of methanol from liquor or condensates used either in some wet-bottom ESPs following the NDCE recovery furnace or to facilitate ash transfer. The extent to which this practice was relevant in the case of the NDCE furnaces tested across Canada is not known.

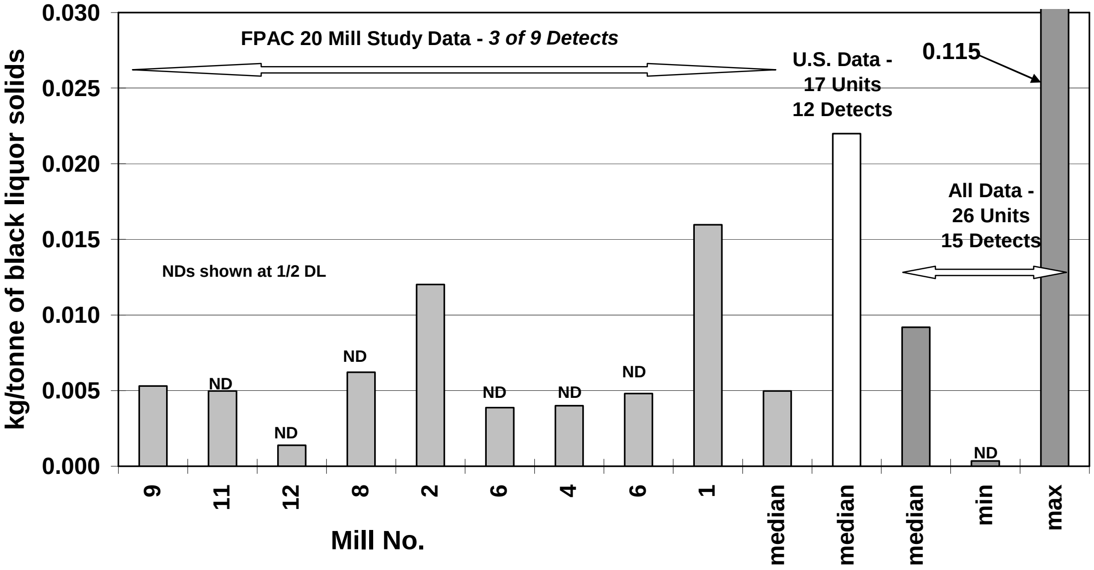


Figure 4.24 Comparison of Methanol Emissions from Canadian and U.S. Kraft Pulp Mill NDCE Recovery Furnaces

Summary for Kraft Pulp Mill Non-Direct Contact Evaporator Recovery Furnaces – Based on a comparison of median and range emissions for five key VOCs from kraft NDCE recovery furnaces, it would appear that the Canadian and U.S. data sets are reasonably comparable to each other so that they could be effectively combined to yield one robust data set. However, either the Canadian data set or the U.S. data set, or both, generally had more than 50% NDs. This situation requires the estimation of a statistically-derived average. Such averages are generally difficult to use in comparisons. Nevertheless, the Canadian data generally fell within the range for the U.S. data for all five NDCE recovery furnace VOC emissions.

4.1.6 *Kraft Pulp Mill Lime Kilns*

Some lime kiln VOC emissions, such as formaldehyde, are mainly products of incomplete fuel combustion, and their emission levels are highly variable among kilns. Some volatile organic compounds enter the kiln with the liquid component of lime mud and are released as the mud is heated. Volatile organic compounds present in scrubber make-up water can also be stripped by the flue gas exiting the kiln. Methanol has been found to be the dominant organic compound present in lime kiln exhaust gases (NCASI 1994b), arising primarily from stripping of scrubber make-up water.

Acetaldehyde, benzene, formaldehyde, and methanol are four VOCs emitted by kraft pulp mill lime kilns that are frequently tested for. Figure 4.25 compares the median and individual acetaldehyde emissions for ten Canadian kraft mill lime kilns (7 detects) with median emissions for 12 such U.S. kilns (8 detects). The Canadian kiln emissions are also compared with median and range of acetaldehyde emissions for the combined set, which now has 24 lime kilns (15 detects). Two ND measurements in the original U.S. data set that were rejected were now included in the combined data set as their DLs became less than twice the highest detected observation of 0.014 kg/ton CaO (measured for one of the two Canadian kilns at Mill 12). Another measurement of 0.0235 kg/ton CaO on a U.S. kiln remained as an outlier in both the original U.S. and in the combined data sets. As seen in Figure 4.25, the emissions for the Canadian kilns were generally in the same overall range as for the U.S. kilns, with the medians being similar, implying the two data sets were comparable.

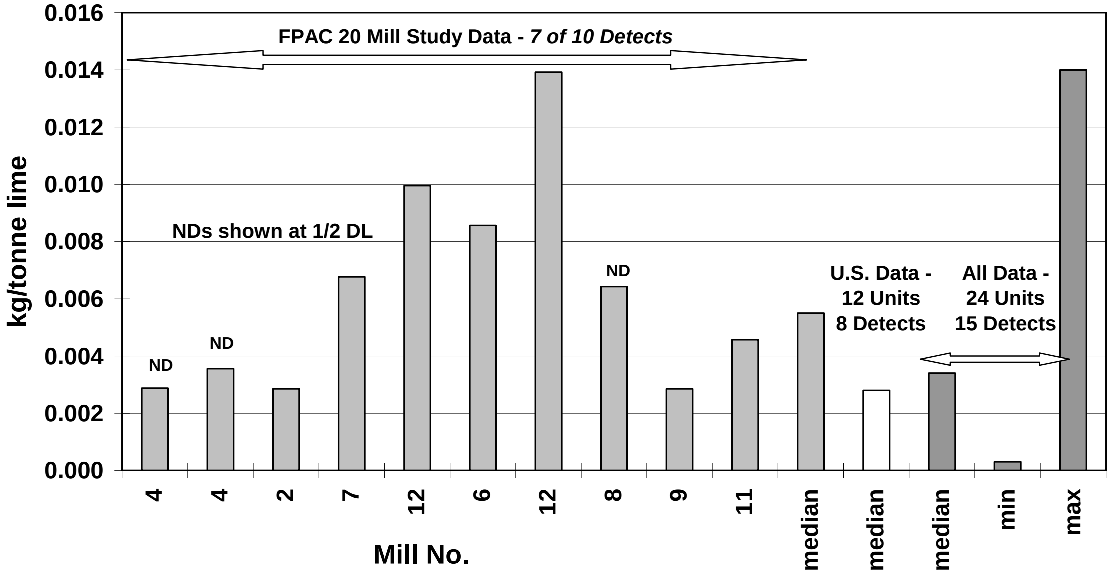


Figure 4.25 Comparison of Acetaldehyde Emissions from Canadian and U.S. Kraft Lime Kilns

Figure 4.26 compares the median and individual benzene emissions for ten Canadian kraft mill lime kilns (9 detects) with median emissions for 25 such U.S. lime kilns (only 7 detects). The Canadian lime kilns emissions are also compared with median and range of benzene emissions for the combined set of 35 lime kilns (16 detects). As seen in Figure 4.26, except perhaps for one of the two Mill 12 Canadian lime kilns, benzene emissions for the rest of the Canadian kilns were well within the range for the U.S. kilns. The medians were not comparable since both the U.S. and combined U.S.-Canadian kiln data sets had over 50% NDs, thus requiring the calculation of statistical averages.

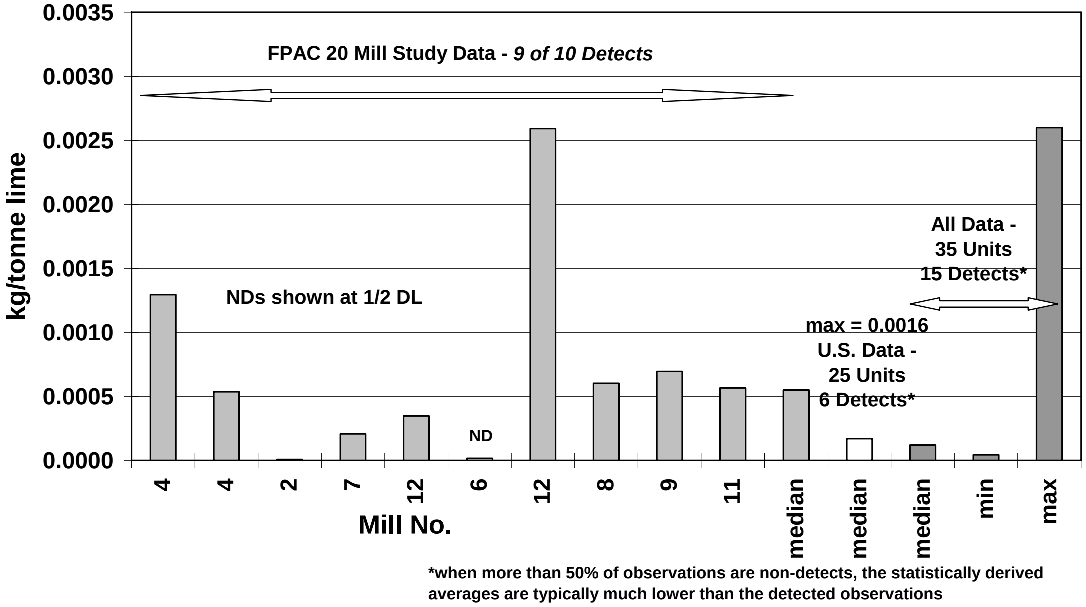


Figure 4.26 Comparison of Benzene Emissions from Canadian and U.S. Kraft Lime Kilns

Figure 4.27 compares the median and individual formaldehyde emissions for ten Canadian kraft mill lime kilns (5 detects) with median emissions for 11 such U.S. lime kilns (6 detects). The Canadian lime kilns emissions are also compared with median and range of formaldehyde emissions for the combined set of 21 lime kilns (11 detects). As seen in Figure 4.27, HCHO emissions for the Canadian kilns fell within the range for the U.S. kilns and the two sets were generally comparable.

Figure 4.28 compares the median and individual methanol emissions for ten Canadian kraft mill lime kilns (7 detects) with median emissions for 28 such U.S. lime kilns (17 detects). The Canadian lime kilns emissions are also compared with median and range of methanol emissions for the combined set of 37 lime kilns (24 detects). The high methanol emissions of 0.525 kg/ton CaO for the Mill 9 Canadian lime kiln was rejected upon application of the Dixon test for outliers to the combined data set (NCASI 2003a). As seen in Figure 4.28, methanol emissions for the rest of the Canadian kilns fell within the range for the U.S. kilns, and the two sets were quite similar.

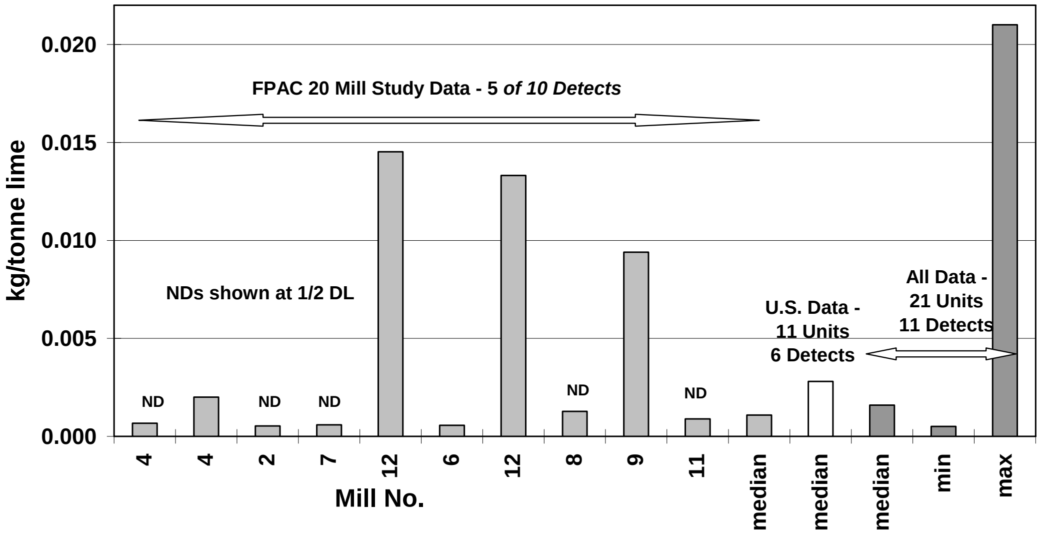


Figure 4.27 Comparison of Formaldehyde Emissions from Canadian and U.S. Kraft Lime Kilns

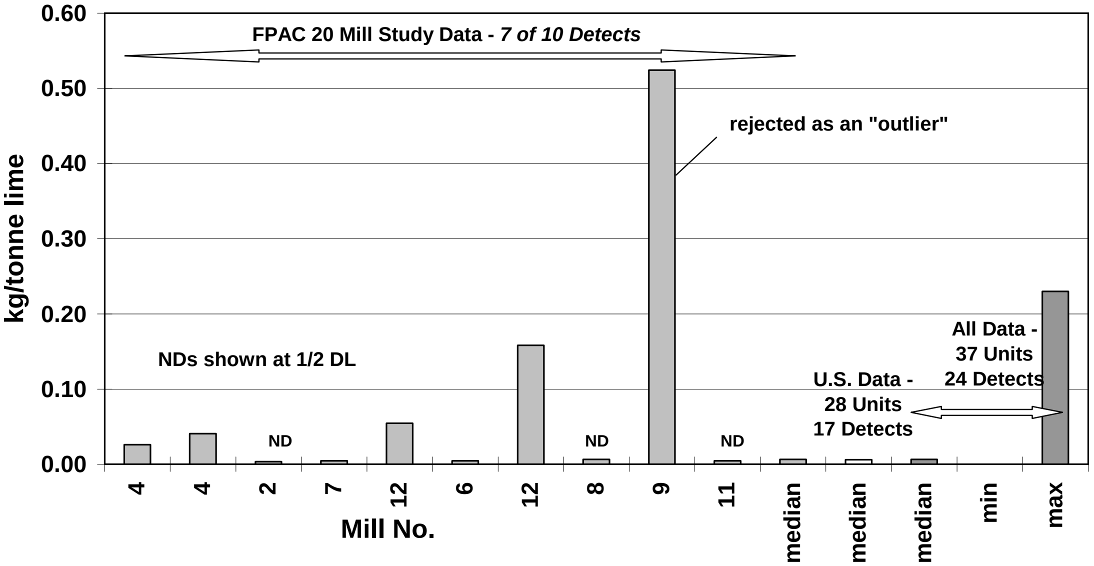


Figure 4.28 Comparison of Methanol Emissions from Canadian and U.S. Kraft Lime Kilns

Summary for Kraft Mill Lime Kilns – Based on a comparison of median and range emissions for five key VOCs from kraft mill lime kilns, it would appear that the Canadian and U.S. data sets are reasonably comparable to each other so that they could be effectively combined to yield one robust data set. Either the Canadian data set fell within the range for the U.S. data set, or a strict comparison of the two data sets was not possible since one set or both had more than 50% NDs. One Canadian kiln that had high methanol emissions was determined to be a statistical outlier. This may have been caused by stripping of scrubber make-up water. However, detailed information to support this was not available. Also, at the time of testing, this kiln burned about 37% crude tall oil, the rest being natural gas.

4.1.7 *Kraft Pulp Mill Smelt Dissolving Tanks*

VOC emissions from smelt dissolving tanks are generally very low, unless process condensates containing higher amounts of VOCs are used to either dissolve the smelt or to scrub the vent gases. Volatile organic compounds such as methanol can be released from the weak wash in both the dissolving tank and the wet scrubber particulate control device. In a study of emissions from four smelt dissolving tanks, NCASI found methanol emissions were closely related to the methanol content of the weak wash used in the scrubbers (NCASI 1994b).

Acetaldehyde, MEK, formaldehyde, and methanol are four VOCs present in present in kraft pulp mill smelt dissolving tank (SDT) vent gases that are frequently tested for. Figure 4.29 compares the median and individual acetaldehyde emissions for eleven Canadian kraft mill SDTs (9 detects) with median emissions for 10 such U.S. SDTs (5 detects). The Canadian SDT emissions are also compared with median and range of acetaldehyde emissions for the combined set of 21 SDTs (14 detects). As seen in Figure 4.29, except for the Mill 4 Canadian SDT, which had the maximum acetaldehyde emission of 0.0033 kg/TBLS, the rest of the Canadian SDT emissions fell generally within the range for the U.S. emissions. Further, the medians for the two sets were similar, suggesting the two sets were quite comparable.

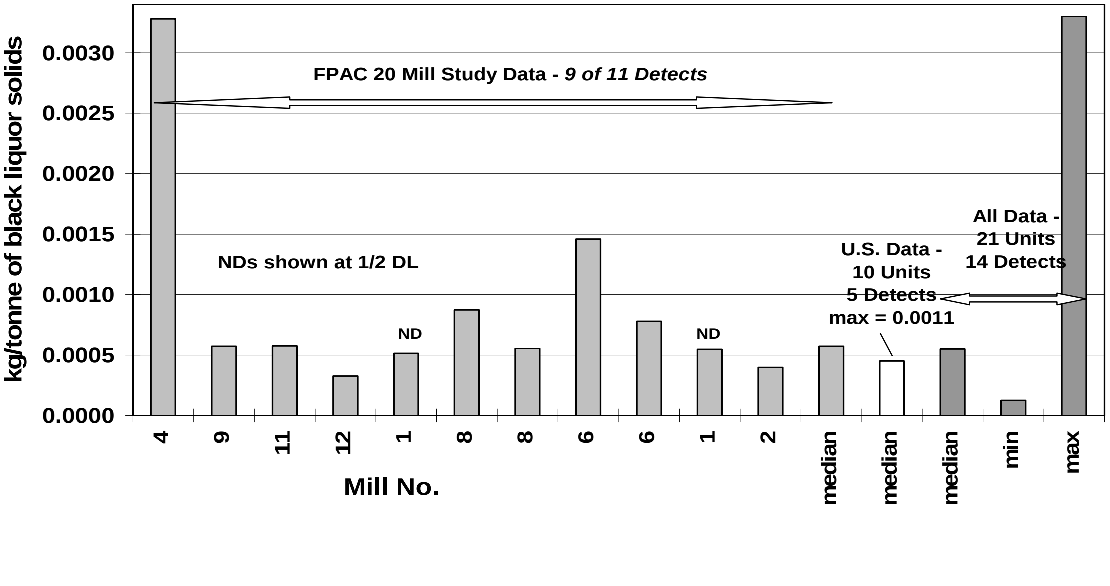


Figure 4.29 Comparison of Acetaldehyde Emissions from Canadian and U.S. Kraft Smelt Dissolving Tanks

Figure 4.30 compares the median and individual MEK emissions for eleven Canadian kraft mill SDTs (only 3 detects) with median emissions for 26 such U.S. SDTs (8 detects). The Canadian SDT emissions are also compared with median and range of MEK emissions for the combined set of 37 SDTs (11 detects). As seen in Figure 4.30, MEK emissions for both the Canadian and U.S. smelt dissolving tanks were similar in that they were mostly non-detect (more than 50% of the time). The three Canadian SDTs with detectable emissions were comparable to those for the U.S. SDT MEK emissions, although one of them had the highest emissions (Mill 4–0.0015 kg/TBLS). Medians for both sets were difficult to compare since only statistical averages could be estimated.

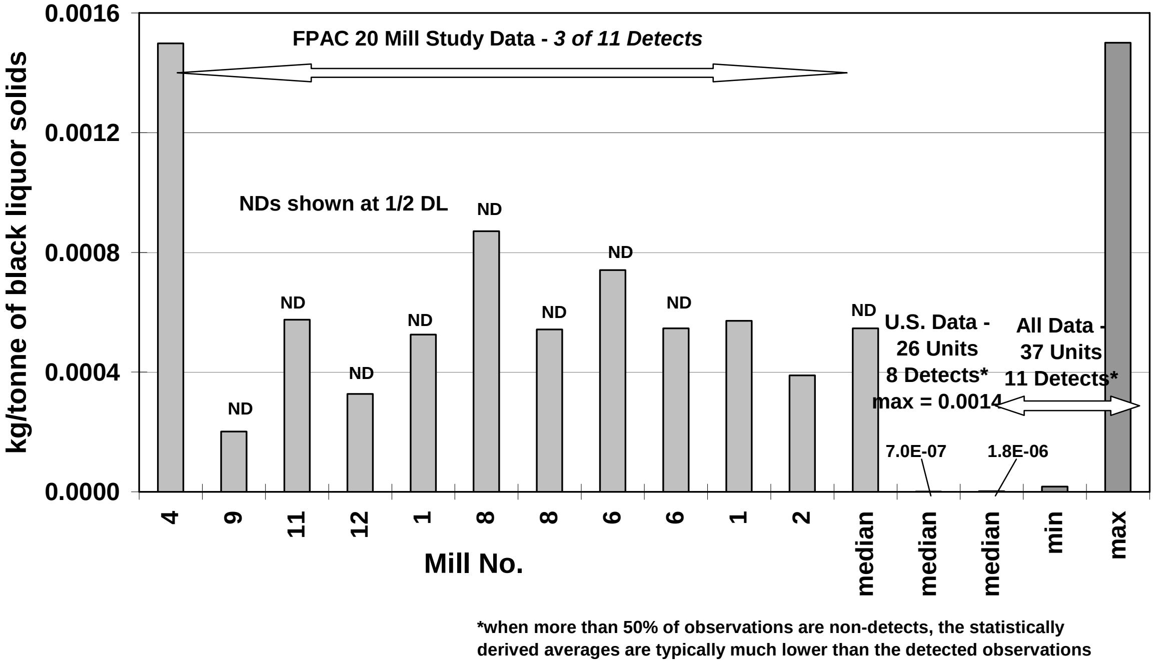
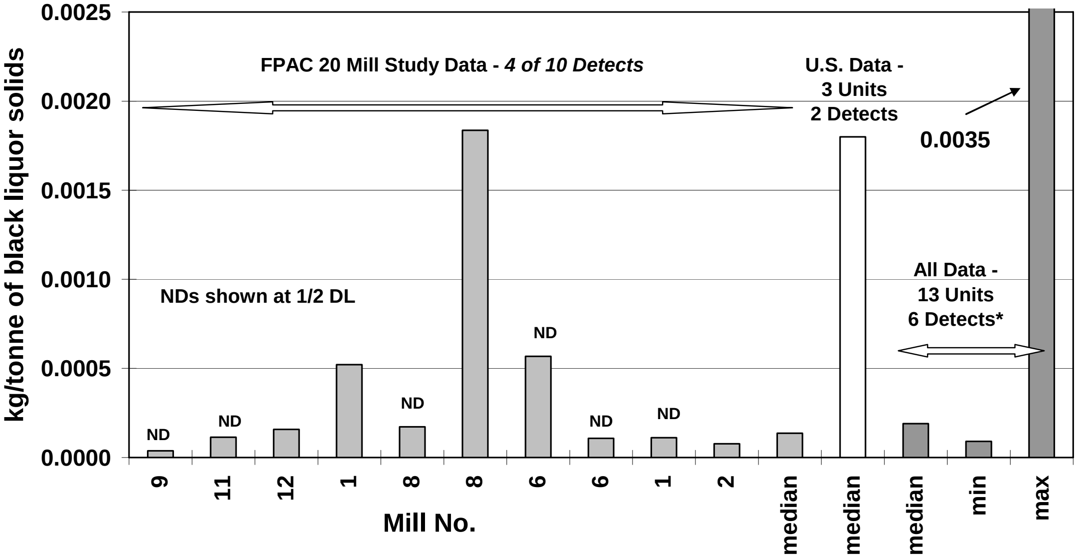


Figure 4.30 Comparison of 2-Butanone (MEK) Emissions from Canadian and U.S. Kraft Smelt Dissolving Tanks

Figure 4.31 compares the median and individual formaldehyde emissions for ten Canadian kraft mill SDTs (4 detects) with median emissions for three such U.S. SDTs (2 detects). The Canadian SDT emissions are also compared with median and range of HCHO emissions for the combined set of 13 SDTs (6 detects). As seen in Figure 4.31, it is difficult to make a comparison between the U.S. and Canadian data for two reasons: the Canadian data set had more than 50% NDs; the U.S. data set had too few data points (only three units tested). Nevertheless, the four detects in the Canadian data set fell within the range for the 3 U.S. SDTs.



*when more than 50% of observations are non-detects, the statistically derived averages are typically much lower than the detected observations

Figure 4.31 Comparison of Formaldehyde Emissions from Canadian and U.S. Kraft Smelt Dissolving Tanks

Figure 4.32 compares the median and individual methanol emissions for eleven Canadian kraft mill SDTs (6 detects) with median emissions for 29 such U.S. SDTs (20 detects). The Canadian SDT emissions are also compared with median and range of methanol emissions for the combined set of 40 SDTs (26 detects). As seen in Figure 4.32, one of the two Mill 1 Canadian SDTs had the highest methanol emissions of all 40 SDTs (0.423 kg/TBLS). Apart from this SDT, the rest of the Canadian mill SDT methanol emissions fell well within the range for the U.S. SDT emissions. Also, the medians for the 11 Canadian, 29 U.S. and 40 combined U.S.-Canadian smelt dissolving tank data sets are all quite similar, suggesting the two data sets were quite comparable. It should be noted that high methanol emissions from smelt tanks are typically associated with the use of methanol-containing condensates to make the weak wash that is used in smelt dissolving operations.

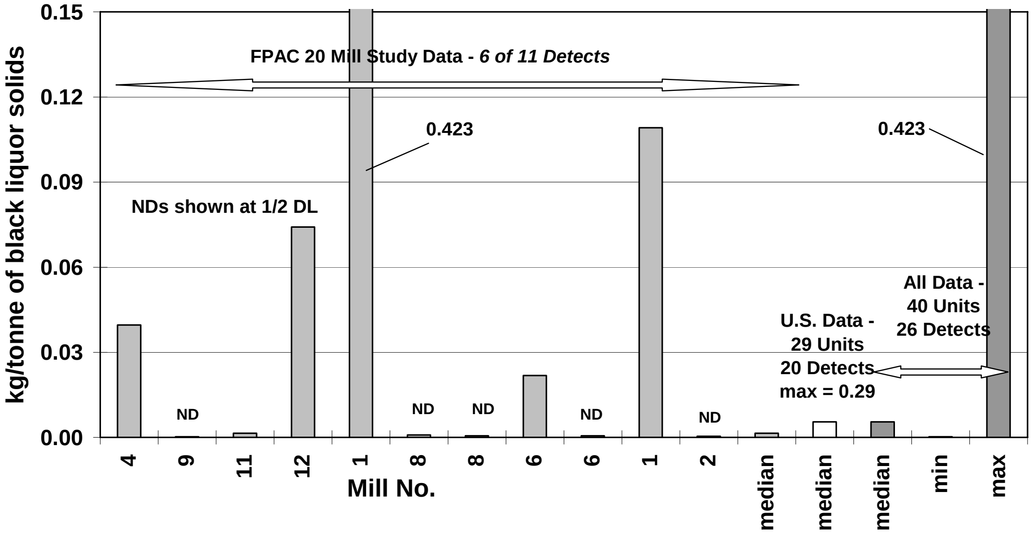


Figure 4.32 Comparison of Methanol Emissions from Canadian and U.S. Kraft Smelt Dissolving Tanks

Summary for Kraft Smelt Dissolving Tanks – Based on a comparison of median and range emissions for five key VOCs from kraft mill smelt dissolving tanks, it would appear that the Canadian and U.S. data sets are reasonably comparable to each other so that they could be effectively combined to yield one robust data set. Either the Canadian data set fell within the range for the U.S. data set, or a strict comparison of the two data sets was not possible since one set or both had more than 50% NDs. Among all smelt tanks, one Canadian smelt tank had the highest acetaldehyde and MEK emissions and another Canadian smelt tank had the highest methanol emissions (all three were determined not to be outliers). Acetaldehyde, MEK and methanol emissions from smelt tanks are generally related to stripping from scrubbing solutions (such as weak wash).

4.1.8 *Thermomechanical Pulping Operations*

All mechanical pulping processes generate copious quantities of steam as a result of the wood's moisture content and the high temperatures involved. Some organic compounds originating in the wood (principally alcohols and terpenes) can be released along with the water vapor. Following grinding or refining, the pulp is transferred to a cyclone device for separation of the fibre from the steam. Except at older stone groundwood (SGW) mills, this steam is sent to one or more condensers for heat recovery. Some of the organic compounds will partition to the condensates, with the remainder going to the atmosphere. Some of the wood components are volatile at process temperatures and are released along with the steam during chip steaming and refining processes. Heat recovery from steam emissions is extensively practiced at TMP mills.

In the mid-1990s, NCASI investigated emissions of gaseous organic compounds from several different mechanical pulping processes (NCASI 1997a). Testing was conducted at two stone groundwood (SGW) mills, one pressurized groundwood (PGW) mill, and three thermomechanical pulping (TMP) mills. Total emissions from the entire pulping line were typically measured. Depending on the equipment configuration, this included vents on heat recovery systems, pulp and filtrate storage tanks, reject refining systems, chip washers, and screens, as well as building exhausts. However, the origin of the organic compounds from these sources is from the grinding or refining process. The measurements indicated methanol and terpenes were the major organic compounds emitted. Five of the pulping lines used only softwoods and one used a pine/cottonwood mix. As such, the comparison with Canadian groundwood and TMP lines for terpenes would not be justified, because hardwoods were being pulped at some of the mills. However, as the data presented below show, a comparison for emissions of volatile non-terpene organics from Canadian and U.S. SGW and TMP lines is perhaps justifiable.

The comparison of speciated VOC emissions for TMP operations between Canadian and U.S. mills is difficult to make since while there were six such operations tested during the FPAC 20-mill study, data for only three such U.S. operations were available. Acetaldehyde, formaldehyde, methanol and phenol are four VOCs emitted by TMP operations that are frequently tested for. Figure 4.33 compares the individual acetaldehyde emissions for six Canadian TMP operations (5 detects) with individual emissions for three U.S. TMP operations (all 3 detects). The median and range of acetaldehyde emissions for the combined set of nine TMP operations (8 detects) are also shown. As seen in Figure 4.33, acetaldehyde emissions for the Mill 6 and Mill 10 Canadian TMP operations were higher than all three U.S. TMP operations, while the remaining four Canadian TMP operations were comparable to the U.S. TMP operations. Median emissions in both sets are similar, suggesting that the two sets are quite comparable. In their TMP operations, Mills 6, 16, 18, and 20 used only softwoods, Mill 15 used mostly softwoods (92%), and Mill 10 used only hardwoods.

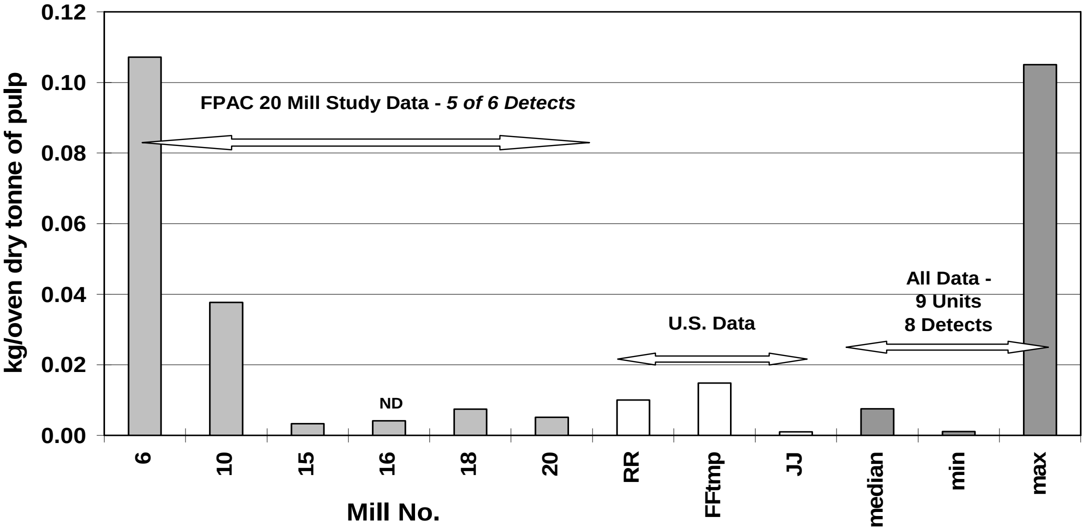


Figure 4.33 Comparison of Acetaldehyde Emissions from Canadian and U.S. Thermomechanical Pulping Operations

Figure 4.34 compares the individual formaldehyde emissions for six Canadian TMP operations (5 detects) with individual emissions for three U.S. TMP operations (2 detects). The median and range of formaldehyde emissions for the combined set of nine TMP operations (7 detects) are also shown. Figure 4.34 shows that with the exception of the Mill 18 HCHO emission, the remaining five Canadian TMP operations had HCHO emissions similar to the three U.S. mills. Median emissions for both sets of data were similar, suggesting the two data sets were reasonably comparable.

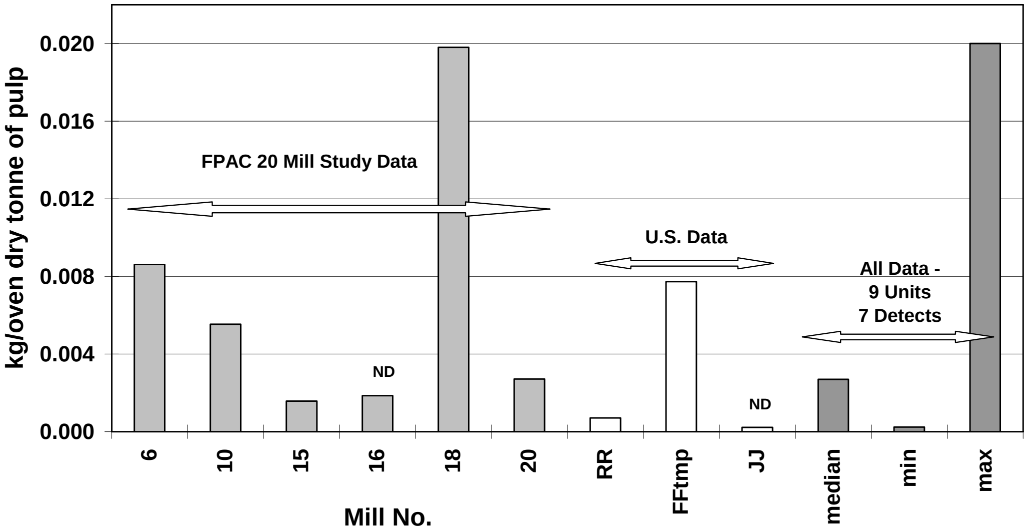


Figure 4.34 Comparison of Formaldehyde Emissions from Canadian and U.S. Thermomechanical Pulping Operations

Figure 4.35 compares the individual methanol emissions for six Canadian TMP operations (all 6 detects) with individual emissions for three U.S. TMP operations (all 3 detects). The median and range of methanol emissions for the combined set of nine TMP operations (all 9 detects) are also shown. As seen in Figure 4.1.35, methanol emissions for the Mill 10 and Mill 18 Canadian TMP operations were higher than for all three U.S. TMP operations, while the remaining four Canadian TMP operations had emissions comparable to the U.S. operations. Median emissions for both sets were similar, howeve3r, suggesting that overall the two sets were quite comparable.

Finally, Figure 4.36 compares the individual phenol emissions for six Canadian TMP operations (only 2 detects) with individual emissions for three U.S. TMP operations (2 detects). The median and range of phenol emissions for the combined set, which consisted of only seven TMP operations (4 detects), are also shown. Two NDs, one for a Canadian TMP operation and another for a U.S. operation, had non-detect emissions where the DLs were over twice the highest detected emission for all TMP operations. These data points were rejected from the combined set. As seen in Figure 4.36, after rejecting the ND data points, the phenol emissions from the rest of the U.S. and Canadian operations were comparable.

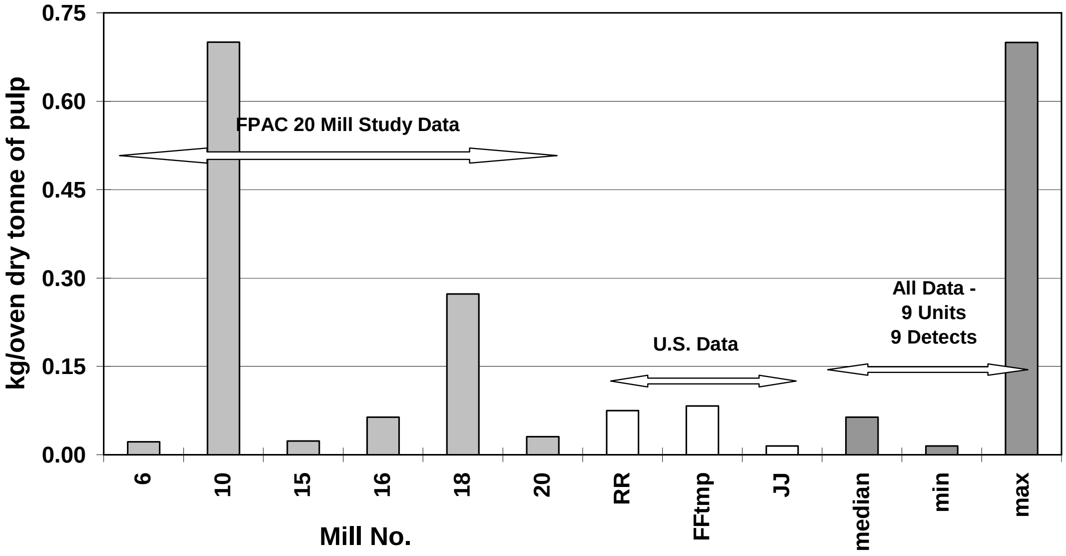


Figure 4.35 Comparison of Methanol Emissions from Canadian and U.S. Thermomechanical Pulping Operations

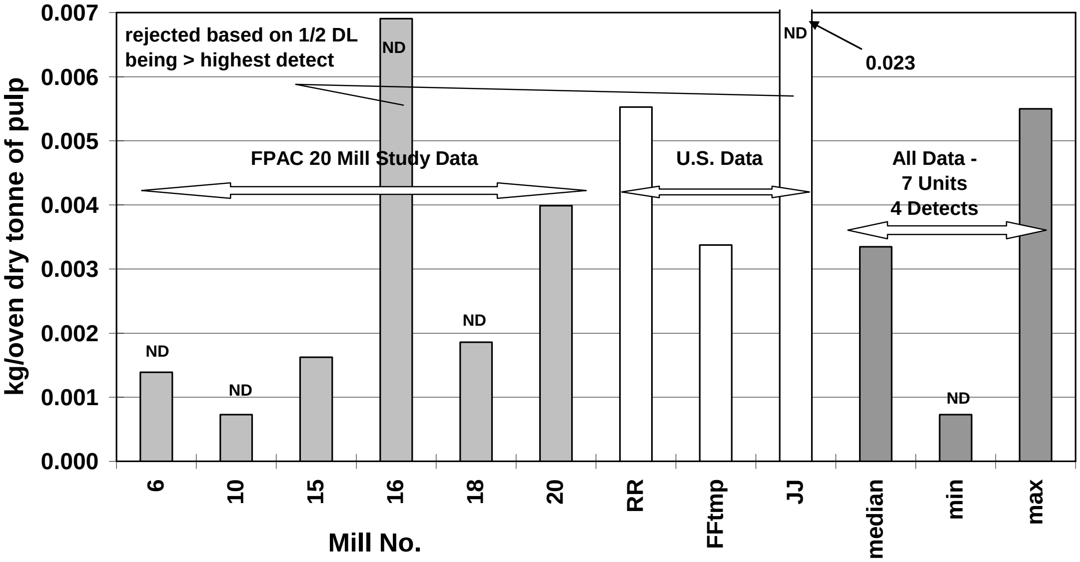


Figure 4.36 Comparison of Phenol Emissions fro Canadian and U.S. Thermomechanical Pulping Operations

Summary for Thermomechanical Pulping Operations – As previously mentioned, a strict comparison of VOC emissions from TMP operations in the U.S. with those in Canada cannot be made since only three such sources were tested in the U.S. Nevertheless, based on a comparison of the median emissions for the six Canadian TMP operations tested with individual emissions from the three U.S. operations, it would appear that the Canadian and U.S. data sets are reasonably comparable, so that they could be effectively combined to yield one robust data set for non-terpene VOC emissions.

4.1.9 *Groundwood Pulping Operations*

This section deals with VOC emissions from groundwood pulping (GWP) operations. Caution should also be exercised when comparing speciated VOC emissions from Canadian GWP operations with similar U.S. operations, since only 3 of the former and two of the latter were tested. Acetaldehyde, formaldehyde, methanol, and phenol are four VOCs emitted by GWP operations that are frequently tested for. Figure 4.37 compares the individual acetaldehyde emissions for three Canadian GWP operations (2 detects) with individual emissions for two U.S. GWP operations (both detects). The median and range of acetaldehyde emissions for the combined set of five GWP operations (4 detects) are also shown. As seen in Figure 4.37, the acetaldehyde emissions from the Mill 19 Canadian GWP operation were the highest among the five operations. Emissions for the other two Canadian GWP operations were similar to those from the two U.S. operations. In their groundwood pulping operations, Mills 18 and 19 used softwoods, while Mill 24 used hardwoods.

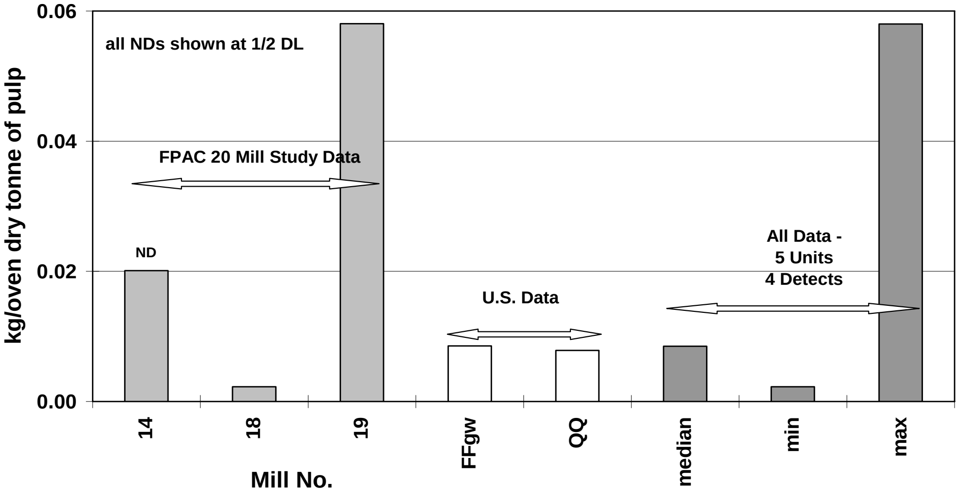


Figure 4.37 Comparison of Acetaldehyde Emissions from Canadian and U.S. Groundwood Pulping Operations

Figure 4.38 compares the individual formaldehyde emissions for three Canadian GWP operations (2 detects) with individual emissions for two U.S. GWP operations (2 detects). The median and range of formaldehyde emissions for the combined set of five GWP operations (4 detects) are shown. Figure 4.38 shows that once again the Mill 19 Canadian GWP operation had the highest formaldehyde emissions. The rest of the four GWP operations, two Canadian and two U.S., had quite similar emissions.

Figure 4.39 compares the individual methanol emissions for three Canadian GWP operations (2 detects) with individual emissions for two U.S. GWP operations (both detects). The median and range of methanol emissions for the combined set of five GWP operations (4 detects) are also shown. Once again, as seen in Figure 4.39, the Mill 19 Canadian GWP operation had the highest methanol emissions. The rest of the four GWP operations, two Canadian and two U.S., had similar emissions.

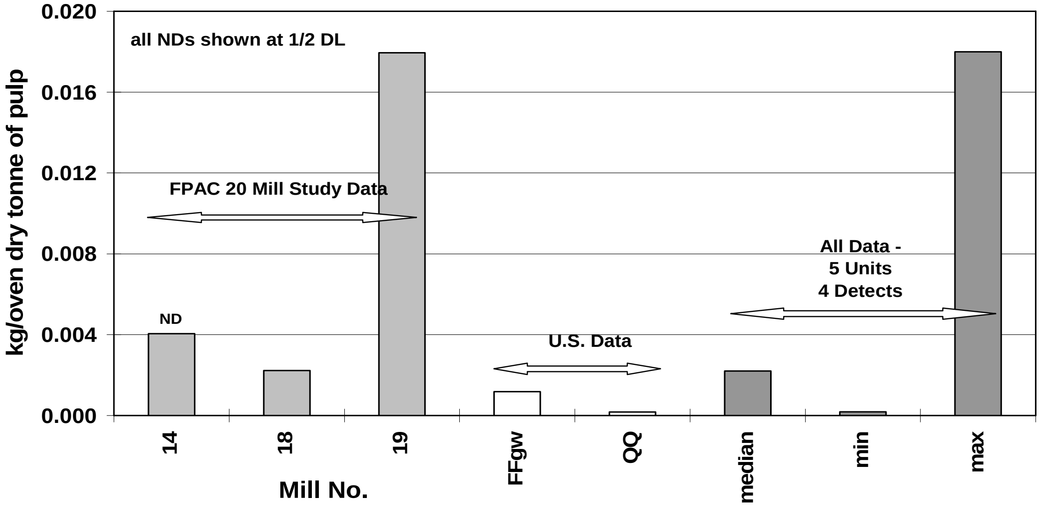


Figure 4.38 Comparison of Formaldehyde Emissions from Canadian and U.S. Groundwood Pulping Operations

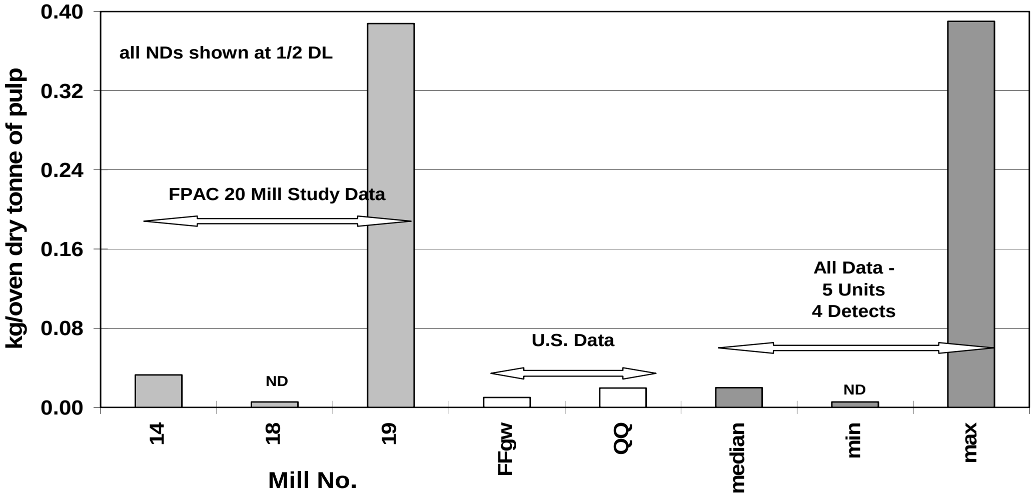


Figure 4.39 Comparison of Methanol Emissions from Canadian and U.S. Groundwood Pulping Operations

Figure 4.40 compares the individual phenol emissions for three Canadian GWP operations (2 detects) with individual emissions from two U.S. GWP operations (1 detect). The median and range of phenol emissions for the combined set of five GWP operations (3 detects) are also shown. Mill 19 in the Canadian data set had the highest emissions. The amount of data on phenol emissions was clearly insufficient to make a clear comparison between U.S. and Canadian GWP operation emissions.

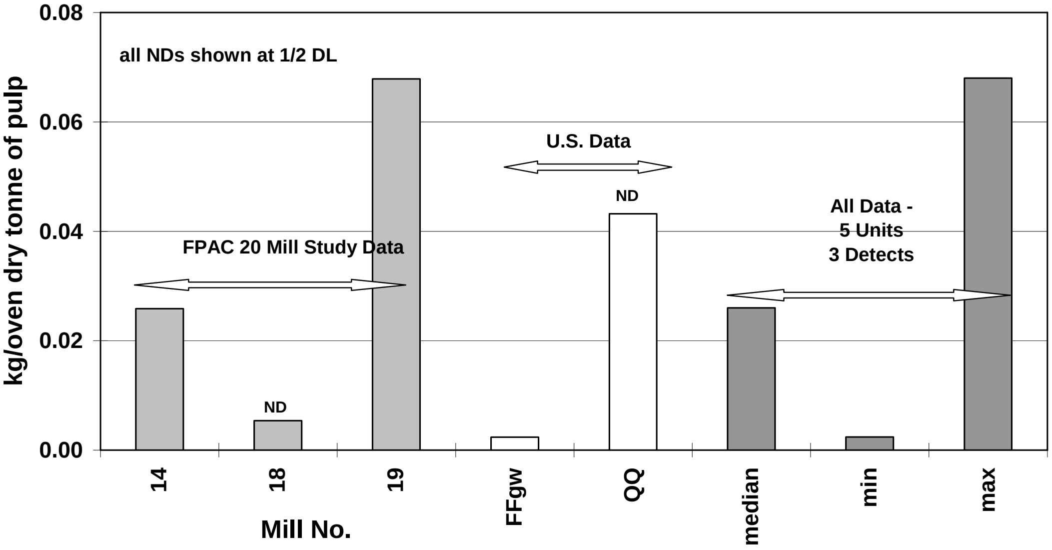


Figure 4.40 Comparison of Phenol Emissions from Canadian and U.S. Groundwood Pulping Operations

Summary for Groundwood Pulping Operations – Since only three Canadian and two U.S. GWP operations were tested for speciated VOC emissions, a strict comparison of these emissions cannot be made. Nevertheless, based on the brief comparisons shown above, it would appear that GWP operations in neither country result in unusually different VOC emissions. Thus the Canadian and U.S. data sets could be effectively combined to yield one robust data set for non-terpene VOC emissions.

4.1.10 *Paper Machines Using Virgin Mechanical Pulps*

Paper machines and pulp dryers are a source of VOCs. Typically, the wet-end and the dry-end speciated and total VOC emissions are approximately equal. VOCs present in the water carrying the pulp to the paper machine or dryer can be released as the water is removed from the sheet. Volatile organic compounds are sometimes present in papermaking additives (defoamers, slimicides, retention aids, wet strength agents, wire and felt cleaners, etc.) and these can also be released during the papermaking process.

Studies of paper machine emissions performed by NCASI (NCASI 1994c, 1997b) have indicated that VOCs present in the pulp slurry being fed to the machine will be found in the roof vent and vacuum system exhaust gases. The most often detected compound is methanol, a byproduct of chemical and mechanical pulping and bleaching processes. However, methanol is also found in recycled fibre slurries, presumably as a result of residual lignin breakdown. Methanol emissions from paper machines at unbleached kraft and semi-chemical mills ranged from 0.15 to 0.75 kg/tonne paper, while paper machines and pulp dryers at bleached kraft mills had emissions under 0.05 kg/tonne paper. At mechanical pulp and recycled pulp mills, emissions were found to range from less than 0.005 to 0.15 kg/tonne paper. Emissions were proportional to the concentration of methanol present in the paper machine whitewater, which is in turn dependent on the amount of methanol being sent to the machine in the pulp slurry. Other compounds found in considerably lower amounts were acetaldehyde, biphenyl, phenol, and chloroform. However, these compounds were not found consistently at all mills. Because of the extremely large gas flow rates in the roof vents, even very low concentrations of compounds can result in relatively large emission rates. Thus, method detection limits become an important issue in the measurement of these emissions.

During the 20-mill FPAC study, several paper machines were tested for speciated VOCs, including five machines using mainly virgin bleached kraft pulp, two making bleached paper, and three drying pulp. However, speciated VOC emission data for only two such U.S. paper machines were available; thus, an adequate comparison of these data cannot be made. Seven paper machines using mainly mechanical pulp were also tested during the FPAC 20-mill study. Speciated VOC emission data for four such machines tested in the U.S. were available. This section compares the Canadian and U.S. VOC emission data for such machines, although the number of U.S. machines tested is small.

Acetaldehyde, biphenyl, formaldehyde, methanol, and phenol are five VOCs emitted by paper machines using virgin mechanical pulp furnish that are frequently tested for, although the source of biphenyl is unclear. Figure 4.41 compares the individual acetaldehyde emissions for seven such Canadian paper machines (3 detects) with individual emissions for four U.S. paper machines that use virgin mechanical pulp furnish (all 4 detects). The median and range of acetaldehyde emissions for the combined set of 11 paper machines that use virgin mechanical pulp furnish (7 detects) are also shown. Ss seen in Figure 4.41, the acetaldehyde emissions for the Canadian and U.S. paper machines that use virgin mechanical pulp furnish are quite comparable.

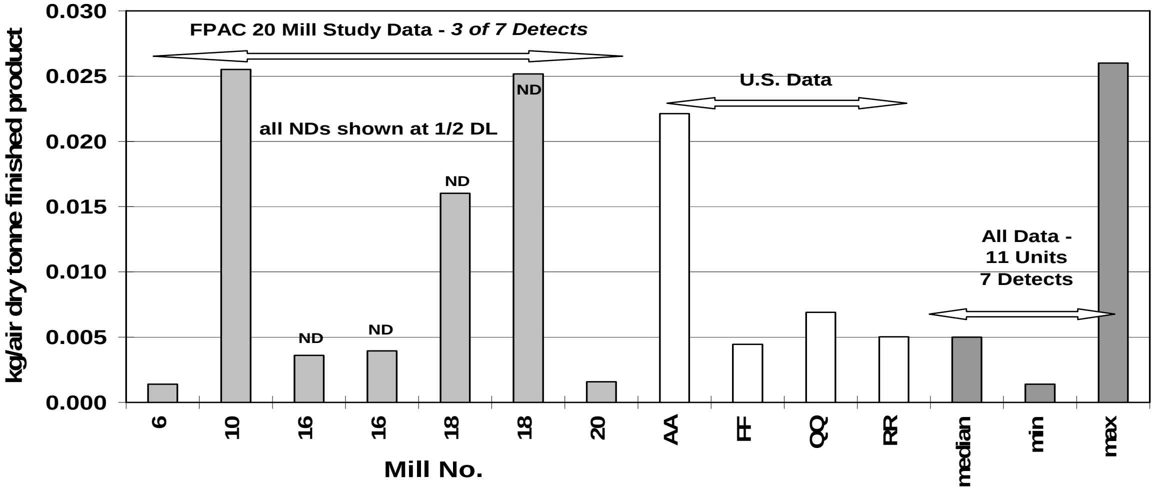


Figure 4.41 Comparison of Acetaldehyde Emissions from Paper Machines Using Virgin Mechanical Pulp Furnish

Figure 4.42 compares the individual biphenyl emissions for five Canadian paper machines that use virgin mechanical pulp furnish with emissions for four U.S. paper machines that use virgin mechanical pulp furnish (all 4 detects). All five of the Canadian machines had non-detect emissions for biphenyl. The median and range of biphenyl emissions for the combined set of nine paper machines that use virgin mechanical pulp furnish (4 detects) are also shown. Since the biphenyl emissions from all five Canadian paper machines tested were NDs, it is difficult to make a proper comparison with the U.S. data. However, at least two of the three U.S. paper machines tested appeared to have more than twice the biphenyl emissions than any of the five Canadian machines sampled. The reasons for this are presently unknown.

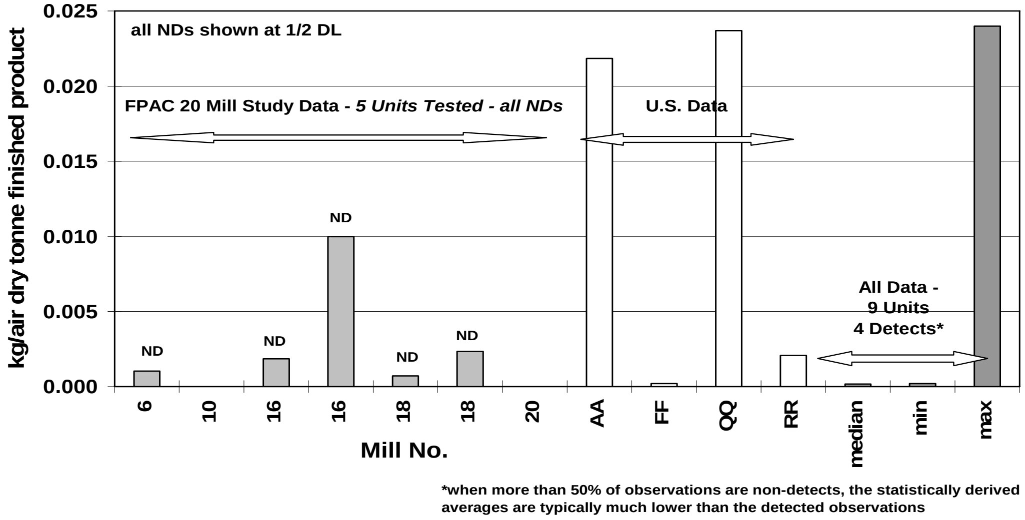


Figure 4.42 Comparison of Biphenyl Emissions from Paper Machines Using Virgin Mechanical Pulp Furnish

Figure 4.43 compares the individual formaldehyde emissions for seven Canadian paper machines that use virgin mechanical pulp furnish (4 detects) with individual emissions for four U.S. paper machines that use virgin mechanical pulp furnish (all 4 detects). The median and range of formaldehyde emissions for the combined set of 11 paper machines that use virgin mechanical pulp furnish (8 detects) are also shown. As seen in Figure 4.43, the median formaldehyde emissions for the Canadian and U.S. paper machines that use virgin mechanical pulp furnish are quite comparable. However, one of the two machines tested at Mill 18 in Canada had HCHO emissions over two times greater than any other machine, but this value was not identified as an outlier.

Figure 4.44 compares the individual methanol emissions for seven Canadian paper machines that use virgin mechanical pulp furnish (3 detects) with individual emissions for four U.S. paper machines that use virgin mechanical pulp furnish (all 4 detects). The median and range of methanol emissions for the combined set of 11 paper machines that use virgin mechanical pulp furnish (7 detects) are also shown. Figure 4.44 shows that the median methanol emissions for the Canadian and U.S. paper machines that use virgin mechanical pulp furnish are quite comparable. Two of the seven Canadian paper machines tested showed rather high levels of methanol (0.30 and 0.74 kg/ADTFP), but they were not identified as outliers. The reasons for this are presently unclear. As previously noted, NCASI studies have shown that emissions of methanol from paper machines are proportional to the concentration of methanol present in the paper machine whitewater, which is in turn dependent on the amount of methanol being sent to the machine in the pulp slurry. Among the two paper machines tested at Mill 18, one processed groundwood and high yield sulphite pulp (2/3:1/3), while the second processed mainly TMP pulp. The latter machine emitted higher levels of formaldehyde and methanol.

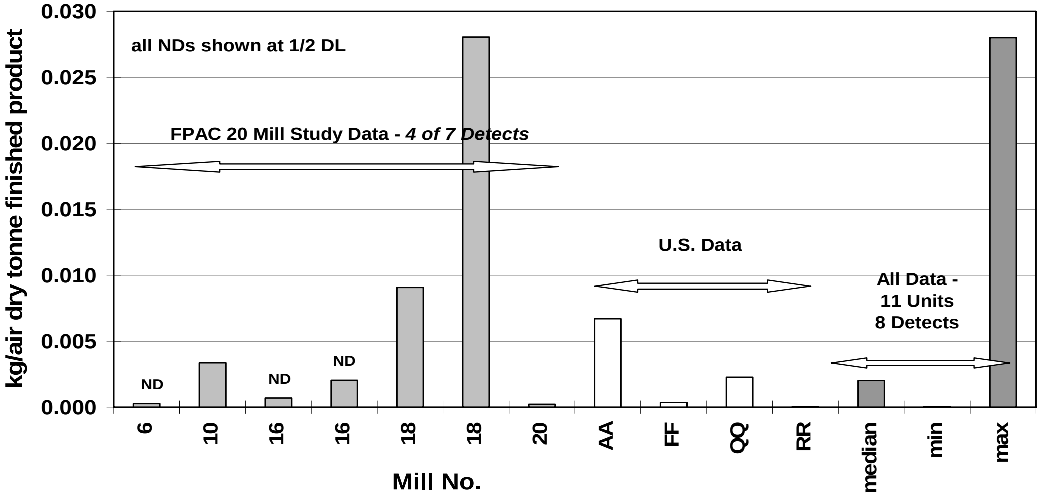


Figure 4.43 Comparison of Formaldehyde Emissions from Paper Machines Using Virgin Mechanical Pulp Furnish

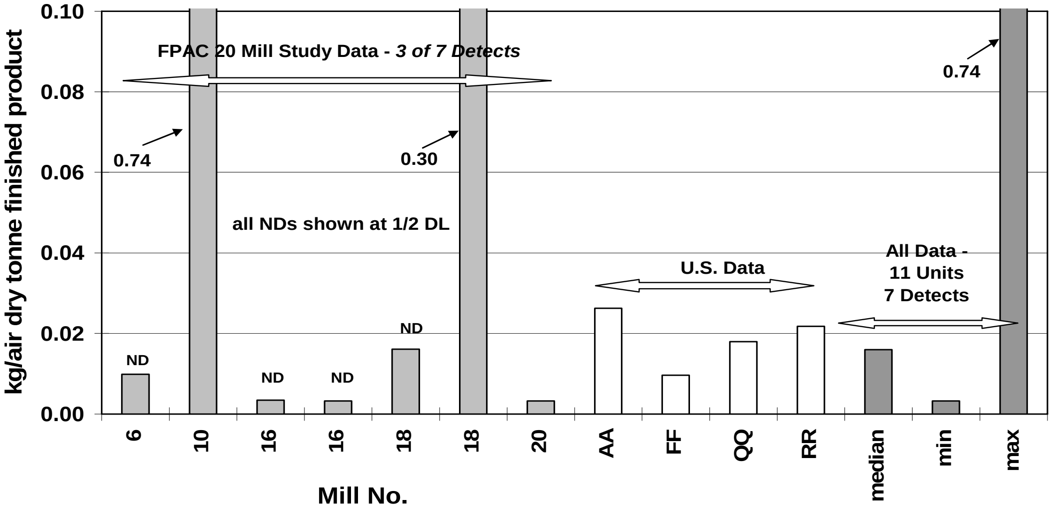
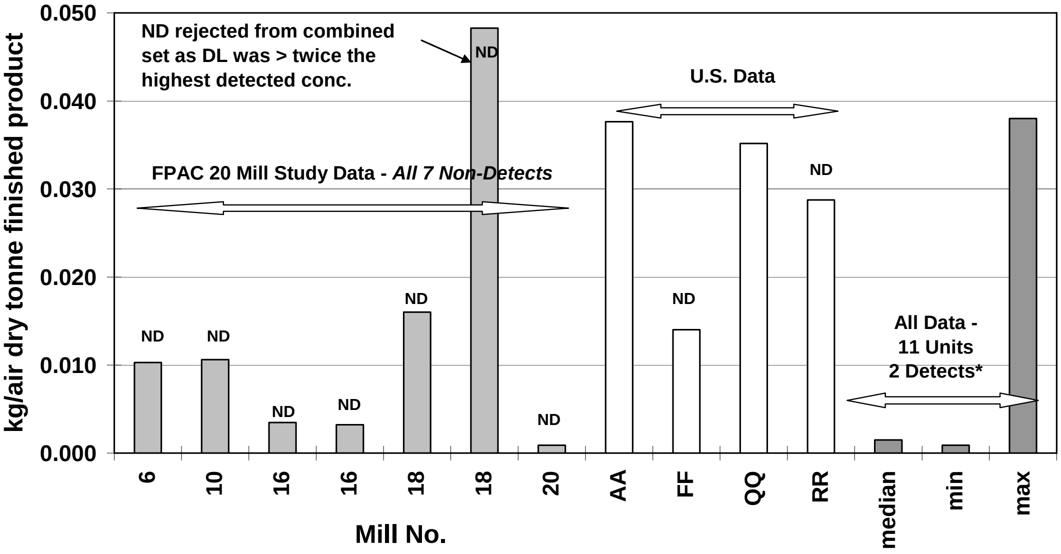


Figure 4.44 Comparison of Methanol Emissions from Paper Machines Using Virgin Mechanical Pulp Furnish

Figure 4.45 compares the individual phenol emissions for seven Canadian paper machines that use virgin mechanical pulp furnish (all 7 non-detects) with individual emissions for four U.S. paper machines that use virgin mechanical pulp furnish (2 detects). The median and range of phenol emissions for the combined set of 11 paper machines that use virgin mechanical pulp furnish (2 detects) are also shown. Since all the tests on the seven Canadian paper machines yielded NDs, it is difficult to draw a comparison between the Canadian and U.S. paper machines for phenol emissions. Also, the median phenol emissions of the combined set is quite low due to the heavily censored nature of this data set (2 of 11 detects).



*when more than 50% of observations are non-detects, the statistically derived averages are typically much lower than the detected observations

Figure 4.45 Comparison of Phenol Emissions from Paper Machines Using Virgin Mechanical Pulp Furnish

Summary for Paper Machines Using Virgin Mechanical Pulp – Since only four U.S. paper machines processing virgin mechanical pulp were tested for speciated VOC emissions, a strict comparison of these emissions with VOC emissions from the seven Canadian paper machines also processing virgin mechanical pulp cannot be made. Nevertheless, based on a comparison of the medians of both data sets shown above, it would appear that paper machines processing mechanical pulp in both countries result in similar VOC emissions.

4.2 Comparison of FPAC 20-Mill Study Data with U.S. Data – CACs and TRS

This section compares selected air emissions data for various unit operations on several criteria air contaminants (CACs) and total reduced sulphur (TRS) generated during the FPAC 20-mill study with averages for similar unit operations in the United Sates. Due to their significant compatibility, both the Canadian and U.S. data sets for CACs were already presented in combined form in NCASI Technical Bulletin No. 884 (NCASI 2004a).

4.2.1 *Direct-Contact Kraft Recovery Furnaces*

Selected data generated during the 20-mill FPAC study on total particulate matter (TPM), PM_{10}, $PM_{2.5}$, and carbon monoxide emissions from Canadian direct contact (DCE) kraft recovery furnaces are compared in this section with similar data on U.S. furnaces.

4.2.1.1 *Direct-Contact Kraft Recovery Furnaces - TPM*

Recovery furnaces are designed and operated to ensure the presence of high levels of sodium fumes in order to capture the sulphur dioxide which is produced as a result of oxidation of reduced sulphur compounds. Consequently, recovery furnace flue gases contain high levels of particulate matter. The uncontrolled particulate matter load from recovery furnaces is highly variable and has been reported to range from 50 to 125 kg/ODTP for DCE furnaces and 100 to 225 kg/ODTP for non-DCE furnaces. The lower particulate loading from DCE furnaces is due to the capture of some particulate matter in the direct contact evaporator. It has been reported that increasing liquor firing density (tonne/day/m^2) increases recovery furnace particulate loading (Nguyen and Rowbottom 1979). Other factors such as bed and furnace temperature, liquor solids, liquor composition, and air distribution also affect uncontrolled particulate emissions from recovery furnaces.

Particulate matter emissions control on kraft recovery furnaces is achieved predominantly by ESPs. Electrostatic precipitator particulate removal efficiencies range from about 90% in older installations to well over 99% in newer units. A few scrubbers have been installed following older ESPs to obtain satisfactory levels of particulate removal. Studies conducted by NCASI showed ESP-equipped recovery furnaces that had particulate emission concentrations below 0.01 gr/dscf (23 mg/Nm^3) contained 80 to 96% particles with less than 3.0 µm diameter (NCASI 1978). For furnaces with higher particulate emissions, 55 to 65% of the total particle mass was in this size regime. The results of this study also suggested that electrostatic precipitators operated on kraft recovery furnaces performed at the same efficiency level on all particle size regimes. Similar results have been reported by Nguyen and Rowbottom (1979). More recent measurements of in-stack filterable particulate matter concentrations showed $PM_{2.5}$ ranged from 35 to 55%, and PM_{10} from 50 to 80%, of the total in-stack filterable particulate emissions. The average total particulate concentration for the five furnaces tested was 0.008 gr/dscf (18 mg/Nm^3) corrected to 8% O_2 (NCASI 2002b).

Figure 4.46 compares total particulate matter (TPM) emissions for three Canadian DCE kraft recovery furnaces with TPM emissions for twenty U.S. DCE furnaces. The figure shows that TPM emissions for the three Canadian furnaces were close to or above the maximum for the 20 U.S. furnaces. Controlled kraft recovery furnace TPM emissions are strictly a function of the control device efficiency, which is typically the particulate removal efficiency of an electrostatic precipitator. Unfortunately, data for only three Canadian DCE furnaces were available during the FPAC study, and as such, it is difficult to conclude whether higher TPM emissions observed here are indicative of other such furnaces operating in Canada.

4.2.1.2 *Direct Contact Kraft Recovery Furnaces – PM_{10}*

Figure 4.47 compares PM_{10} emissions for two Canadian DCE kraft recovery furnaces with PM_{10} emissions for two U.S. DCE furnaces. The PM_{10} emissions are expressed as a percentage of the TPM emissions. As seen in Figure 4.47, the fractions of TPM emissions that are PM_{10} in the Canadian furnaces are quite similar to those in the U.S. furnaces.

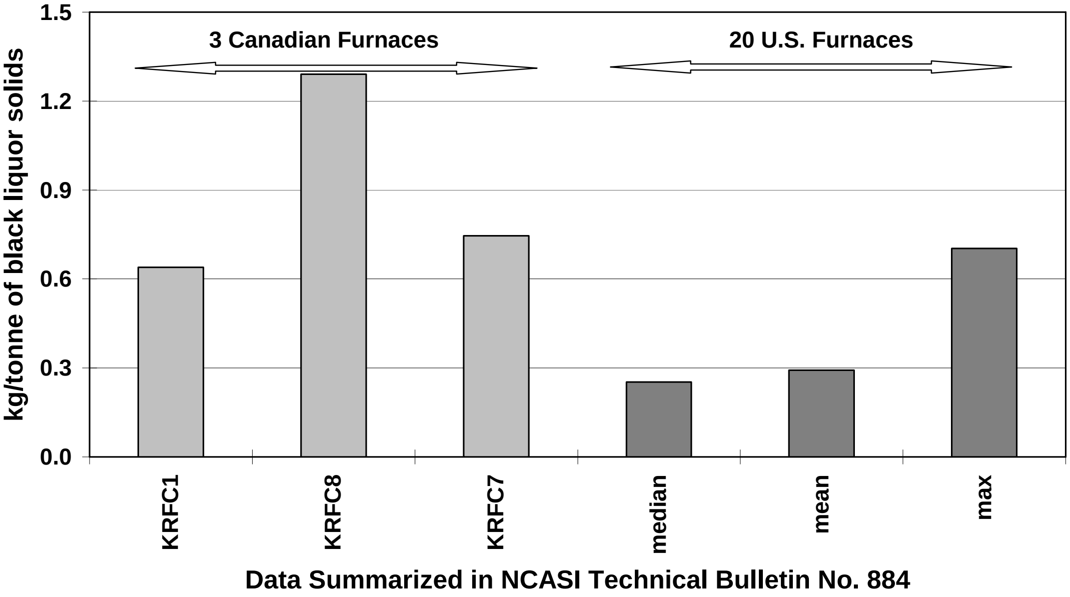


Figure 4.46 Comparison of Total Particulate Matter Emissions from Canadian and U.S. Kraft DCE Recovery Furnaces

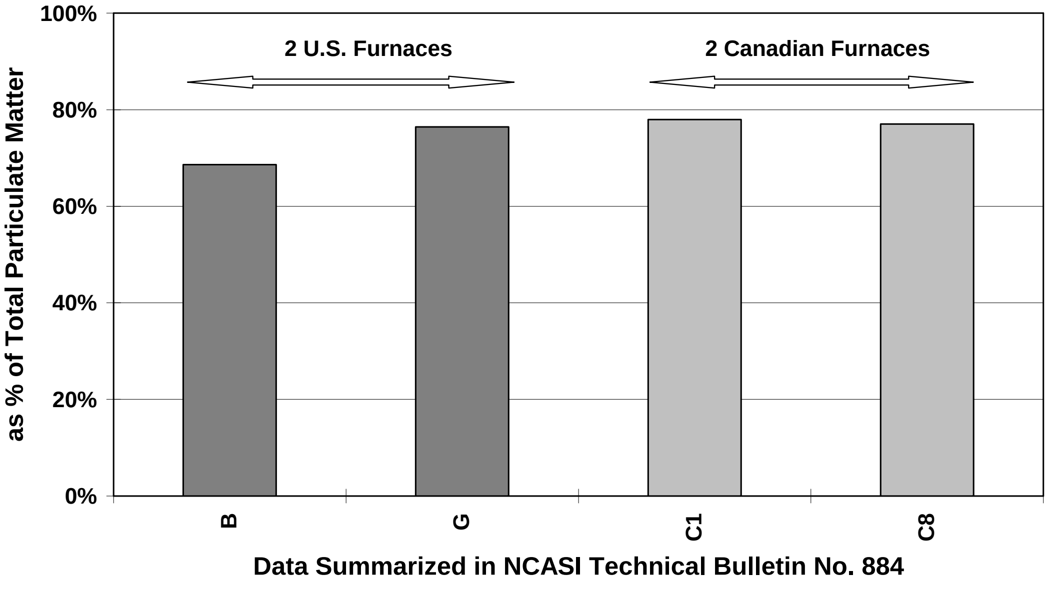


Figure 4.47 Comparison of PM_{10} Emissions from Canadian and U.S. Kraft DCE Recovery Furnaces

4.2.1.3 *Direct Contact Kraft Recovery Furnaces – $PM_{2.5}$*

Figure 4.48 compares $PM_{2.5}$ emissions for two Canadian DCE kraft recovery furnaces with $PM_{2.5}$ emissions for two U.S. DCE furnaces. Once again, the $PM_{2.5}$ emissions are expressed as a percentage of the TPM emissions. Figure 4.48 shows that the fractions of TPM emissions that are $PM_{2.5}$ in the Canadian furnaces are also quite similar to those in the U.S. furnaces.

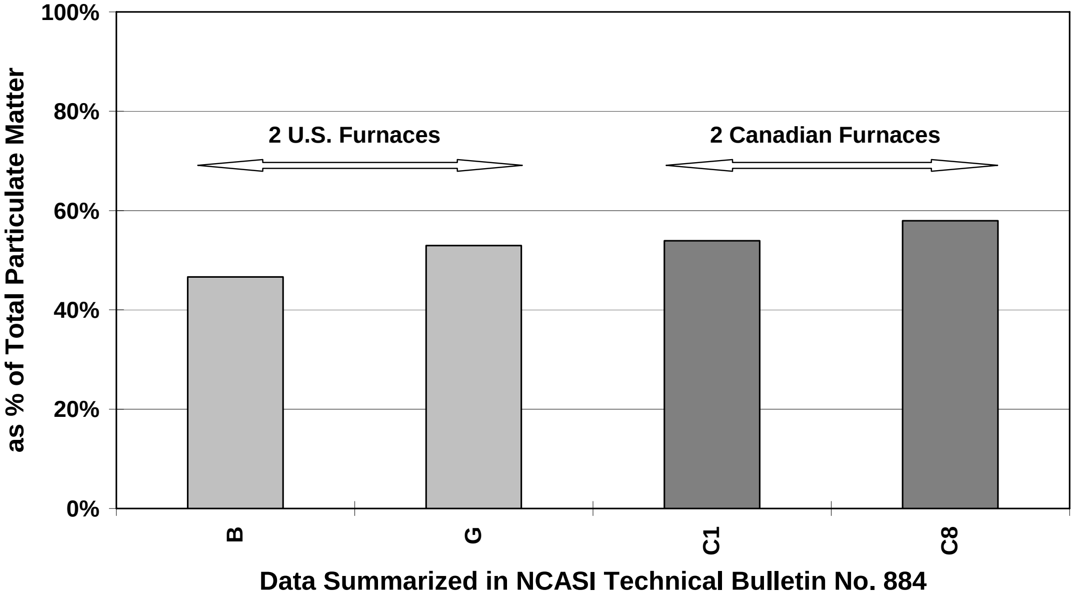


Figure 4.48 Comparison of $PM_{2.5}$ Emissions from Canadian and U.S. Kraft DCE Recovery Furnaces

4.2.1.4 *Direct Contact Kraft Recovery Furnaces – CO*

VOC and CO emissions from kraft recovery furnaces result from incomplete combustion of the organic matter in the liquor. Complete combustion would result in all of the organic carbon in the black liquor being converted to CO_2. CO emissions from recovery furnaces have been found to fluctuate markedly with time, and long-term mean values vary considerably from furnace to furnace. CO levels are affected by swings in liquor firing rates and liquor solids content. Empirical evidence suggests a loose positive correlation between CO and TRS emissions.

CO and VOC emissions are a function of the level of excess air used to complete oxidation of the products of incomplete combustion (PICs) within the upper furnace and also the degree of mixing achieved within the upper furnace. Additional tertiary and quaternary combustion air firing levels would be expected to minimize emissions of CO and VOC from kraft recovery furnaces. Like for any other combustion device, control strategies to minimize CO and VOC emissions involve increasing the residence time, oxygen content, temperature, and level of turbulence in the furnace combustion zone.

Figure 4.49 compares CO emissions for three Canadian NDCE kraft recovery furnaces with CO emissions for sixteen U.S. direct and non-direct contact (NDCE) recovery furnaces. Note that CO emissions are unaffected by whether the furnace is of the DCE or NDCE type. As seen in Figure 4.49, the CO emissions for the three Canadian furnaces generally fall within the range for the U.S. furnaces.

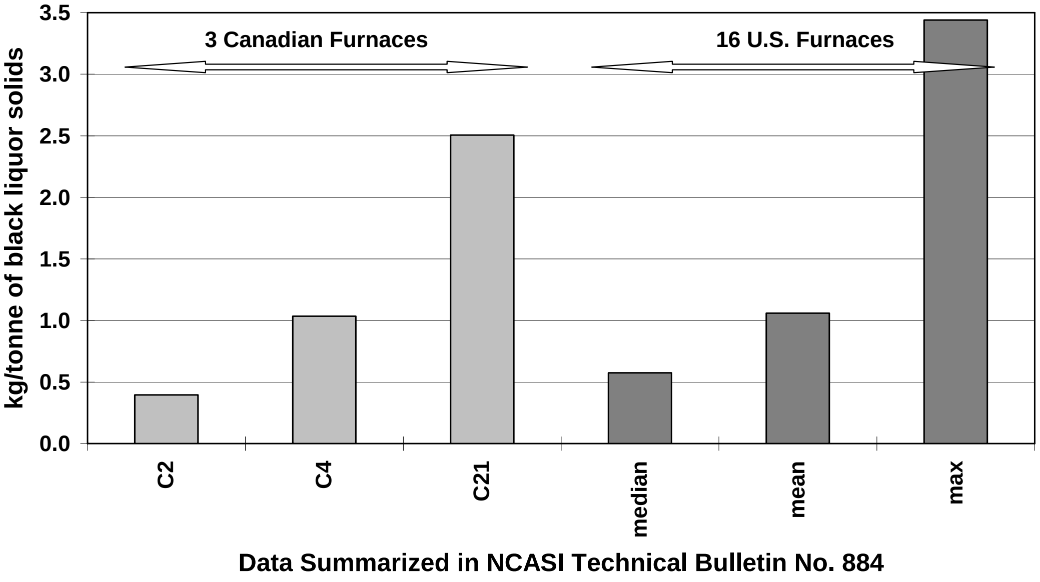


Figure 4.49 Comparison of CO Emissions from Canadian NDCE Kraft Recovery Furnaces to U.S. Kraft DCE and NDCE Recovery Furnaces

4.2.2 *Non-Direct Contact Kraft Recovery Furnaces*

Selected data generated during the 20-mill FPAC study on air emissions of total particulate matter (TPM), PM_{10}, $PM_{2.5}$, SO_2, NO_x, and total reduced sulphur (TRS) from Canadian non-direct contact (NDCE) kraft recovery furnaces are compared in this section with similar data on U.S. furnaces.

4.2.2.1 *Non-Direct Contact Kraft Recovery Furnaces - TPM*

Figure 4.50 compares total particulate matter (TPM) emissions for nine Canadian NDCE kraft recovery furnaces with TPM emissions for eleven U.S. NDCE furnaces. Figure 4.50 shows that unlike for DCE furnaces, the NDCE furnace TPM emissions for the Canadian furnaces are similar to and generally fall within the range for the U.S. furnaces.

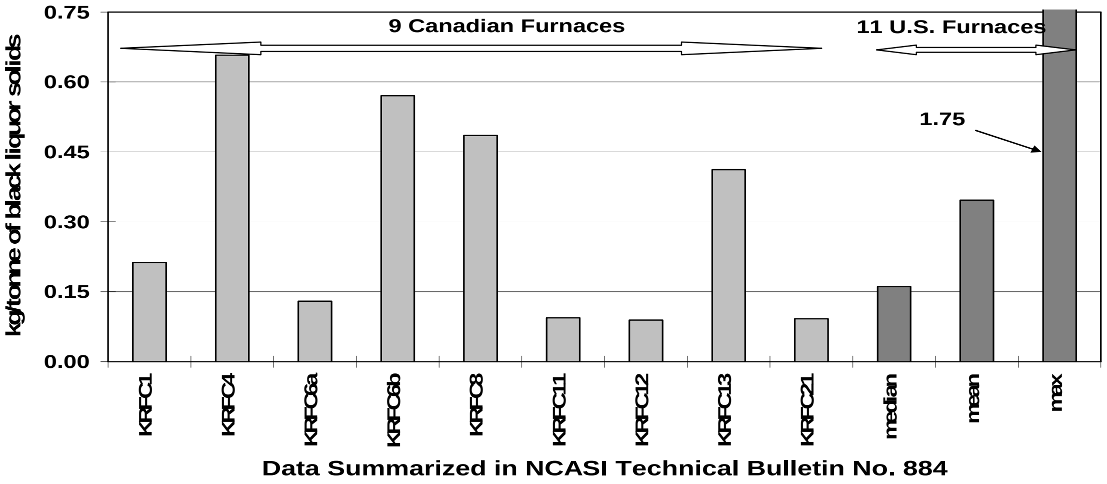


Figure 4.50 Comparison of Total Particulate Matter Emissions from Canadian and U.S. Kraft NDCE Recovery Furnaces

4.2.2.2 *Non-Direct Contact Kraft Recovery Furnaces – PM_{10}*

Figure 4.51 compares PM_{10} emissions for seven Canadian NDCE kraft recovery furnaces with PM_{10} emissions for six U.S. NDCE furnaces. The PM_{10} emissions are expressed as a percentage of the TPM emissions. Figure 4.51 shows that the fractions of TPM emissions that are PM_{10} in the Canadian furnaces are somewhat higher than those in the U.S. furnaces, but generally fall within the same range.

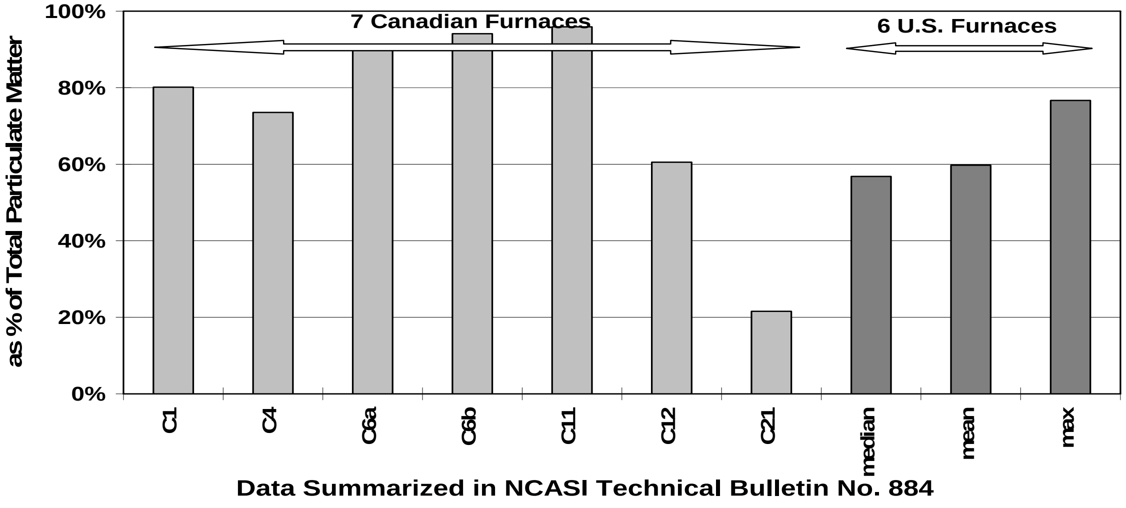


Figure 4.51 Comparison of PM_{10} Emissions from Canadian and U.S. Kraft NDCE Recovery Furnaces

4.2.2.3 *Non-Direct Contact Kraft Recovery Furnaces – $PM_{2.5}$*

Figure 4.52 compares $PM_{2.5}$ emissions for seven Canadian NDCE kraft recovery furnaces with $PM_{2.5}$ emissions for three U.S. NDCE furnaces. The $PM_{2.5}$ emissions are expressed as a percentage of the TPM emissions. Once again, as seen in Figure 4.5, the fractions of TPM emissions that are $PM_{2.5}$ in the Canadian furnaces are somewhat higher than those in the U.S. furnaces, but the U.S. data are very limited.

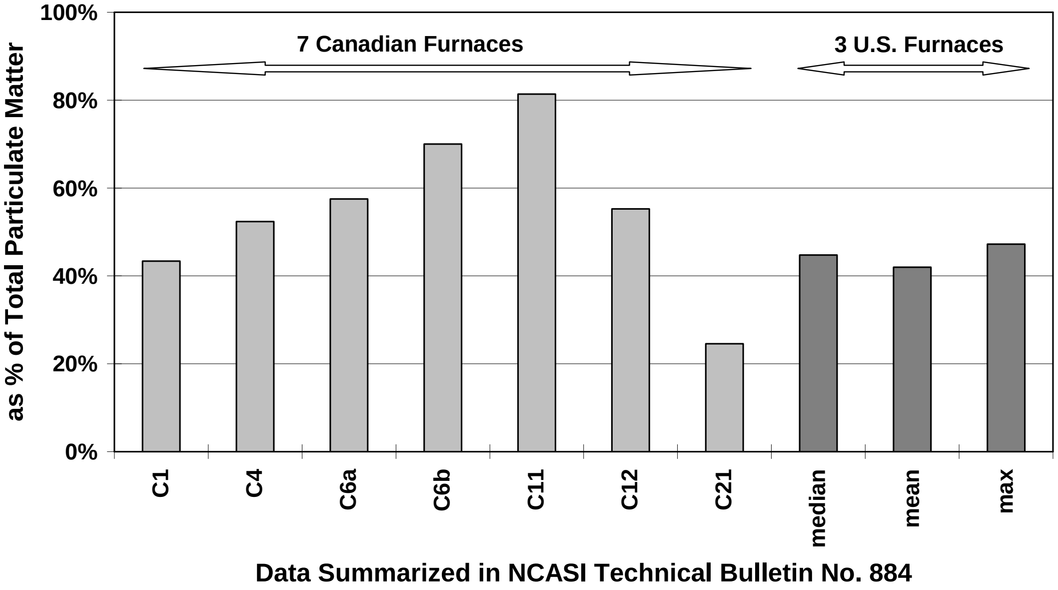


Figure 4.52 Comparison of $PM_{2.5}$ Emissions from Canadian and U.S. Kraft NDCE Recovery Furnaces

4.2.2.4 *Non-Direct Contact Kraft Recovery Furnaces – SO_2*

Black liquor contains a significant amount of sulphur, nominally 3 to 5% by weight of the dissolved solids. While the vast majority of this sulphur leaves the furnace in the smelt, a small fraction (generally under 1%) can escape in gaseous or particulate form. Average SO_2 concentrations in stack gases can range from nearly 0 to 500 ppm and can be extremely variable. SO_2 emissions depend on a variety of factors, which include a) liquor properties such as sulphidity (or sulphur to sodium ratio), heat value, and solids content; b) combustion air and liquor firing patterns; c) furnace design; and d) other furnace operational parameters (NCASI 1991). Liquor sulphidity in most kraft mills today is low enough that it is no longer considered a determining factor for SO_2 emissions (NCASI 1991). Optimizing liquor properties (such as solids content, Btu value) and combustion air firing patterns so as to ***yield maximum and uniform temperatures in the lower furnace*** are currently considered the best strategies for minimizing kraft recovery furnace SO_2 emissions. On average, SO_2 emissions from NDCE units tend to be lower than from DCE units.

Figure 4.53 compares SO_2 emissions for five Canadian NDCE kraft recovery furnaces with SO_2 emissions for forty-six U.S. NDCE furnaces equipped with continuous monitoring systems. Figure 4.53 shows that SO_2 emissions from the Canadian furnaces are similar to and within the range of those from U.S. furnaces.

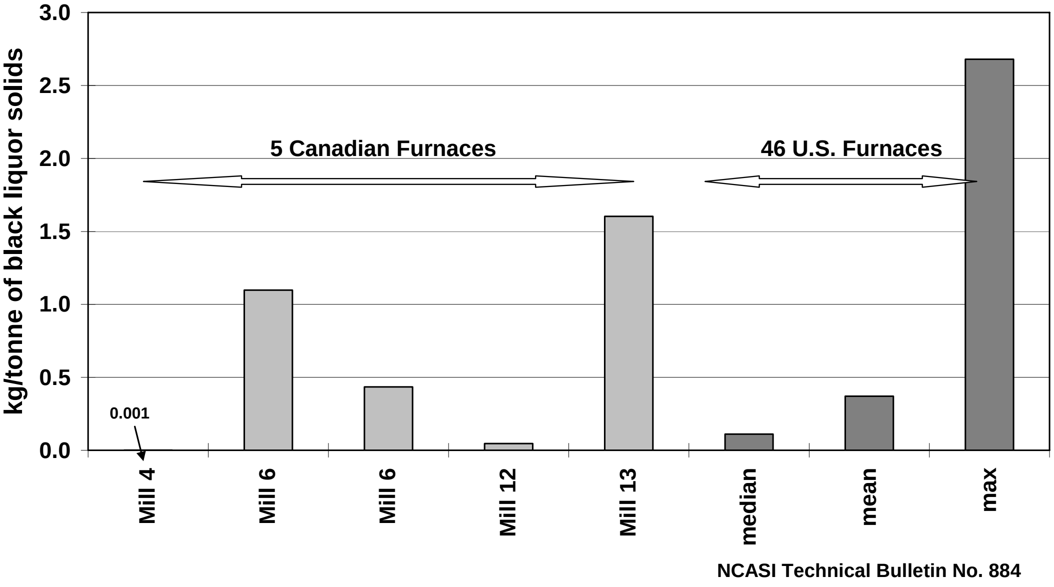


Figure 4.53 Comparison of Sulphur Dioxide Emissions from Canadian and U.S. Kraft NDCE Recovery Furnaces

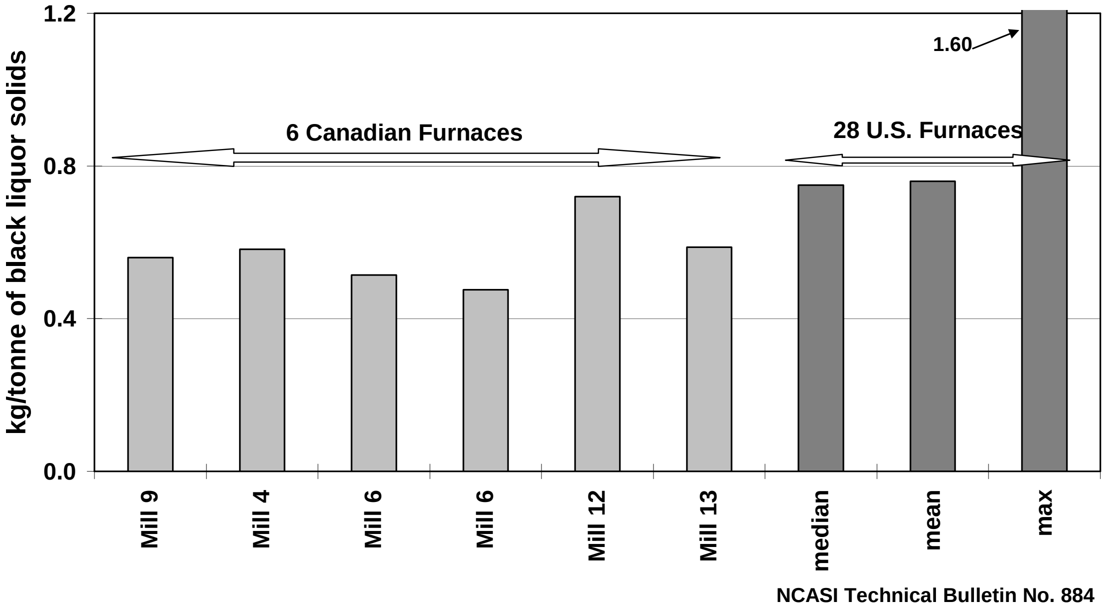
4.2.2.5 *Non-Direct Contact Kraft Recovery Furnaces – NO_x*

Nitrogen in black liquor ranges from about 0.05 to 0.25% of the liquor solids content, typically averaging about 0.1%. During black liquor combustion, nearly three fourths of the liquor nitrogen is released during pyrolysis or devolatilization, partly as ammonia and partly as N_2. The NH_3 released partly oxidizes to NO and partly reduces to N_2. The remaining liquor nitrogen will be bound in the char residue, mostly as a reduced species in the salt residue or smelt. Forssen et al. (1997) have suggested that the oxidation of the NH_3 released during pyrolysis is perhaps the main contributor to the overall NO formation during normal black liquor combustion. Overall conversions of black liquor nitrogen to NO are quite low compared with other fuels, ranging from 10 to about 25%. NO_x levels are typically somewhat higher for NDCE furnaces than DCE units. Besides the greater ages of the DCE units and perhaps a less robust combustion temperature environment, the reasons for this are unclear.

An NCASI investigation into the origins of kraft recovery furnace NO_x emissions and related parameters concluded that black liquor N content was perhaps the most important factor affecting NO_x emissions from kraft recovery furnaces (NCASI 1992). Excess oxygen in the zone where the bulk of liquor combustion takes place was considered the second most important factor for NO_x formation. While very little can be done to affect the liquor nitrogen content, staged air combustion, which is already integral to the operation of most recovery furnaces, is perhaps the best strategy for minimizing NO_x formation. The precise distribution of combustion air between primary, secondary and, if relevant, tertiary or quaternary air levels is most likely furnace-specific.

Forssen, Kilpinen, and Hupa (1998) conclude that NO in kraft recovery furnaces is formed from the oxidation of ammonia produced during liquor droplet devolatilization, and this oxidation is strongly dependent on the temperature and number of stages in which the air is mixed with the devolatilized gases. The authors implied that additional air feed levels in the upper furnace may aid in minimizing NO_x formation, although no full-scale test results were used to support this conclusion. A recent NCASI report (NCASI 2003b) looks at the NH_3-NO-O_2 homogeneous gas phase chemistry in kraft recovery furnaces at various temperatures and residence times. It shows how in spite of NO_x generation within kraft recovery furnaces being generally agreed upon as purely a “fuel NO_x” phenomenon, temperatures within a furnace can nevertheless have a significant effect on the extent of oxidation of the NH_3 released during pyrolysis to NO. Preliminary reports of success in applying staged combustion principles by installing quaternary air ports in certain large furnaces resulting in about a 20 to 40% reduction in baseline NO_x levels is consistent with the NH_3-NO-O_2 homogeneous gas phase chemistry.

Figure 4.54 compares NO_x emissions for six Canadian NDCE kraft recovery furnaces with NO_x emissions for twenty-eight U.S. NDCE furnaces equipped with continuous NO_x monitors. Once again, as seen in Figure 4.54, the NO_x emissions from the Canadian furnaces are similar and within the range for those from the U.S. furnaces.



NCASI Technical Bulletin No. 884

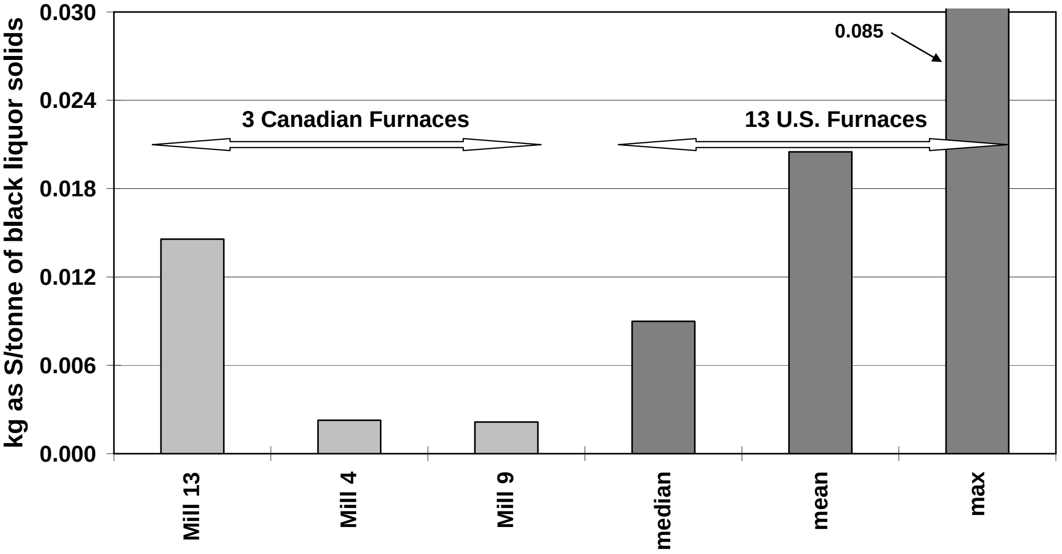
Figure 4.54 Comparison of Oxides of Nitrogen Emissions from Canadian and U.S. Kraft NDCE Recovery Furnaces

4.2.2.6 *Non-Direct Contact Kraft Recovery Furnaces – TRS*

Three factors have contributed to a significant reduction in TRS emissions from recovery furnaces. These are a) avoidance of firing black liquor solids at rates far above the furnace design capacity, which caused excessive H_2S emissions; b) widespread adoption of black liquor oxidation to minimize H_2S pick-up across direct contact evaporators; and c) the increasing number of NDCE-type furnace installations. In addition, notable design improvements have led to better combustion conditions in the furnace. Average concentrations of H_2S in recovery furnace flue gases now range from less than 1 to about 10 ppm for NDCEs (most NDCEs have TRS levels well below 5 ppm), and from 5 to 40 ppm for DCEs with black liquor oxidation. Even with low TRS concentrations, the recovery furnace can still have significant mass emissions because of the high flue gas volumes.

For kraft recovery furnaces equipped with wet bottom ESPs, especially NDCE units, TRS emissions can also result from reduced sulphur compounds being picked up from inadvertent contact between the unoxidized black liquor and the furnace flue gases as the latter pass through the ESP. Modifications to the duct work and internal baffling that minimize contact between the flue gases and the unoxidized liquor may alleviate this problem. Other remedies include replacement of the liquor with water in the bottom of the ESP and conversion of the ESP from a wet bottom to a dry bottom.

Figure 4.55 compares TRS emissions for three Canadian NDCE kraft recovery furnaces with TRS emissions for thirteen U.S. NDCE furnaces. Figure 4.55 shows that the TRS emissions from the three Canadian furnaces are somewhat lower than but within the range of TRS emissions from the 13 U.S. furnaces. However, the Canadian data set had only three furnaces.



NCASI Technical Bulletin No. 849

Figure 4.55 Comparison of Total Reduced Sulphur Emissions from Canadian and U.S. Kraft NDCE Recovery Furnaces

4.2.3 *Smelt Dissolving Tank Vents*

Selected data generated during the 20-mill FPAC study on air emissions of total particulate matter (TPM) and total reduced sulphur (TRS) from Canadian smelt dissolving tanks are compared in this section with similar data on U.S. smelt dissolving tanks.

4.2.3.1 *Smelt Dissolving Tank Vents - TPM*

As with the recovery furnace, particulate emissions from smelt dissolving tanks (SDTs) are comprised of mainly sodium compounds with much smaller amounts of potassium compounds and some trace metal compounds. The dominant compound is sodium carbonate, followed by sodium sulphate. Roughly 90% (by weight) of the particles have equivalent aerodynamic diameters under 10 µm, and 50% have diameters under 1 µm (Pinkerton and Blosser 1981; NCASI 1978). Particulate control of smelt-dissolving tank vent gases is accomplished by installing demister pads, packed towers, or venturi scrubbers. Mist eliminators often follow venturi scrubbers to capture any entrained water droplets.

Figure 4.56 compares total particulate matter (TPM) emissions for ten Canadian smelt dissolving tank (SDT) vents with TPM emissions for twenty-six U.S. SDT vents. As seen in Figure 4.56, the Canadian SDT TPM emissions are similar to and generally fall within the range for the U.S. SDTs, although two of the Canadian SDT vents had the highest TPM emissions among all 36 SDTs.

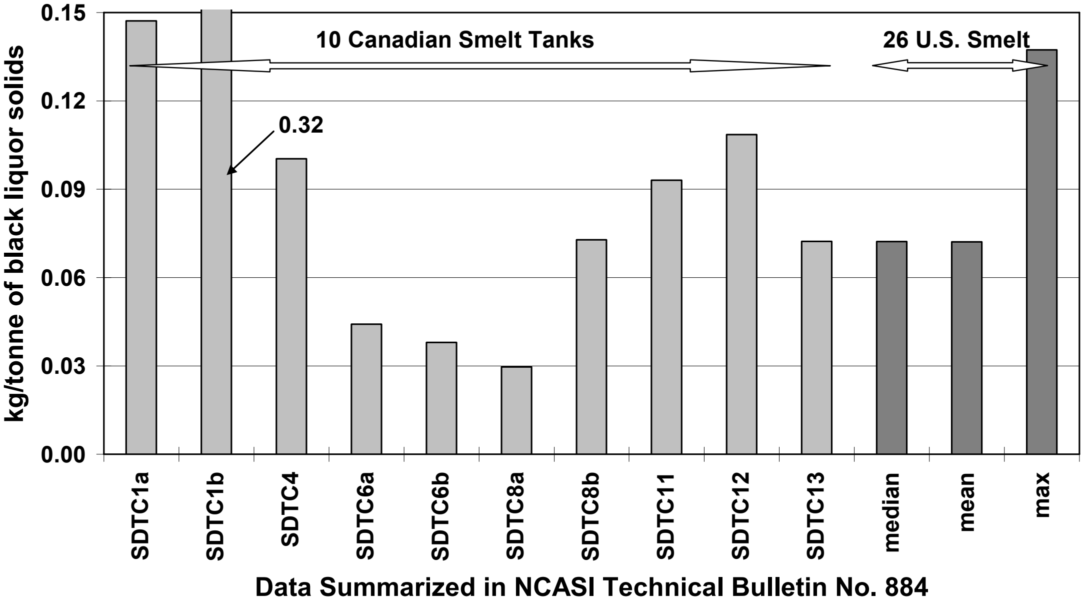


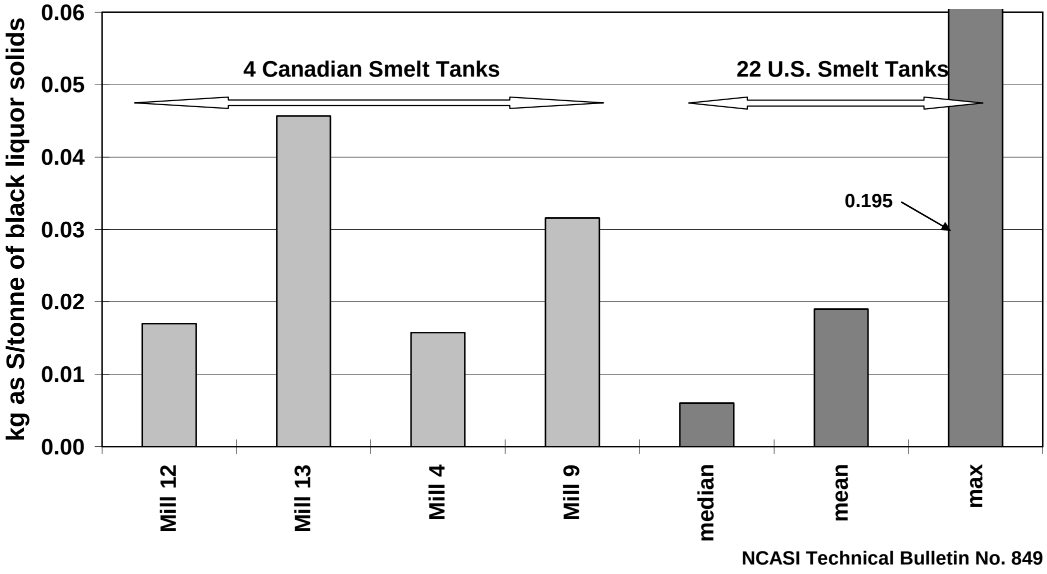
Figure 4.56 Comparison of Total Particulate Matter (TPM) Emissions from Canadian and U.S. Smelt Dissolving Tank Vents

4.2.3.2 *Smelt Dissolving Tank Vents - TRS*

Reduced sulphur compounds (RSCs) arise principally from the sulphides present in smelt and in weak wash. H_2S is the main RSC present in smelt tank vent gases, with typical concentrations measured in the range of 5 to 20 ppm. It is believed to be generated mainly by the steam shattering of smelt (Frederick, Danko, and Ayers 1996). However, if condensates containing organic RSCs (methyl mercaptan, dimethyl sulphide, and dimethyl disulphide) are used in the recausticizing area, higher levels of RSCs could be present in the weak wash, providing greater potential for stripping of these compounds during smelt dissolving or vent gas scrubbing operations.

H_2S emissions can be reduced by lowering the steam pressure at the shatter jets and by using more efficient shatter jet nozzles (Frederick, Danko, and Ayers 1996). Scrubbers using weak wash as scrubbing media can reduce vent gas concentrations of H_2S and methyl mercaptan, but not dimethyl sulphide and dimethyl disulphide. This is because H_2S and CH_3SH are weakly acidic whereas $(CH_3)_2S$ and $(CH_3)_2S_2$ are neutral and therefore not readily scrubbed with alkaline solutions. Scrubbing with an alkaline solution ($pH \geq 11$) is the key to controlling TRS emissions from smelt dissolving tank vent stacks. Caustic or oxidized white liquor is the most effective scrubbing medium, followed by weak wash or green liquor. Water alone is not as effective. When weak wash is used for scrubbing media, it is necessary to use good quality weak wash having less than 20 mg/L settleable solids. A recent NCASI report reviews available information on emissions of RSCs and TRS from smelt dissolving tanks, including the experiences of several U.S. kraft pulp mills that had problems meeting TRS emission limits (NCASI 2005b).

Figure 4.57 compares TRS emissions for four Canadian smelt dissolving tank (SDT) vents with TRS emissions for twenty-two U.S. SDT vents. Figure 4.57 shows that the Canadian SDT TRS emissions are similar to and generally fall within the range for the U.S. SDTs.



NCASI Technical Bulletin No. 849

Figure 4.57 Comparison of Total Reduced Sulphur (TRS) Emissions from Canadian and U.S. Smelt Dissolving Tank Vents

4.2.4 *Kraft Lime Kilns*

Data generated during the 20-mill FPAC study on emissions of total particulate matter (TPM), PM_{10}, $PM_{2.5}$, SO_2, and TRS from kraft lime kilns are compared in this section with similar data for U.S. kilns. Relatively few lime kilns both in the U.S. and in Canada are equipped with ESPs, the majority being equipped with wet scrubbers.

4.2.4.1 *Kraft Lime Kilns with ESPs - TPM*

While passing through the kiln, the combustion gases pick up a good deal of particulate matter that must be removed before the gases exit to the atmosphere. Mechanical devices such as dust chambers or cyclones are generally used to remove larger particles, which are mainly calcium-containing. A wet scrubber or electrostatic precipitator follows for removal of smaller particulates, which are mainly sodium sulphate and sodium carbonate and have aerodynamic diameters less than 10 µm. Particulate matter from fuel oil and petroleum coke burning will be captured as well. Most lime kilns are controlled by venturi scrubbers, with pressure drops ranging from 17 to 34 inches of water, although ESPs are used in new installations. Particulate emissions from lime kilns with ESPs tend to be much lower than from those with wet scrubbers.

Figure 4.58 compares total particulate matter (TPM) emissions for three Canadian kraft lime kilns with ESPs with TPM emissions for four U.S. kilns also equipped with ESPs. As seen in Figure 4.58, the TPM emissions from the Canadian and U.S. kilns equipped with ESPs were generally comparable, with one kiln from both sets having higher than average emissions.

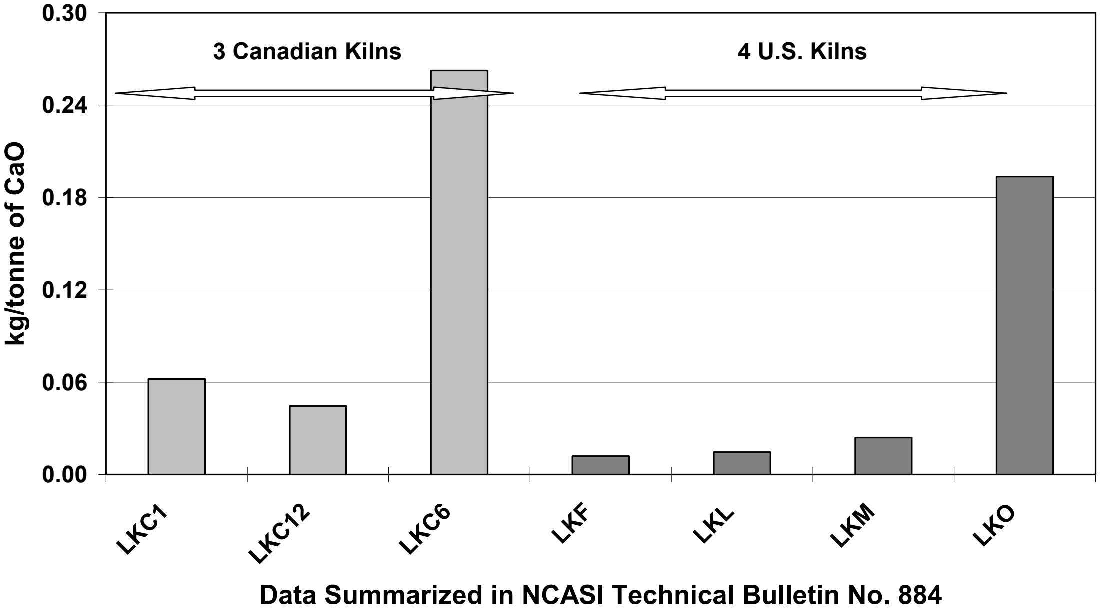


Figure 4.58 Comparison of Total Particulate Matter Emissions from Canadian and U.S. Kraft Lime Kilns with ESPs

4.2.4.2 *Kraft Lime Kilns with ESPs – PM_{10}*

Figure 4.59 compares PM_{10} emissions for three Canadian kraft lime kilns equipped with ESPs with PM_{10} emissions for three U.S. kilns also with ESPs. The PM_{10} emissions are expressed as a percentage of the TPM emissions. Figure 4.59 shows that the fractions of TPM emissions that are PM_{10} in the Canadian kilns are comparable to those from the U.S. kilns.

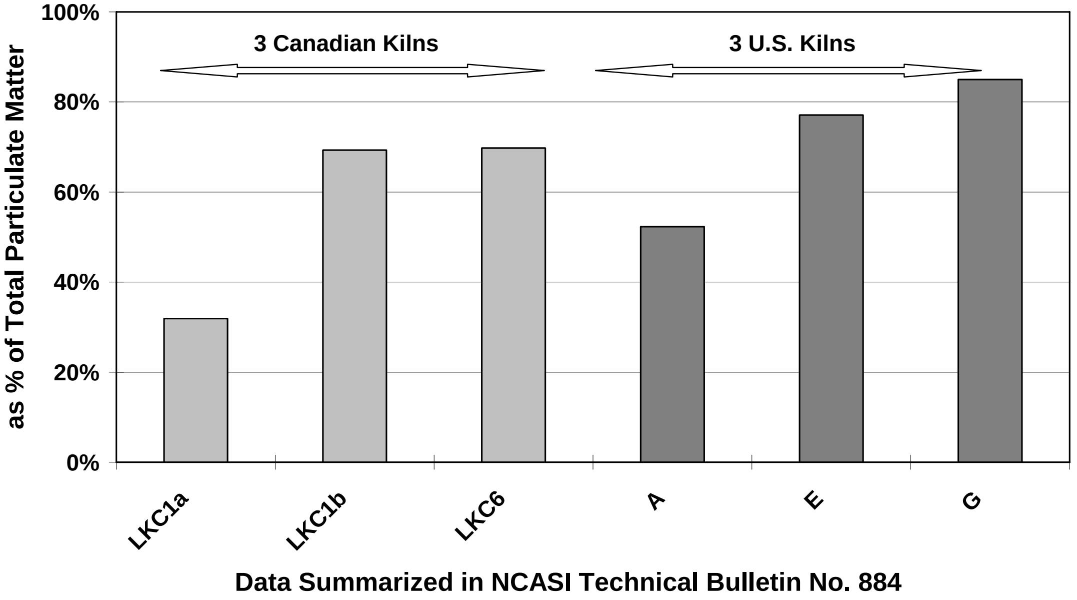


Figure 4.59 Comparison of PM_{10} Emissions from Canadian and U.S. Kraft Lime Kilns with ESPs

4.2.4.3 *Kraft Lime Kilns with ESPs – $PM_{2.5}$*

Figure 4.60 compares $PM_{2.5}$ emissions for three Canadian kraft lime kilns equipped with ESPs with $PM_{2.5}$ emissions for three U.S. kilns also with ESPs. The $PM_{2.5}$ emissions are also expressed as a percentage of the TPM emissions. Figure 4.60 shows that the fractions of TPM emissions that are $PM_{2.5}$ in the Canadian kilns are generally smaller than those for the U.S. kilns. Since the number of kilns in both sets is just three, it is difficult to explain this difference, or to comment on its relevancy. Nevertheless, two of the three Canadian kilns tested showed 0% $PM_{2.5}$ emissions, which appear a bit suspect.

4.2.4.4 *Kraft Lime Kilns with Wet Scrubbers - TPM*

Figure 4.61 compares total particulate matter (TPM) emissions for eight Canadian kraft lime kilns with wet scrubbers with TPM emissions for twenty-three U.S. kilns also equipped with wet scrubbers. As seen in Figure 4.61, the TPM emissions for the Canadian kilns equipped with wet scrubbers are comparable to the averages for similar U.S. kilns, and fall within the range for the U.S. kilns.

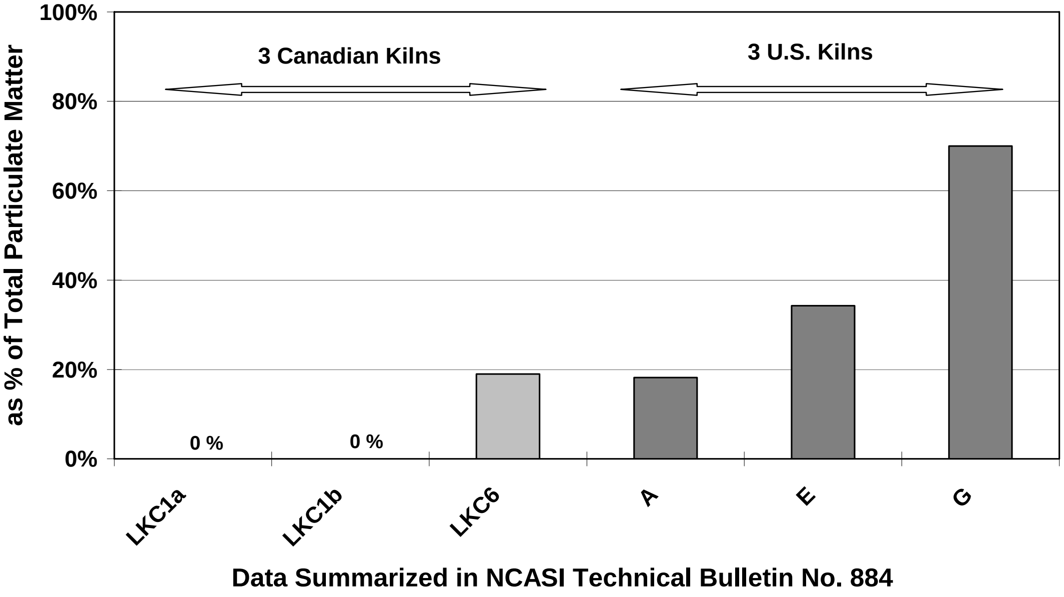


Figure 4.60 Comparison of $PM_{2.5}$ Emissions from Canadian and U.S. Kraft Lime Kilns with ESPs

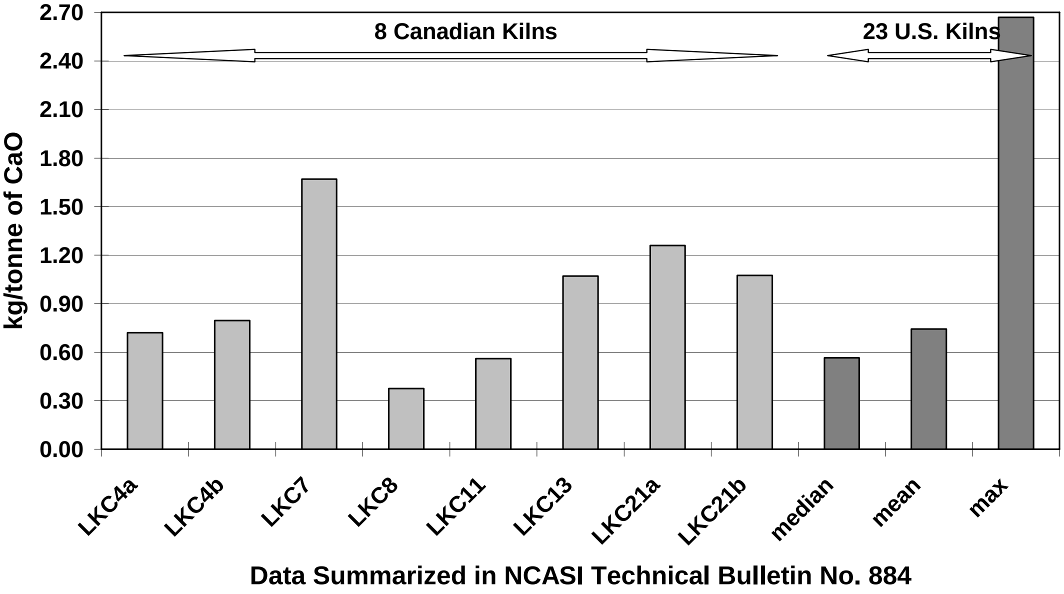


Figure 4.61 Comparison of Total Particulate Matter Emissions from Canadian and U.S. Kraft Lime Kilns with Wet Scrubbers

4.2.4.5 *Kraft Lime Kilns with Wet Scrubbers – SO_2*

Sulphur dioxide is formed in lime kilns when fuel oil or petroleum coke is burned as primary fuel. SO_2 will also be formed if noncondensible gases (NCGs) or stripper off-gases (SOGs) containing sulphur are burned in the kiln. Lime muds also contain a small amount of sulphur, which when oxidized, would form SO_2. Thus, fossil fuels such as fuel oil, kraft mill NCG/SOGs, and soluble sulphides in lime mud can contribute a significant amount of sulphur to the inputs of a lime kiln. However, the regenerated quicklime in the kiln acts as an excellent in situ scrubbing agent, and venturi scrubbers following the kiln can further augment this SO_2 removal process since the scrubbing solution becomes alkaline from the captured lime dust. Consequently, even though the potential for SO_2 formation in a kiln that burns sulphur-containing fuels with or without NCGs/SOGs is high, most lime kilns emit very low levels of SO_2 (50 ppm or less). Some kilns do, however, occasionally emit higher levels of SO_2 (50 to 200 ppm). It is unclear why this happens. Under certain low oxygen conditions, elevated SO_2 levels have been reportedly observed in lime kiln exit gases ahead of the scrubber (Burgess, pers. comm.). Another theory proposed is that the SO_2 generated in the kiln is captured exclusively by the sodium salts (Na_2CO_3 and Na_2SO_4) resulting from volatilization of the lime mud Na content and not by the calcium salts (Kiiskila 1990). Thus, when the ratio of total sulphur input to the kiln to the sodium content in lime mud fed to the kiln increases beyond 1, either by increasing the sulphur input from fuels, NCGs, etc. or from decreasing lime mud Na levels from better mud washing, the efficiency of SO_2 capture also begins to fall.

Emission test data with corresponding fuel input information for over 30 kilns were summarized in an NCASI report (NCASI 2004a). SO_2 concentrations did not appear to be related to either the fuel type (oil, gas) or the presence or absence of LVHC NCG or SOG burning in the kiln. A preliminary sulphur input-output balance was also carried out on 25 kilns with wet scrubbers and seven kilns with ESPs. These kilns had sulphur inputs from fuel oil, NCGs, and SOGs, or just lime mud. The results showed over 95% of the SO_2 generated from the oil, NCG/SOGs, or lime mud was captured within the kiln. Average SO_2 emissions from seven kilns equipped with ESPs were somewhat higher than the average emissions for 25 kilns equipped with wet scrubbers.

Figure 4.62 compares sulphur dioxide (SO_2) emissions for two Canadian kraft lime kilns with wet scrubbers with SO_2 emissions for twenty-three U.S. kilns equipped with wet scrubbers. As seen in Figure 4.62, the SO_2 emissions for the two Canadian kilns were somewhat higher than the averages for the U.S. kilns, but were lower than the maximum value for the U.S. data set.

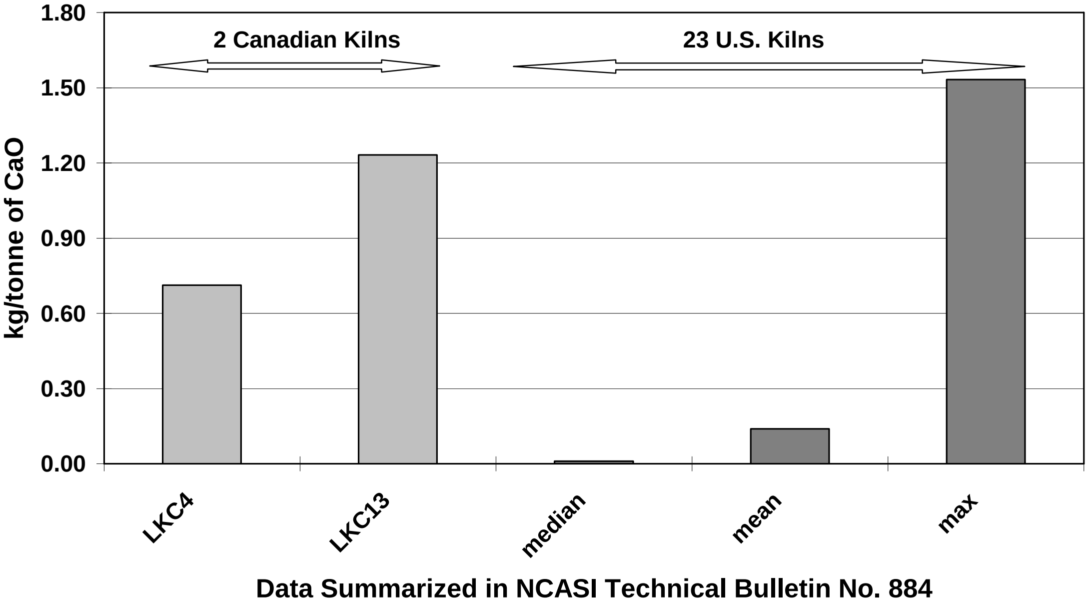


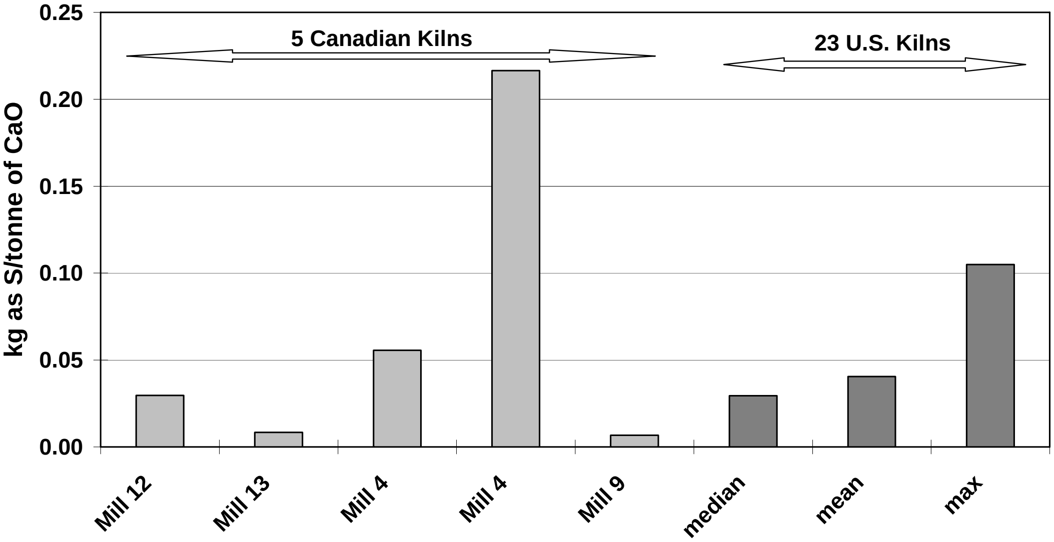
Figure 4.62 Comparison of Sulphur Dioxide Emissions from Canadian and U.S. Kraft Lime Kilns with Wet Scrubbers

4.2.4.6 *Kraft Lime Kilns – TRS*

Lime mud is the primary source of H_2S, which can be released when CO_2-rich flue gas comes into contact with sodium sulphide in the lime mud fed to the kiln. If a scrubber is used, the scrubber make-up water can be a potential source of reduced sulphur compounds (RSCs) if condensates or other RSC-containing liquids are used; organic RSCs can be stripped as the flue gas passes through the scrubber. Minimizing concentrations of RSCs in the scrubber make-up water will reduce the potential for this stripping. Many mills use lime kilns for the burning of concentrated NCGs that contain high concentrations of RSCs. Under normal operating conditions, the RSCs are oxidized to SO_2 in the kiln. Under upset conditions, it is possible that a portion of the RSCs will not be oxidized and thus be emitted. Under low oxygen conditions in the kiln, fuel sulphur may cause an increase in TRS emissions (Burgess, pers. comm..).

Lime kiln TRS control mainly involves achieving a high degree of lime mud washing. Lime mud is the precipitate resulting from the causticizing reaction when Na_2CO_3 in the green liquor is converted to NaOH and lime is converted to $CaCO_3$. Sodium sulphide entrained in the lime mud reacts with CO_2 in the cold end of the kiln, giving rise to H_2S emissions. Proper operation of the lime mud filter to prevent Na_2S from entering the lime kiln and allowing for oxidation of any residual Na_2S to $Na_2S_2O_3$ is usually sufficient to keep H_2S levels below about 8 ppm. The use of sulphide-free streams such as fresh water or clean condensate for make-up in the scrubber also prevents H_2S formation by contact with kiln gases. Maintaining sufficient excess oxygen in the flue gases to ensure H_2S formed during the drying of lime mud is oxidized to SO_2 is also a potential alternative to further reduce lime kiln TRS emissions (Jarvensivu, Kivivasara, and Saari 1998). Occasionally, addition of caustic to the scrubber make-up can serve to reduce TRS emissions if these emissions become unacceptably elevated.

Figure 4.63 compares total reduced sulphur (TRS) emissions for five Canadian kraft lime kilns (all with wet scrubbers) with TRS emissions for twenty-three U.S. kilns (also all with wet scrubbers). As seen in Figure 4.63, the TRS emissions for four of the five Canadian kilns were comparable to the averages for the U.S. kilns. However, one of the two Mill 4 kilns had the highest TRS emissions among both sets of data.



NCASI Technical Bulletin No. 849

Figure 4.63 Comparison of Total Reduced Sulphur Emissions from Canadian and U.S. Kraft Lime Kilns with Wet Scrubbers

4.2.5 *Kraft Thermal Oxidizers*

Due to several advantages they offer, many kraft mills have opted to burn NCGs in stand-alone thermal oxidizers. Oxidizers generate high levels of SO_2 normally requiring add-on SO_2 control (scrubbers). NO_x emissions can result from burning ammonia-rich SOGs in thermal oxidizers (NCASI 2004b). Measurements at nine oxidizers showed conversion rates of SOG NH_3 to NO ranging from 5% to 38%.

Only one kraft mill thermal oxidizer was tested for SO_2, NO_x, CO, and TRS during the 20-mill FPAC study. These emissions are compared with the median and maximum emissions for several U.S. thermal oxidizers in Figure 4.64. As seen in this figure, the emissions of SO_2, NO_x, CO and TRS for the single Mill 12 Canadian thermal oxidizer fall within the range of emissions for the U.S. thermal oxidizers.

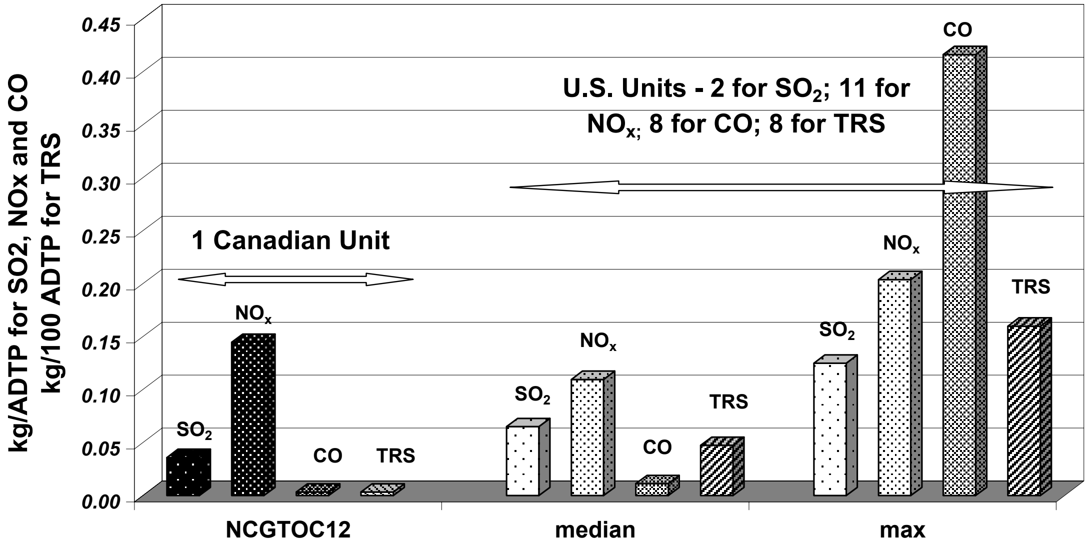


Figure 4.64 Comparison of SO_2, NO_x, CO and TRS Emissions Between One Canadian and Several U.S. Thermal Oxidizers

4.2.6 *Sulphite Recovery Furnaces*

Selected data generated during the 20-mill FPAC study on total particulate matter (TPM), SO_2, and NO_x emissions from Canadian sulphite recovery furnaces are compared in this section with similar data on U.S. furnaces.

4.2.6.1 *Sulphite Recovery Furnaces - TPM*

Particulate emissions are a concern for sulphite recovery furnaces that burn both ammonium and magnesium base liquor. The principal issue at ammonium base mills is the formation of very small ammonium salt particles (such as ammonium sulphate) in the furnace and absorber. These particles can result in a visible plume from the recovery furnace stack, sometimes referred to as blue haze. Particulates from magnesium base liquor combustion are mainly MgO. However, trace metals can be present in both ammonium and magnesium base liquor combustion gases.

Figure 4.65 compares total particulate matter (TPM) emissions for four Canadian sulphite recovery furnaces with TPM emissions for three U.S. sulphite recovery furnaces. All three U.S. furnaces burned magnesium base liquor, while three out of four Canadian furnaces burned ammonium base liquor (C22 was Mg base). Figure 4.65 shows that the Canadian furnace TPM emissions were comparable to those from the U.S. furnaces.

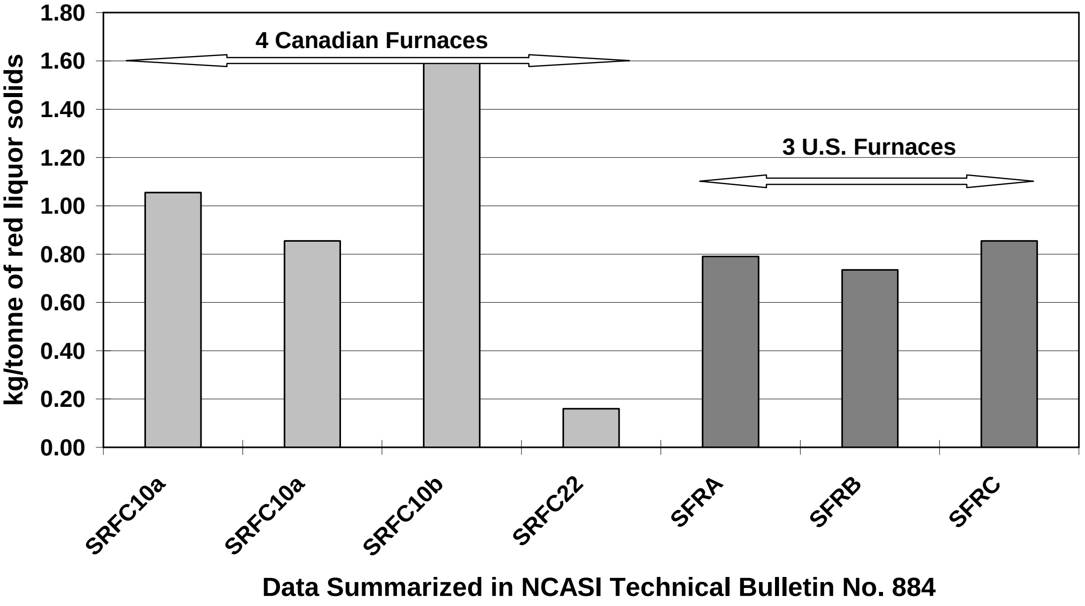


Figure 4.65 Comparison of Total Particulate Matter Emissions from Canadian and U.S. Sulphite Recovery Furnaces

4.2.6.2 *Sulphite Recovery Furnaces – SO_2*

Gases resulting from combustion of spent sulphite pulping liquor contain significant concentrations of SO_2. These gases are generally routed through various absorbers and scrubbers to recover SO_2. Where magnesium base liquor is burned, magnesium oxide particles are first recovered from the combustion flue gases and then the MgO is used to make new pulping liquor.

Figure 4.66 compares sulphur dioxide emissions for four Canadian sulphite recovery furnaces with SO_2 emissions for eight U.S. sulphite recovery furnaces. Figure 4.66 shows that the Canadian furnace SO_2 emissions fall within the range of emissions for the U.S. furnaces. It should be noted that the maximum emission from one U.S. furnace of about 13.6 kg/TBLS corresponded to an unusual situation where the digester gases were directed to the recovery stack without scrubbing.

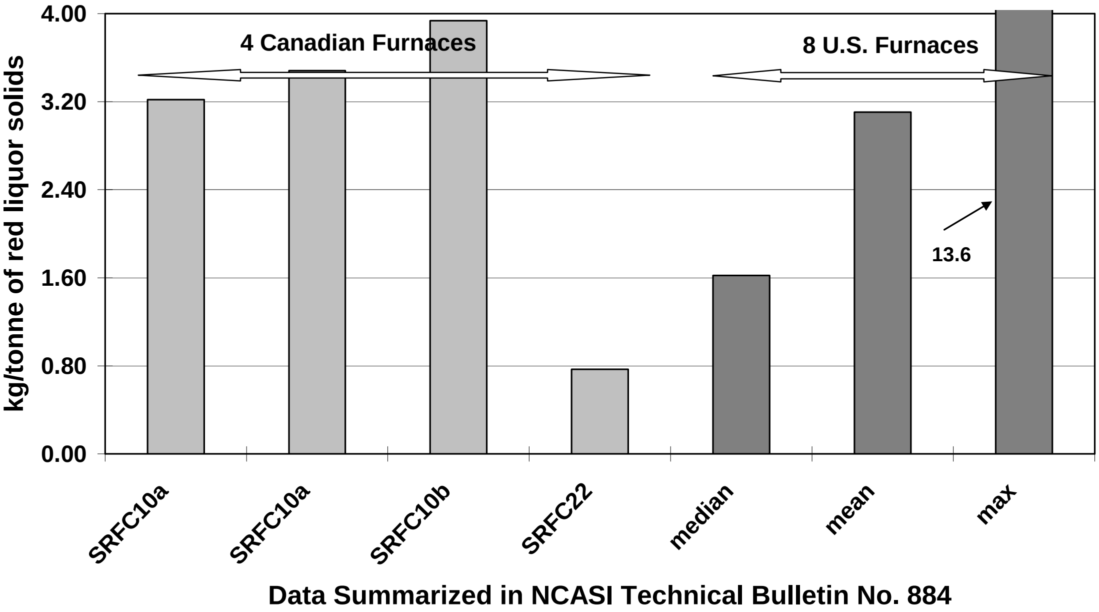


Figure 4.66 Comparison of Sulphur Dioxide Emissions from Canadian and U.S. Sulphite Recovery Furnaces

4.2.6.3 Sulphite Recovery Furnaces – NO_x

Spent liquor contains nitrogen that originated in the wood chips. Combustion of liquor results in NO and NO_2, which are mainly of "fuel NOx" origin. When spent ammonium base liquor is burned, there will be additional NO_x formed due to the presence of ammonium in the spent liquor.

Figure 4.67 compares emissions of the oxides of nitrogen (NO_x) for four Canadian sulphite recovery furnaces with NO_x emissions for seven U.S. sulphite recovery furnaces, and shows the Canadian furnace NO_x emissions fall within the range of emissions for the U.S. furnaces.

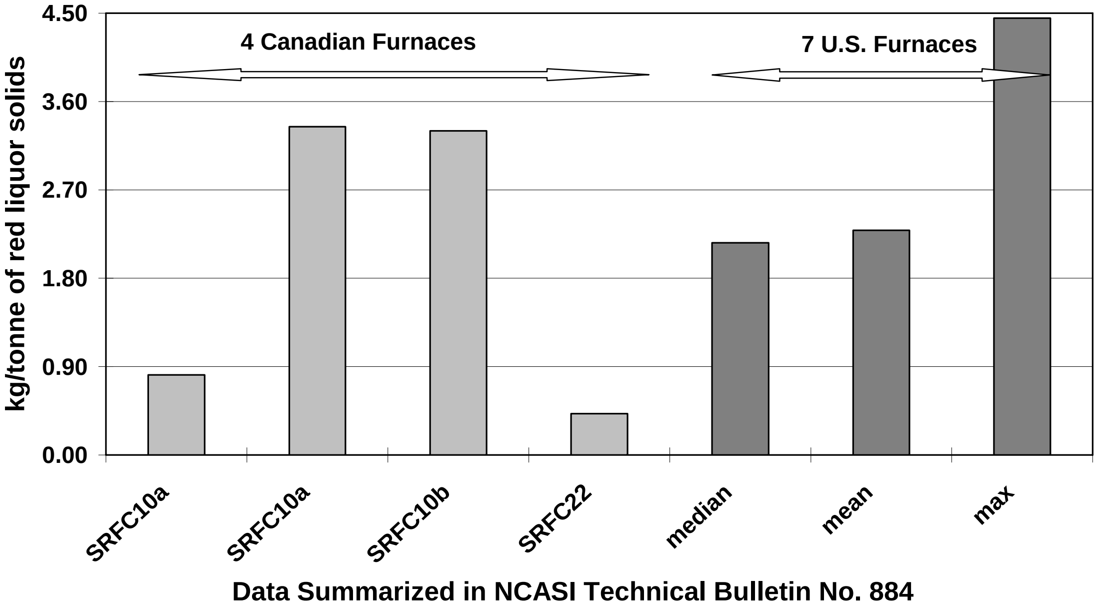


Figure 4.67 Comparison of Oxides of Nitrogen (NO_x) Emissions from Canadian and U.S. Sulphite Recovery Furnaces

4.3 Comparison of FPAC 20-Mill Study Data with U.S. Data – Metals

This section compares the mean emissions of several metals (Sb, As, Be, Cd, Cr, Co, Pb, Mn, Hg, Ni, Se, P, Ba, Cu, Zn, Ag, and Th) from two DCE and three NDCE kraft recovery furnaces, five smelt dissolving tanks, one lime kiln with an ESP, and two lime kilns with wet scrubbers, all measured during the FPAC 20-mill study, with range (minimum and maximum) and average metal emissions from similar unit operations in the U.S. The latter were reported in NCASI Technical Bulletin No. 858 (NCASI 2003a). The metals testing on the Canadian kraft recovery sources were carried out solely at Mills 1, 8, and 11 in the 20-mill FPAC study. The measurement method used was EPA Method 29. The same method (or its earlier draft form) was used to obtain most of the data in the case of the U.S. recovery sources.

4.3.1 *Kraft Direct Contact Recovery Furnaces*

Metals enter the kraft recovery cycle through the wood pulp, make-up water, make-up chemicals, equipment corrosion, and fossil fuels used in recovery furnaces and lime kilns. When black liquor is burned in a recovery furnace, a small fraction of the metals in the liquor will be emitted through the flue gases leaving the ESP. Typically, metal purges via emissions from kraft recovery unit operations, which include the recovery furnace, lime kiln and smelt dissolving tank, are much smaller than those through pulping and recovery area solid wastes such as waste treatment system residuals, lime mud, slaker grits, and dregs (Someshwar 1997).

Figure 4.68 compares the mean emissions of Sb, As, Be, Cd, Cr, Co, Pb, Mn, Hg, Ni, Se, P, Ba, Cu, Zn, Ag, and Th for two Canadian direct contact (DCE) recovery furnaces with the minimum, maximum and average emissions for up to twelve U.S. DCE furnaces. As seen in Figure 4.68, the mean emissions for most of the metals for the two Canadian DCE furnaces fall within the range for the U.S. furnaces. However, mean emissions for Mn, Cu, and P were higher than the maximum emissions measured for the U.S. furnaces. Also, while all twelve U.S. furnaces showed non-detect levels for Hg, the two Canadian furnaces yielded detects. It should be noted that this comparison is limited since data for only two Canadian DCE recovery furnaces were available.

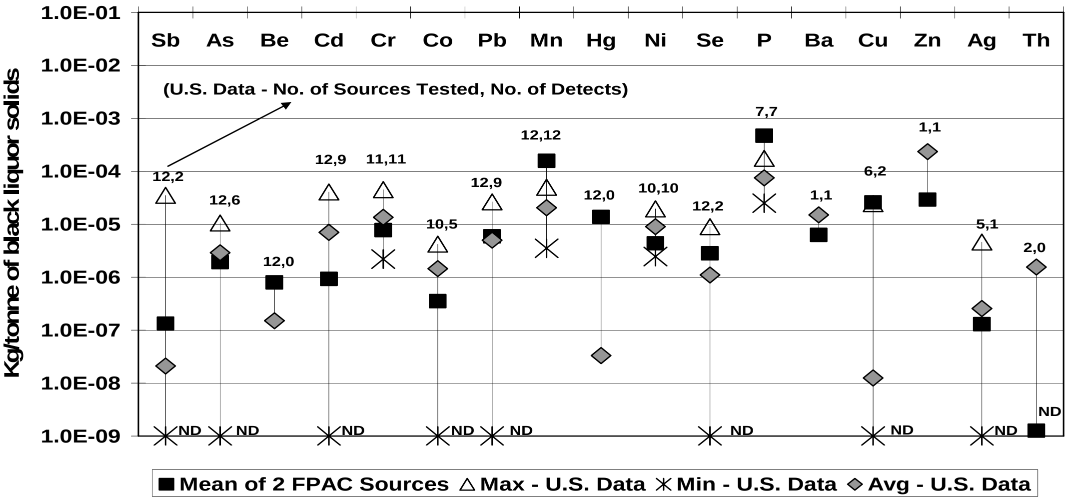


Figure 4.68 Comparison of Trace Metal Emissions from Canadian and U.S. Direct Contact Kraft Recovery Furnaces

4.3.2 *Kraft Non-Direct Contact Recovery Furnaces*

Figure 4.69 compares the mean emissions of Sb, As, Be, Cd, Cr, Co, Pb, Mn, Hg, Ni, Se, P, Ba, Cu, Zn, Ag, and Th for three Canadian non-direct contact evaporator (NDCE) recovery furnaces with the minimum, maximum and average emissions for up to twelve U.S. NDCE furnaces. As seen in Figure 4.69, the mean emissions of most of the metals for the three Canadian NDCE furnaces fall within the range for the U.S. furnaces. However, mean emissions for Mn, Hg, and P are at or near the maximum emissions measured for the U.S. furnaces. Once again, it should be noted that this comparison is limited since data for only three Canadian NDCE recovery furnaces were available.

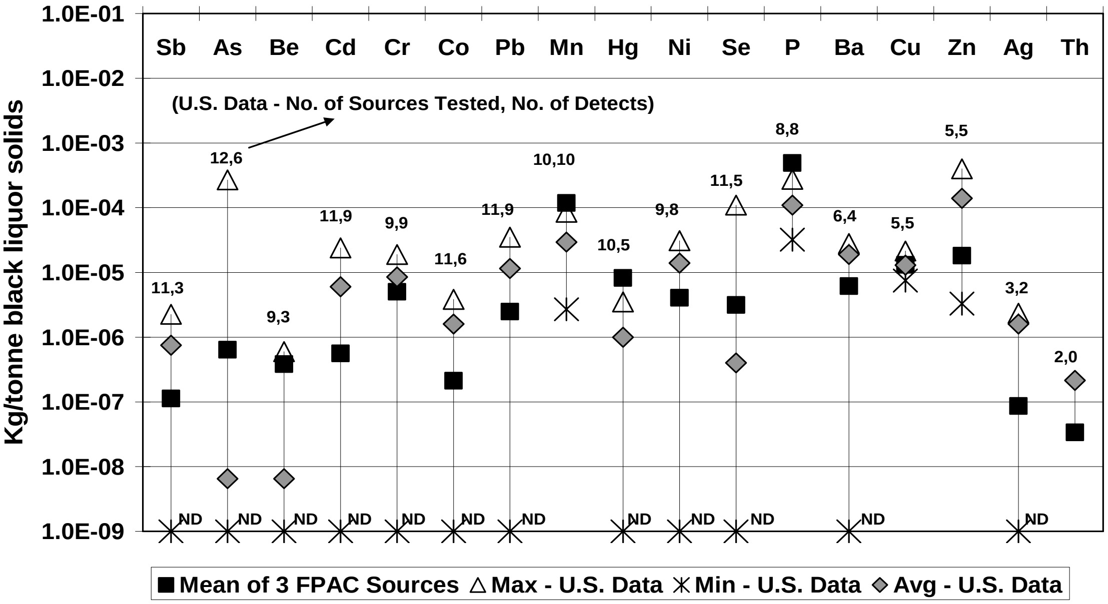


Figure 4.69 Comparison of Trace Metal Emissions from Canadian and U.S. Non-Direct Contact Kraft Recovery Furnaces

4.3.3 *Kraft Smelt Dissolving Tanks*

Trace metals are present in the smelt product leaving a kraft recovery furnace. During the smelt-water reaction in the smelt tank, trace quantities of metals present in the smelt will be volatilized and a portion will pass through the smelt tank vent gas scrubber or mist eliminator.

Figure 4.70 compares the mean emissions of Sb, As, Be, Cd, Cr, Co, Pb, Mn, Hg, Ni, Se, P, Ba, Cu, Zn, Ag, and Th for five Canadian smelt dissolving tanks with the minimum, maximum, and average emissions for up to twelve U.S. smelt dissolving tanks. Once again, as seen in Figure 4.70, the mean emissions of most of the metals for the five Canadian smelt dissolving tanks fall within the range for the U.S. smelt tanks. However, mean emissions for Mn, Hg and P are once again near the maximum emissions measured for the U.S. smelt tanks.

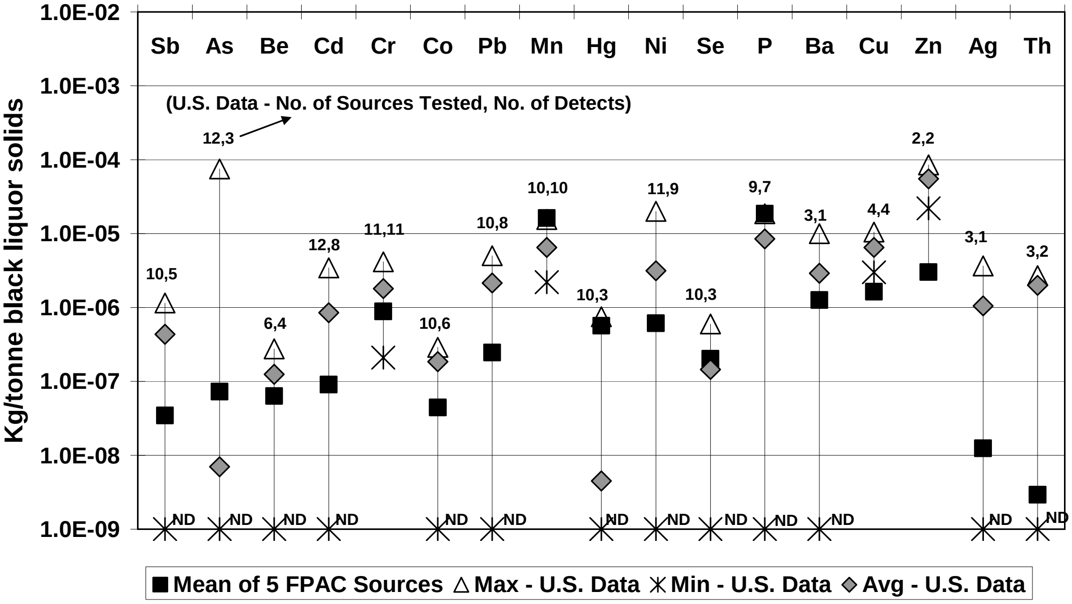


Figure 4.70 Comparison of Trace Metal Emissions from Canadian and U.S. Smelt Dissolving Tanks

4.3.4 *Kraft Lime Kilns with ESPs*

Trace metals are present in the lime mud that results from clarifying white liquor. The washed lime mud is calcined in the lime kiln by the firing of a fossil fuel such as fuel oil or natural gas. Trace quantities of metals present in the lime mud as well as the fossil fuel will be volatilized and will not be completely captured by the lime kiln particulate collection device (scrubber or ESP). The relationship between trace metals emissions and emissions of total particulate from lime kilns is not well understood. Data on trace metal emissions from lime kilns compiled by NCASI for kilns with ESPs and with venturi scrubbers (NCASI 2003a) show that the lower PM emissions from kilns with ESPs generally translate into lower emissions of trace metals.

Figure 4.71 compares the mean emissions of Sb, As, Be, Cd, Cr, Co, Pb, Mn, Hg, Ni, Se, P, Ba, Cu, Zn, Ag, and Th for one Canadian lime kiln equipped with an ESP with the minimum, maximum, and average emissions for up to four U.S. lime kilns also equipped with ESPs. As seen in Figure 4.71, the mean metal emissions for the Canadian lime kiln generally fall within the range for the U.S. lime kilns. However, once again, the emissions for Mn, Hg and P appear to be on the high end of the range for the four U.S. kilns.

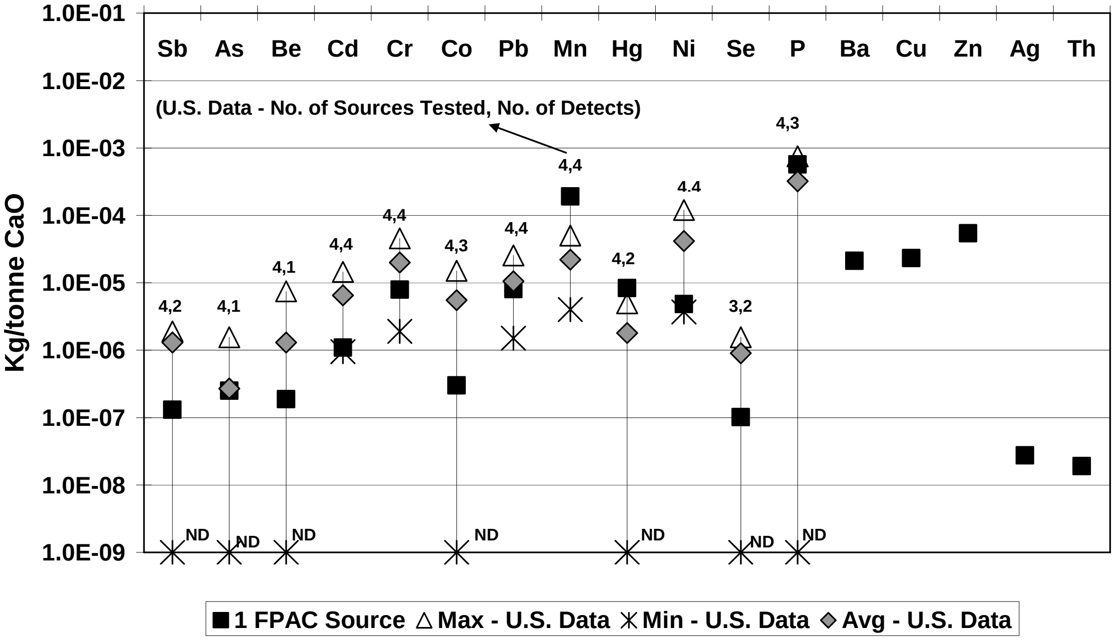


Figure 4.71 Comparison of Trace Metal Emissions from Canadian and U.S. Kraft Lime Kilns with ESPs

4.3.5 *Kraft Lime Kilns with Wet Scrubbers*

Figure 4.72 compares the mean emissions of Sb, As, Be, Cd, Cr, Co, Pb, Mn, Hg, Ni, Se, P, Ba, Cu, Zn, Ag, and Th for two Canadian lime kiln equipped with wet scrubbers with the minimum, maximum, and average emissions for up to thirteen U.S. lime kilns also equipped with wet scrubbers. As seen in Figure 4.72, the mean metal emissions for the two Canadian lime kilns with wet scrubbers generally fall within the range for the U.S. lime kilns. Mean emissions for Hg, P and Ba appear to be on the high end of the range for the U.S. kilns.

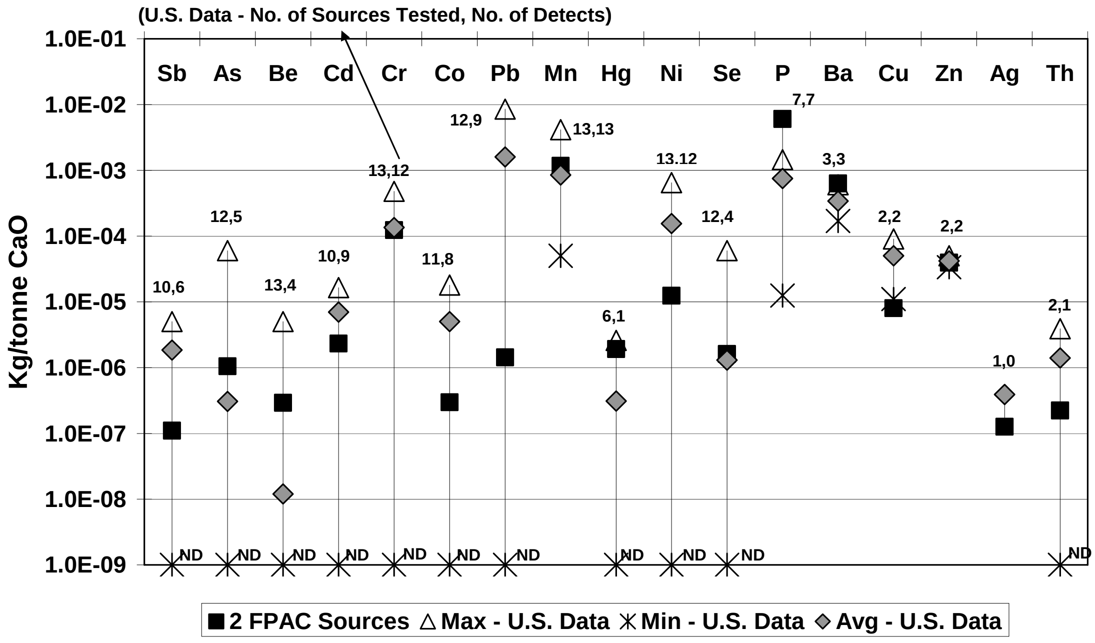


Figure 4.72 Comparison of Trace Metal Emissions from Canadian and U.S. Kraft Lime Kilns with Wet Scrubbers

5.0 SUMMARY

The U.S. pulp and paper industry carried out a number of rather comprehensive emission characterization studies in the 1990s to address EPA rulemaking initiatives. NCASI compiled and analyzed these data on behalf of the industry so that they could be used for a variety of other purposes such as obtaining air permits and meeting the Toxic Release Inventory (TRI) annual reporting requirements. The U.S. emissions data also proved to be helpful to Canadian companies in meeting their NPRI reporting obligations, given the minimal amount of available Canadian emission testing information for most of the substances covered by the NPRI at the time that NCASI prepared the first *NPRI Handbook for Pulp and Paper Facilities*, in 2000.

In 2002, FPAC (Forest Products Association of Canada) coordinated an extensive sampling program to measure emissions of selected volatile organic compounds, criteria air contaminants, reduced sulphur compounds, and metals from various process units at kraft, sulphite, and mechanical pulp mills. Twenty mills throughout the country participated in the program, and the effort generated a significant body of data that was intended for use in responding to anticipated Environment Canada regulatory initiatives focused on pulp and paper mill emissions. Prior to this effort, only limited emissions data for Canadian mills were available and they had not been systematically organized.

Because Canadian and U.S. pulp and paper mills use similar production processes and because many emission sampling methods are nearly identical in the two countries, assembling a single comprehensive set of North American emissions data from the U.S. data set and the FPAC data set appeared to be a reasonable goal. Having a single set of data would certainly enhance the consistency of emission estimates made in the two countries and would allow for more reasoned comparisons of mill emissions between the Canadian and U.S. industry. However, there needed to be some assurance that the two data sets were in fact compatible and that there were not underlying fundamental differences between Canadian and U.S. pulp mill operations that would prohibit combining them.

The individual mill reports prepared by sampling contractors for the 20-mill FPAC study were first examined by NCASI to identify any obvious sampling problems and calculation errors. Appropriate corrections were made and highly suspect results were either not used or flagged. Essential process descriptions and production data were obtained from the mills if they were unavailable in the contractor reports. The resulting FPAC database was then compared to the U.S. database for several volatile organic compounds (methanol, formaldehyde, acetaldehyde, propionaldehyde, phenol, methyl ethyl ketone, benzene), criteria air contaminants (total PM, PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO), total reduced sulphur compounds, and metals. The comparisons were conducted only for pulp mill sources. Sampling of emissions from boilers and some fugitive sources was included in the FPAC effort, but the results were not addressed in this comparison.

Comparisons were made for kraft recovery furnaces (with and without direct contact evaporators), smelt dissolving tanks, lime kilns (equipped with ESPs or wet scrubbers), bleach plants, and oxygen delignification systems at kraft mills, kraft mill thermal oxidizers, sulphite recovery furnaces, TMP pulping, groundwood pulping, and paper machines using mechanical pulp furnish. The comparisons were qualitative in nature, and involved examining the individual unit results from the FPAC study versus the median and range for the entire U.S. data set. Overall, for the substances and process units examined, the FPAC results almost always fell within the range observed in the U.S. data set. Furthermore, the median of the combined data set was usually quite close to the median of the U.S. data set. The data comparison suggests there are no fundamental differences between the FPAC and U.S. emissions data, and thus supports combining the two data sets.

There are at least three limitations to the comparison. First, emissions of terpenes were not examined. It is likely that terpene emissions from mechanical pulping of softwoods are dependent on the pulpwood terpene content, which can vary significantly among species. Intuitively, one would expect greater terpene emissions from pine than from less resinous species such as spruce and fir. Second, emission rates of the substances that were examined in this comparison were known to be mainly affected by process conditions, water reuse practices, and/or control equipment efficiency. These factors vary from mill to mill, and there can be a broad range in emission levels for a given substance from a given unit process. Only limited process information was available for the FPAC mills, so it was not possible to identify the reasons why a particular unit process had a much different emission rate than other apparently similar unit processes. Thus, a data point identified statistically as an outlier relative to the other data points may very well have been a valid data point for a unique set of process conditions. Third, there may be too few data to make conclusive comparisons for some unit processes. This was the case for mechanical pulping operations (very few sampled in the U.S.) and kraft mill thermal oxidizers (only one sampled in the FPAC program).

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APPENDIX A

SUMMARY OF AIR EMISSION DATA FOR SPECIATED VOCs USING THE NCASI IMPINGER/CANISTER METHOD 99.01

The following tables summarize the speciated VOC emission data generated on various major and minor sources during the 20-mill FPAC study. Table A1 addresses emissions from major kraft pulp mill sources. Table A2 addresses emissions from miscellaneous kraft pulp mill sources. Table A3 addresses emissions from sulphite pulp mill sources. Table A4 addresses emissions from non-chemical pulp mills including thermomechanical pulp and groundwood pulp mills, and Table A5 addresses emissions from various other pulp mill sources such as cooling towers, bark and chip transportation systems, and fugitive emissions from bark and chip piles. All data are provided in units of kg emissions per unit of production. Emissions from tanks are provided in kg/hr/tank. Emissions from area sources are given in mg/sec/m^2.

Table A1 Summary Speciated VOC Emission Data from FPAC 20 Mill Study – Major Kraft Pulp Mill Operations

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon Tetrachloride	3-Carene
21	Black Liquor Oxidation	kg/t BLS	3.8E-02	9.3E-03	1.2E-04		*4.1E-06*	9.6E-03	4.1E-03	*6.9E-06*	*1.7E-03*
	Bleach Plants										
9	Bleach plant - 100% sftwd	kg/ADTBP	3.0E-04	*4.1E-04*	1.8E-06		*3.2E-06*	*4.3E-04*	1.9E-05	*5.7E-06*	*1.9E-04*
4	Bleach plant - 100% sftwd	kg/ADTBP	8.2E-04	*4.4E-03*	9.9E-05	*2.0E-05*	*6.6E-05*	*5.5E-03*	3.8E-06	1.5E-06	9.9E-03
12	Bleach Plant (47% hdwd, 53% sftwd)	kg/ADTBP	2.4E-03	9.8E-04	8.8E-07		*1.2E-05*	*1.9E-03*		3.5E-06	6.2E-04
6	Bleach plant - 100% sftwd	kg/ADTBP	3.8E-03	*4.8E-03*	4.5E-05	*3.8E-04*	8.6E-05	*4.9E-03*	2.4E-04	*8.6E-05*	3.6E-02
2	Bleach plant - 100% sftwd	kg/ADTBP	1.1E-03	*2.3E-03*	*1.8E-05*		*1.3E-05*	*2.3E-03*		*3.6E-05*	3.2E-04
7	Bleach Plant Scrubber - 100% hdwd	kg/ADTBP	1.0E-03	*2.1E-03*	*3.7E-06*	*3.3E-05*	*6.6E-06*	*2.1E-03*	9.3E-06	*1.2E-05*	*3.2E-03*
	Brown Stock Washers – VDW Type										
2	Brown Stock Washers	kg/ADTUBP	4.2E-03	*2.3E-03*	*1.9E-05*		*1.3E-05*	*2.3E-03*		*3.8E-05*	1.2E-03
6	Brown Stock Washers	kg/ADTUBP	8.3E-03	*9.8E-03*	5.2E-05	*7.0E-07*	*7.6E-05*	2.9E-04	1.7E-03	*1.3E-04*	5.6E-01
7	Brown Stock Washers	kg/ADTUBP	1.3E-03	4.7E-04	5.4E-05	1.1E-04		8.3E-04	1.0E-04		*1.7E-04*
9	Brown Stock Washers	kg/ADTUBP	3.2E-03	*5.6E-03*	*2.4E-05*		*4.2E-05*	*5.8E-03*	1.4E-04	*7.1E-05*	4.8E-02
21	Brown Stock Washers	kg/ADTUBP	4.3E-03	*7.6E-03*	4.1E-06		*5.9E-06*	3.7E-03	8.2E-05	*9.5E-06*	*1.1E-02*
21	Brown Stock Washers	kg/ADTUBP	8.6E-03	*1.9E-02*	1.2E-05		*1.1E-05*	8.4E-03	1.1E-04	*1.8E-05*	*2.0E-02*
12	Brown Stock Washers	kg/ADTUBP	2.9E-04	*5.3E-04*	1.3E-05		4.7E-06	1.0E-03		*1.0E-05*	5.5E-05
	Brownstock Washers – Other[a]										
6	Diffusion Washer Filtrate Tank Vent	kg/ADTUBP	5.2E-04	*6.1E-05*	8.0E-07		1.1E-05	1.8E-03	4.2E-05	*1.1E-06*	7.4E-04
	Deckers										
7	Decker Vent	kg/ADTUBP	7.6E-05	6.8E-05	7.4E-06	2.9E-06		7.0E-05	2.3E-06		*4.3E-04*

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT - air dry metric tonne; BLS – black liquor solids; BP & UBP – bleached and unbleached pulp

[a] Other washers - diffusion, pressure, belt and baffle

Table A1 Continued

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane	1,2-dimethoxyethane	Ethylbenzene
21	Black Liquor Oxidation	kg/t BLS	*3.4E-06*	1.9E-06	*1.5E-03*	*1.6E-03*	*3.0E-06*	*2.9E-06*	8.2E-06	*6.9E-06*	*1.6E-06*
	Bleach Plants										
9	Bleach plant - 100% sftwd	kg/ADTBP	*2.8E-06*	4.3E-04	*1.7E-04*	*2.3E-04*	*2.4E-06*	*2.5E-06*	1.6E-05		*3.9E-06*
4	Bleach plant - 100% sftwd	kg/ADTBP	*5.3E-05*	3.3E-03	*1.5E-03*	*2.1E-03*	1.8E-06	6.9E-07	6.7E-05	*1.1E-04*	*1.3E-04*
12	Bleach Plant (47% hdwd, 53% sftwd)	kg/ADTBP	5.4E-06	3.4E-04	*5.5E-04*	*6.1E-04*	*2.2E-05*	*2.3E-05*	*1.9E-05*		1.7E-06
6	Bleach plant - 100% sftwd	kg/ADTBP	*4.2E-05*	3.5E-03	*4.1E-03*	1.3E-02	*3.7E-05*	*3.6E-05*	3.5E-04	*1.2E-04*	*6.0E-05*
2	Bleach plant - 100% sftwd	kg/ADTBP	*2.7E-05*	7.8E-06	*5.7E-04*	1.9E-04	*2.3E-05*	*2.3E-05*	*2.0E-05*		*2.5E-05*
7	Bleach Plant Scrubber - 100% hdwd	kg/ADTBP	*5.3E-06*	1.2E-03	*2.8E-03*	*3.2E-03*	*4.7E-06*	*4.7E-06*	1.6E-05	*1.1E-05*	*8.0E-06*
	Brown Stock Washers – VDW Type										
2	Brown Stock Washers	kg/ADTUBP	*2.8E-05*	*3.0E-05*	*6.0E-04*	*6.7E-04*	*2.4E-05*	*2.5E-05*	*2.1E-05*		*2.6E-05*
6	Brown Stock Washers	kg/ADTUBP	*6.4E-05*	9.6E-04	*1.7E-02*	1.7E-01	*5.6E-05*	6.9E-07	3.9E-04	*1.8E-04*	1.1E-06
7	Brown Stock Washers	kg/ADTUBP	5.4E-06	4.1E-06	*2.3E-03*	*2.6E-03*		3.9E-06	3.2E-03		
9	Brown Stock Washers	kg/ADTUBP	*3.5E-05*	3.9E-05	*2.1E-03*	9.9E-03	*3.0E-05*	*3.2E-05*	*3.9E-05*	*7.0E-05*	*5.2E-05*
21	Brown Stock Washers	kg/ADTUBP	*3.5E-06*	1.0E-05	*9.4E-03*	*1.1E-02*	*3.0E-06*	*3.1E-06*	2.2E-05	*9.9E-06*	*6.7E-06*
21	Brown Stock Washers	kg/ADTUBP	*6.5E-06*	1.0E-04	*1.7E-02*	*1.9E-02*	*5.6E-06*	*5.7E-06*	7.6E-05	*1.8E-05*	*1.2E-05*
12	Brown Stock Washers	kg/ADTUBP	2.8E-06	1.6E-06	*1.6E-04*	*1.8E-04*	*6.5E-06*	*6.6E-06*	*5.7E-06*		1.6E-06
	Brownstock Washers – Other[a]										
6	Diffusion Washer Filtrate Tank Vent	kg/ADTUBP	*5.3E-07*	9.2E-07	*6.1E-05*	1.0E-03	*4.7E-07*	*4.6E-07*	1.1E-05	*1.5E-06*	*7.6E-07*
	Deckers										
7	Decker Vent	kg/ADTUBP	1.0E-06	1.8E-05	*3.8E-04*	*4.3E-04*		6.0E-07	3.5E-05		

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT - air dry metric tonne; BLS – black liquor solids; BP & UBP – bleached & unbleached pulp

[a] Other washers - diffusion, pressure, belt and baffle

Table A1 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
21	Black Liquor Oxidation	kg/t BLS	3.3E-04	*5.6E-07*	*1.7E-03*	3.1E-01	3.1E-03		*1.7E-03*	*1.7E-03*	*1.7E-03*
	Bleach Plants										
9	Bleach plant - 100% sftwd	kg/ADTBP	3.4E-05	*3.2E-06*		8.8E-03	*4.3E-04*	*1.6E-05*	8.3E-04	*2.1E-04*	*1.7E-04*
4	Bleach plant - 100% sftwd	kg/ADTBP	1.8E-05	*6.1E-05*	*1.8E-03*	9.1E-02	*4.9E-03*	*3.0E-04*	1.5E-03	3.3E-02	9.8E-03
12	Bleach Plant (47% hdwd, 53% sftwd)	kg/ADTBP	1.6E-03	*2.0E-05*	*6.2E-04*	3.7E-02	*1.9E-03*		*1.9E-03*	*6.2E-04*	*6.2E-04*
6	Bleach plant - 100% sftwd	kg/ADTBP	5.7E-03	5.0E-05	8.2E-02	2.3E-01	3.2E-03	*2.4E-04*	*1.1E-02*	2.2E-02	1.0E-02
2	Bleach plant - 100% sftwd	kg/ADTBP	1.0E-03	2.0E-05	2.6E-04	1.4E-01	*2.3E-03*		*2.3E-03*	*3.2E-05*	*3.2E-05*
7	Bleach Plant Scrubber - 100% hdwd	kg/ADTBP	*4.1E-04*	*6.5E-06*	*3.2E-03*	2.7E-03	*2.1E-03*	*3.1E-05*	*2.1E-03*	*3.2E-03*	*3.2E-03*
	Brown Stock Washers – VDW Type										
2	Brown Stock Washers	kg/ADTUBP	*4.5E-04*	2.1E-05	2.0E-03	1.3E-01	*2.3E-03*		*2.3E-03*	*3.4E-05*	*3.4E-05*
6	Brown Stock Washers	kg/ADTUBP	1.5E-02	5.6E-05	1.4E+00	1.9E+00	1.2E-04	*3.6E-04*	*1.0E-02*	8.8E-01	3.1E-01
7	Brown Stock Washers	kg/ADTUBP	*2.8E-04*	8.4E-07	*2.6E-03*	1.5E-01	4.7E-04	7.0E-06	4.8E-04	*2.6E-03*	*2.6E-03*
9	Brown Stock Washers	kg/ADTUBP	1.0E-03	*4.2E-05*	6.3E-02	5.6E-01	*5.9E-03*	*2.1E-04*	*8.8E-03*	8.1E-02	3.0E-02
21	Brown Stock Washers	kg/ADTUBP	6.7E-03	1.4E-05	*1.1E-02*	2.0E-01	3.1E-03		*7.7E-03*	*1.1E-02*	*1.1E-02*
21	Brown Stock Washers	kg/ADTUBP	*2.0E-03*	5.7E-05	*2.0E-02*	5.5E-01	*1.6E-02*		*1.9E-02*	*2.0E-02*	*2.0E-02*
12	Brown Stock Washers	kg/ADTUBP	1.2E-04	*5.8E-06*	9.8E-05	9.6E-02	1.7E-03		*5.3E-04*	8.7E-04	*1.8E-04*
	Brownstock Washers – Other[a]										
6	Diffusion Washer Filtrate Tank Vent	kg/ADTUBP	4.3E-04	1.2E-06	2.5E-03	6.2E-02	6.2E-05	*3.0E-06*	*6.3E-05*	4.0E-03	2.3E-03
	Deckers										
7	Decker Vent	kg/ADTUBP	*2.7E-05*		*4.3E-04*	7.0E-03	*1.4E-04*		7.7E-05	*4.3E-04*	*4.3E-04*

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT - air dry metric tonne; BLS – black liquor solids; BP & UBP – bleached & unbleached pulp

[a] Other washers - diffusion, pressure, belt and baffle

Table A1 Continued

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
21	Black Liquor Oxidation	kg/t BLS	2.9E-03	1.7E-05	*5.4E-06*	2.4E-04	*5.1E-06*	2.3E-05	*5.3E-06*	*5.5E-05*	1.3E-05
	Bleach Plants										
9	Bleach plant - 100% sftwd	kg/ADTBP	*4.1E-04*	*2.6E-06*	*4.3E-06*	2.4E-05	*5.0E-06*	*3.3E-06*	*4.3E-06*	*4.5E-05*	*4.8E-06*
4	Bleach plant - 100% sftwd	kg/ADTBP	6.6E-05	2.4E-06	*8.3E-05*	5.9E-05	*9.5E-05*	*6.3E-05*	1.3E-06	*8.6E-04*	*1.3E-04*
12	Bleach Plant (47% hdwd, 53% sftwd)	kg/ADTBP	*1.9E-03*	4.4E-06	*3.4E-05*	5.6E-05	*3.1E-05*	3.4E-06	8.5E-06	*4.2E-05*	1.5E-06
6	Bleach plant - 100% sftwd	kg/ADTBP	*4.6E-03*	1.7E-04	*6.4E-05*	1.3E-03	*7.5E-05*	*5.0E-04*	*6.4E-05*	*2.0E-04*	*9.9E-05*
2	Bleach plant - 100% sftwd	kg/ADTBP	*2.3E-03*	*2.5E-05*	*3.9E-05*	4.4E-06	*3.1E-05*	*3.1E-05*	6.0E-06	*4.3E-05*	*5.0E-05*
7	Bleach Plant Scrubber - 100% hdwd	kg/ADTBP	*2.1E-03*	*4.9E-06*		*4.3E-06*	*1.0E-05*	*6.3E-06*	*8.7E-06*	*8.5E-05*	*1.3E-05*
	Brown Stock Washers – VDW Type										
2	Brown Stock Washers	kg/ADTUBP	*2.3E-03*	*2.6E-05*	*4.1E-05*	2.2E-06	*3.3E-05*	*3.3E-05*	5.9E-06	2.2E-05	*5.3E-05*
6	Brown Stock Washers	kg/ADTUBP	1.9E-04	2.8E-04	1.2E-06	1.2E-03	*1.1E-04*	*7.5E-05*	2.1E-06	*1.0E-03*	1.3E-04
7	Brown Stock Washers	kg/ADTUBP	5.0E-04	1.8E-05		4.0E-06		*3.1E-05*	8.1E-06	6.8E-06	2.3E-07
9	Brown Stock Washers	kg/ADTUBP	*5.5E-03*	1.1E-04	*5.7E-05*	3.3E-04	*6.6E-05*	*4.4E-05*	*5.6E-05*	*6.0E-04*	*6.4E-05*
21	Brown Stock Washers	kg/ADTUBP	3.3E-03	*3.3E-06*	*7.5E-06*	3.4E-05	*8.4E-06*	*4.2E-06*	*7.4E-06*	*8.0E-05*	1.9E-05
21	Brown Stock Washers	kg/ADTUBP	*1.3E-02*	4.9E-06	*1.4E-05*	7.3E-05	*1.5E-05*	*1.0E-05*	*1.4E-05*	*1.5E-04*	3.1E-05
12	Brown Stock Washers	kg/ADTUBP	*5.3E-04*	7.3E-05	2.0E-06	4.2E-05	*9.0E-06*	7.7E-05	3.9E-06	4.4E-06	2.2E-06
	Brownstock Washers – Other^a										
6	Diffusion Washer Filtrate Tank Vent	kg/ADTUBP	6.0E-05	9.4E-06	*8.4E-07*	4.6E-05	*9.5E-07*	*6.3E-07*	*8.2E-07*	*8.6E-06*	2.0E-06
	Deckers										
7	Decker Vent	kg/ADTUBP	7.2E-05	*1.1E-06*				*0.0E+00*	1.5E-06		

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT - air dry metric tonne; BLS – black liquor solids; BP & UBP – bleached & unbleached pulp

^{a} Other washers - diffusion, pressure, belt and baffle

Table A1 Continued

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon tetrachloride	3-Carene
	Deknotters										
6	BSW Knotter Vents	kg/ADTUBP	2.3E-04	*9.7E-06*	6.0E-07		*4.2E-07*	7.2E-04	3.1E-06	*7.0E-07*	3.1E-03
7	BSW Knotter Vents	kg/ADTUBP	1.5E-04	1.4E-04	2.3E-06	3.2E-06	5.5E-06	7.7E-04	2.0E-05		*8.4E-04*
	Lime Kilns										
4	Lime Kiln #1 w/scrubber - No. 6 oil	kg/t CaO	*5.8E-03*	*6.4E-03*	1.3E-03		*1.8E-04*	*9.1E-03*	*5.0E-04*	*1.4E-04*	*5.9E-03*
4	Lime Kiln #2 w/scrubber - No. 6 oil	kg/t CaO	*7.1E-03*	*7.6E-03*	5.4E-04		*1.4E-04*	8.2E-03	6.9E-04	*1.1E-04*	*4.0E-03*
2	Lime Kiln w/scrubber - nat. gas	kg/t CaO	2.9E-03	2.7E-03	7.8E-06		*3.5E-05*	2.7E-03		*9.9E-05*	1.7E-03
7	Lime Kiln w/scrubber - No. 6 oil	kg/t CaO	6.8E-03	*6.0E-03*	2.1E-04		*2.1E-05*	*6.1E-03*	1.6E-04		*1.0E-02*
12	Lime Kiln w/ESP - nat. gas	kg/t CaO	1.0E-02	2.5E-03	3.5E-04		4.2E-05	*5.0E-03*		*7.8E-05*	1.4E-04
6	Lime Kiln w/ESP - nat. gas & oil	kg/t CaO	8.6E-03	*6.9E-02*	*3.3E-05*		*5.7E-05*	5.8E-02	1.3E-04	*9.6E-05*	*3.0E-03*
1	Lime Kiln w/ESP - nat. gas	kg/t CaO	1.4E-02	5.6E-03	2.6E-03		2.1E-04	*1.1E-02*		*1.9E-04*	*0.0E+00*
8	Lime Kiln w/scrubber - nat. gas	kg/t CaO	6.4E-03	*1.3E-02*	6.0E-04		*6.6E-05*	*1.3E-02*		*2.0E-04*	*0.0E+00*
9	Lime Kiln w/scrubber - gas & CTO	kg/t CaO	*5.7E-03*	*5.9E-03*	7.0E-04	*5.6E-04*	*4.9E-05*	*6.2E-03*	7.6E-04	*8.3E-05*	*2.7E-03*
11	Lime Kiln w/scrubber - gas & CTO	kg/t CaO	4.6E-03	*8.9E-03*	5.7E-04		*5.1E-05*	*9.0E-03*		*1.5E-04*	*0.0E+00*
	Thermal Oxidizers										
12	CNCG SO_2 Scrubber Vent	kg/ADTUBP	*1.1E-04*	*1.1E-04*	4.8E-07		*5.4E-07*	*1.1E-04*		1.5E-06	1.1E-05
	Oxygen Delignification Systems										
9	Oxygen Delig. System	kg/ADTUBP	1.8E-02	*5.9E-04*	9.8E-07		*5.0E-05*	2.0E-02	9.5E-06	*8.7E-05*	
3	2-stage followed by 2 P-O wash presses	kg/ADTUBP	6.4E-03	2.9E-05	*9.4E-07*		6.6E-07	4.5E-04		*1.9E-06*	4.0E-04
2	Blow tank vent only[1]	kg/ADTUBP	2.5E-03	*2.1E-05*	1.4E-06		3.2E-06	7.4E-04		2.4E-06	1.6E-03
	[1] reactor vents to blow tank										

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT - air dry metric tonne; UBP – unbleached pulp

Table A1 Continued

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane	1,2-dimethoxyethane	Ethylbenzene
	Deknotters										
6	BSW Knotter Vents	kg/ADTUBP	*3.5E-07*	7.1E-07	*9.8E-07*	1.7E-03	*3.1E-07*	*3.1E-07*	*3.9E-07*	*9.8E-07*	5.0E-07
7	BSW Knotter Vents	kg/ADTUBP	1.9E-06	1.1E-06	*7.4E-04*	*8.2E-04*		1.2E-06	1.1E-04		
	Lime Kilns										
4	Lime Kiln #1 w/scrubber - No. 6 oil	kg/t CaO	*1.4E-04*	8.8E-04	*4.8E-03*	*6.9E-03*	*1.2E-04*	*1.2E-04*	*1.6E-04*	*2.9E-04*	*3.5E-04*
4	Lime Kiln #2 w/scrubber - No. 6 oil	kg/t CaO	*1.1E-04*	1.8E-04	*3.1E-03*	7.8E-03	*9.4E-05*	*9.6E-05*	1.2E-04	*2.3E-04*	*2.7E-04*
2	Lime Kiln w/scrubber - nat. gas	kg/t CaO	1.8E-05	*7.6E-05*	*1.5E-03*	*1.7E-03*	*6.2E-05*	*6.4E-05*	2.1E-05		1.4E-05
7	Lime Kiln w/scrubber - No. 6 oil	kg/t CaO	*1.7E-05*	2.3E-04	*8.9E-03*	*9.9E-03*	*1.4E-05*	*1.5E-05*	6.5E-05	*3.5E-05*	*2.5E-05*
12	Lime Kiln w/ESP - nat. gas	kg/t CaO	5.2E-06	*6.0E-05*	1.2E-03	1.8E-04	*4.9E-05*	*5.0E-05*	3.7E-05		*5.4E-05*
6	Lime Kiln w/ESP - nat. gas & oil	kg/t CaO	*4.7E-05*	*5.0E-05*	*2.7E-03*	*3.6E-03*	*4.1E-05*	*4.1E-05*	1.6E-04	*9.4E-05*	*6.7E-05*
1	Lime Kiln w/ESP - nat. gas	kg/t CaO	*1.4E-04*	*1.5E-04*	*0.0E+00*	*0.0E+00*	*1.1E-04*	*1.3E-04*	*1.0E-04*		*1.3E-04*
8	Lime Kiln w/scrubber - nat. gas	kg/t CaO	*1.5E-04*	*1.5E-04*	*0.0E+00*	*0.0E+00*	*1.3E-04*	*1.3E-04*	*1.1E-04*		*1.3E-04*
9	Lime Kiln w/scrubber - gas & CTO	kg/t CaO	*4.1E-05*	*4.3E-05*	*2.3E-03*	*3.2E-03*	*3.5E-05*	*3.6E-05*	*1.2E-04*	*8.1E-05*	*5.7E-05*
11	Lime Kiln w/scrubber - gas & CTO	kg/t CaO	*1.2E-04*	*1.2E-04*	*0.0E+00*	*0.0E+00*	*1.0E-04*	*1.0E-04*	*8.6E-05*		*1.0E-04*
	Thermal Oxidizers										
12	CNCG SO_2 Scrubber Vent	kg/ADTUBP	2.5E-07	5.0E-08	*2.4E-05*	*2.7E-05*	*9.6E-07*	*9.8E-07*	*8.4E-07*		7.9E-08
	Oxygen Delignification Systems										
9	Oxygen Delig. System	kg/ADTUBP	*4.1E-05*	2.9E-06			*3.5E-05*	*3.5E-05*	5.0E-05		*6.0E-05*
3	2-stage followed by 2 P-O wash presses	kg/ADTUBP	3.7E-07	5.5E-07	2.6E-05	1.5E-04	2.8E-07	*1.2E-06*	1.8E-06		*1.3E-06*
2	Blow tank vent only[1]	kg/ADTUBP	6.3E-06	2.0E-06	1.7E-05	1.2E-04	5.4E-06	2.5E-06	1.9E-06		4.1E-06
	[1]reactor vents to blow tank										

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT - air dry metric tonne; UBP – unbleached pulp

Table A1 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
	Deknotters										
6	BSW Knotter Vents	kg/ADTUBP	5.7E-06	*3.9E-07*	7.2E-03	1.6E-02	5.5E-05	*2.0E-06*	1.4E-05	4.5E-03	2.0E-03
7	BSW Knotter Vents	kg/ADTUBP	*5.7E-05*		*8.4E-04*	2.5E-01	*2.9E-04*	*1.5E-06*	1.5E-04	*8.4E-04*	*8.4E-04*
	Lime Kilns										
4	Lime Kiln #1 w/scrubber - No. 6 oil	kg/t CaO	*1.3E-03*	*1.6E-04*	*5.9E-03*	2.6E-02	*7.7E-03*	*8.0E-04*	3.8E-03	*5.9E-03*	*4.9E-03*
4	Lime Kiln #2 w/scrubber - No. 6 oil	kg/t CaO	2.0E-03	*1.3E-04*	1.3E-02	4.0E-02	*8.1E-03*	*6.2E-04*	6.5E-02	4.6E-03	*3.3E-03*
2	Lime Kiln w/scrubber - nat. gas	kg/t CaO	*1.1E-03*	*5.5E-05*	*1.7E-03*	*6.9E-03*	*5.4E-03*		6.8E-03	*8.7E-05*	*8.7E-05*
7	Lime Kiln w/scrubber – No. 6 oil	kg/t CaO	*1.2E-03*	*2.0E-05*	*1.0E-02*	4.4E-03	*6.1E-03*	*9.8E-05*	*6.0E-03*	*1.0E-02*	*1.0E-02*
12	Lime Kiln w/ESP - nat. gas	kg/t CaO	1.5E-02	*4.3E-05*	5.1E-04	5.5E-02	*5.7E-03*		*5.0E-03*	2.8E-04	2.1E-04
6	Lime Kiln w/ESP - nat. gas & oil	kg/t CaO	5.6E-04	1.1E-04	*3.0E-03*	4.4E-03	*4.3E-03*	*2.7E-04*	1.5E-02	*3.0E-03*	*2.5E-03*
1	Lime Kiln w/ESP - nat. gas	kg/t CaO	1.3E-02	6.4E-04	*0.0E+00*	1.6E-01	*1.1E-02*		*1.1E-02*	*0.0E+00*	*0.0E+00*
8	Lime Kiln w/scrubber - nat. gas	kg/t CaO	*2.5E-03*	*1.1E-04*	*0.0E+00*	*1.3E-02*	*1.3E-02*		1.8E-02	*0.0E+00*	*0.0E+00*
9	Lime Kiln w/scrubber - gas & CTO	kg/t CaO	9.4E-03	4.7E-05	*2.7E-04*	5.2E-01	*6.3E-03*	*2.3E-04*	*6.0E-03*	*2.7E-03*	*2.3E-03*
11	Lime Kiln w/scrubber - gas & CTO	kg/t CaO	*1.8E-03*	*8.6E-05*	*0.0E+00*	*8.9E-03*	*9.0E-03*		*8.9E-03*	*0.0E+00*	*0.0E+00*
	Thermal Oxidizers										
12	CNCG SO_2 Scrubber Vent	kg/ADTUBP	7.3E-05	*8.6E-07*	*2.7E-05*	*1.1E-04*	*1.1E-04*		*1.1E-04*	*2.7E-05*	*2.7E-05*
	Oxygen Delignification Systems										
9	Oxygen Delig. System	kg/ADTUBP	2.7E-04	2.0E-06		3.6E-01	*9.5E-04*	*2.3E-04*	4.5E-03		
3	2-stage followed by 2 P-O wash presses	kg/ADTUBP	1.2E-04	1.3E-05	5.1E-04	2.2E-01	3.3E-05		3.6E-05	2.5E-04	9.9E-06
2	Blow tank vent only[1]	kg/ADTUBP	2.9E-05	5.1E-06	1.7E-03	7.9E-02	2.6E-05		*2.1E-05*	1.1E-03	9.4E-04
	[1] reactor vents to blow tank										

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT - air dry metric tonne; UBP – unbleached pulp

Table A1 Continued

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
	Deknotters										
6	BSW Knotter Vents	kg/ADTUBP	3.3E-05	5.5E-06	*5.2E-07*	2.6E-05	*6.1E-07*	*4.2E-07*	*5.3E-07*	*5.7E-06*	1.2E-06
7	BSW Knotter Vents	kg/ADTUBP	1.6E-04	*6.0E-06*		4.4E-06		4.9E-05	2.9E-06		
	Lime Kilns										
4	Lime Kiln #1 w/scrubber - No. 6 oil	kg/t CaO	*6.4E-03*	*1.3E-04*	*2.2E-04*	8.9E-05	*2.5E-04*	*1.7E-04*	*2.1E-04*	*2.3E-03*	*3.3E-04*
4	Lime Kiln #2 w/scrubber - No. 6 oil	kg/t CaO	*7.6E-03*	*1.0E-04*	*1.7E-04*	1.0E-04	*1.9E-04*	*1.3E-04*	*1.7E-04*	*1.8E-03*	*2.6E-04*
2	Lime Kiln w/scrubber - nat. gas	kg/t CaO	*5.4E-03*	6.7E-05	*1.1E-04*	2.3E-03	*8.6E-05*	*8.6E-05*	2.1E-05	6.5E-05	5.1E-05
7	Lime Kiln w/scrubber – No. 6 oil	kg/t CaO	*6.0E-03*	*1.5E-05*		5.3E-05	*3.1E-05*	*2.0E-05*	*2.7E-05*	*2.7E-04*	*4.1E-05*
12	Lime Kiln w/ESP - nat. gas	kg/t CaO	*5.0E-03*	3.2E-05	*1.6E-04*	1.3E-04	*6.7E-05*	*6.7E-05*	*6.6E-05*	1.8E-05	6.3E-05
6	Lime Kiln w/ESP - nat. gas & oil	kg/t CaO	2.4E-03	*4.4E-05*	*8.8E-05*	4.9E-05	*8.4E-05*	*5.6E-05*	*1.0E-04*	*7.6E-04*	*1.1E-04*
1	Lime Kiln w/ESP - nat. gas	kg/t CaO	*1.1E-02*	*1.3E-04*	*2.1E-04*	5.8E-04	*1.7E-04*	*1.7E-04*	*1.6E-04*	*2.1E-04*	*2.5E-04*
8	Lime Kiln w/scrubber - nat. gas	kg/t CaO	*1.3E-02*	*1.3E-04*	*2.2E-04*	*1.1E-04*	*1.8E-04*	*1.8E-04*	*7.0E-04*	*2.2E-04*	*1.1E-03*
9	Lime Kiln w/scrubber - gas & CTO	kg/t CaO	*5.9E-03*	*3.8E-05*	*6.3E-05*	5.3E-04	*7.2E-05*	*4.8E-05*	*6.2E-05*	*6.5E-04*	1.1E-04
11	Lime Kiln w/scrubber - gas & CTO	kg/t CaO	*8.9E-03*	*1.0E-04*	*1.7E-04*	*8.6E-05*	*1.4E-04*	*1.4E-04*	*1.4E-04*	*1.9E-04*	*2.1E-04*
	Thermal Oxidizers										
12	CNCG SO_2 Scrubber Vent	kg/ADTUBP	*1.1E-04*	1.0E-07	*3.3E-05*	8.7E-07	*1.3E-06*	*1.3E-06*	3.8E-07	3.2E-07	6.9E-08
	Oxygen Delignification Systems										
9	Oxygen Delig. System	kg/ADTUBP	3.0E-04	1.4E-05	*6.3E-05*	7.9E-05	*7.5E-05*	*4.8E-05*	*6.2E-05*	*6.5E-04*	*7.2E-05*
3	2-stage followed by 2 P-O wash presses	kg/ADTUBP	4.5E-05	1.3E-05	*2.0E-06*	2.0E-06	*1.6E-06*	*1.6E-06*	6.5E-07	7.6E-07	*1.9E-06*
2	Blow tank vent only[1]	kg/ADTUBP	3.6E-05	2.2E-05	4.4E-06	1.1E-05	2.7E-06	4.0E-06	6.5E-06	1.7E-05	5.3E-06
	[1] reactor vents to blow tank										

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT - air dry metric tonne; UBP – unbleached pulp

Table A1 Continued

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon tetrachloride	3-Carene
	Bleached Paper Machines & Pulp Dryers										
4	Coated paper - BK + SGW (70:30)	kg/ADTFP	*1.8E-02*	*1.8E-02*	1.7E-04		*1.9E-04*	*2.1E-02*	1.6E-03	*1.5E-04*	*6.2E-03*
12	Bleached kraft paper	kg/ADTFP	7.2E-04	*1.4E-03*	*1.2E-05*		*8.5E-06*	1.8E-04		*2.4E-05*	*4.3E-04*
6	Pulp Dryer - Bleached kraft	kg/ADTFP	*1.2E-02*	*2.0E-02*	*1.1E-04*	*2.2E-03*	*2.0E-04*	*2.1E-02*	1.1E-03	*3.3E-04*	*1.2E-02*
7	Pulp Dryer - Bleached kraft	kg/ADTFP	1.3E-02	*2.2E-02*	3.8E-04		*6.9E-05*	*2.2E-02*	4.2E-04	*3.9E-05*	*3.3E-02*
9	Pulp Dryer - Bleached kraft	kg/ADTFP	2.1E-02	*3.7E-02*	*1.4E-04*		*2.5E-04*	*3.9E-02*	3.1E-04	*4.2E-04*	*2.0E-02*
	Recovery Furnaces, DCE										
7	Recovery Furnace - DCE w/ESP + WS	kg/t BLS	*8.1E-03*	*7.2E-03*	3.8E-04		*1.9E-05*	*7.3E-03*	3.0E-04	*3.3E-05*	*1.2E-02*
1	Recovery Furnace - DCE w/ESP	kg/t BLS	1.3E-02	*1.1E-02*	4.4E-04		*7.0E-05*	*1.1E-02*		*2.0E-04*	*3.0E-06*
8	Recovery Furnace - DCE w/ESP	kg/t BLS	*1.5E-02*	*1.5E-02*	1.1E-03		*8.3E-05*	*1.5E-02*		*2.3E-04*	*4.4E-06*
	Recovery Furnaces, NDCE										
9	Recovery Furnace - NDCE	kg/t BLS	*9.8E-03*	*1.0E-02*	*4.1E-05*	*8.1E-04*	*7.1E-05*	*1.1E-02*	*1.0E-04*	*1.2E-04*	2.2E-02
11	Recovery Furnace - NDCE	kg/t BLS	*1.0E-02*	*1.0E-02*	9.1E-04		*6.1E-05*	*1.0E-02*		*1.7E-04*	*2.8E-06*
12	Recovery Furnace - NDCE	kg/t BLS	1.4E-03	*2.8E-03*	4.2E-06		*1.6E-05*	*2.8E-03*		6.0E-06	*8.1E-04*
8	Recovery Furnace - NDCE	kg/t BLS	6.4E-03	*1.2E-02*	2.7E-04		*6.6E-05*	*1.2E-02*		*2.0E-04*	*0.0E+00*
2	Recovery Furnace - NDCE	kg/t BLS	*9.9E-03*	*9.9E-03*	1.2E-04		*4.9E-05*	5.0E-03		*1.4E-04*	2.5E-03
6	Recovery Furnace #3 - NDCE	kg/t BLS	5.0E-03	*7.9E-03*	9.6E-05	*6.6E-04*	*5.8E-05*	1.3E-01	5.4E-04	9.6E-05	*4.4E-03*
4	Recovery Furnace - NDCE	kg/t BLS	*7.8E-03*	*8.2E-03*	8.9E-04		*1.2E-04*	*1.0E-02*	*3.3E-04*	*9.5E-05*	*3.6E-03*
6	Recovery Furnace #4 - NDCE	kg/t BLS	8.5E-03	*9.8E-03*	4.4E-05	*8.6E-04*	*8.1E-05*	2.2E-02	3.7E-04	*1.3E-04*	3.0E-03
1	Recovery Furnace - NDCE	kg/t BLS	1.6E-02	*1.0E-02*	2.7E-03		3.7E-04	*1.0E-02*		*1.6E-04*	*2.8E-06*

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; FP - finished product; BLS – black liquor solids

Table A1 Continued

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane	1,2-dimethoxyethane	Ethylbenzene
	Bleached Paper Machines & Pulp Dryers										
4	Coated paper - BK + SGW (70:30)	kg/ADTFP	*1.5E-04*	2.1E-04	*5.1E-03*	*7.2E-03*	*1.3E-04*	*1.3E-04*	2.1E-04	*3.2E-04*	4.6E-06
12	Bleached kraft paper	kg/ADTFP	3.8E-07	3.0E-06	*3.8E-04*	*4.2E-04*	*1.5E-05*	*1.6E-05*	2.6E-05		2.0E-07
6	Pulp Dryer - Bleached kraft	kg/ADTFP	*1.6E-04*	*1.7E-04*	*1.2E-02*	*1.5E-02*	*1.4E-04*	*1.4E-04*	2.0E-02	*4.6E-04*	*2.3E-04*
7	Pulp Dryer - Bleached kraft	kg/ADTFP	*5.8E-05*	*7.9E-05*	*3.0E-02*	*3.3E-02*	*4.9E-05*	*4.9E-05*	2.4E-03	*1.2E-04*	*8.3E-05*
9	Pulp Dryer - Bleached kraft	kg/ADTFP	*2.1E-04*	2.9E-04	*1.3E-02*	*1.7E-02*	*1.8E-04*	*1.8E-04*	4.3E-04		*2.9E-04*
	Recovery Furnaces, DCE										
7	Recovery Furnace - DCE w/ESP + WS	kg/t BLS	*1.6E-05*	*3.4E-05*	*1.1E-02*	*1.2E-02*	*1.4E-05*	*1.6E-05*	*1.3E-04*	*3.2E-05*	*2.3E-05*
1	Recovery Furnace - DCE w/ESP	kg/t BLS	*1.4E-04*	*1.5E-04*	*3.0E-06*	*3.0E-06*	*1.2E-04*	*1.2E-04*	*1.1E-04*		*1.4E-04*
8	Recovery Furnace - DCE w/ESP	kg/t BLS	*1.7E-04*	*1.8E-04*	*4.4E-06*	*4.4E-06*	*1.4E-04*	*1.5E-04*	*1.3E-04*		*1.6E-04*
	Recovery Furnaces, NDCE										
9	Recovery Furnace - NDCE	kg/t BLS	*5.9E-05*	*6.3E-05*	*3.6E-03*	*4.9E-03*	*5.1E-05*	*5.2E-05*	2.8E-04	*1.2E-04*	*8.4E-05*
11	Recovery Furnace - NDCE	kg/t BLS	*1.3E-04*	*1.3E-04*	*2.8E-06*	*2.8E-06*	*1.1E-04*	*1.1E-04*	*9.4E-05*		*1.2E-04*
12	Recovery Furnace - NDCE	kg/t BLS	1.5E-05	7.1E-06	*7.2E-04*	*8.0E-04*	3.2E-06	*3.0E-05*	*2.5E-05*		4.1E-06
8	Recovery Furnace - NDCE	kg/t BLS	*1.4E-04*	*1.5E-04*	*0.0E+00*	*0.0E+00*	*1.2E-04*	*1.2E-04*	*1.0E-04*		*1.3E-04*
2	Recovery Furnace - NDCE	kg/t BLS	2.5E-05	*1.1E-04*	*2.2E-03*	7.4E-04	*8.7E-05*	*8.9E-05*	*7.6E-05*		*9.5E-05*
6	Recovery Furnace #3 - NDCE	kg/t BLS	*4.8E-05*	*5.1E-05*	*3.9E-03*	*5.0E-03*	*4.3E-05*	*4.2E-05*	3.8E-04	*9.7E-05*	*6.8E-05*
4	Recovery Furnace - NDCE	kg/t BLS	*9.4E-05*	*9.9E-05*	*3.0E-03*	*4.2E-03*	*8.1E-05*	*8.2E-05*	8.9E-05	*1.9E-04*	*2.3E-04*
6	Recovery Furnace #4 - NDCE	kg/t BLS	7.0E-05	*6.7E-05*	2.8E-03	3.6E-03	*5.5E-05*	*5.4E-05*	8.8E-04	1.0E-04	*8.8E-05*
1	Recovery Furnace - NDCE	kg/t BLS	*1.2E-04*	*1.2E-04*	*2.8E-06*	*2.8E-06*	*1.0E-04*	*1.0E-04*	*8.7E-05*		*1.1E-04*

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; FP - finished product; BLS – black liquor solids

Table A1 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
	Bleached Paper Machines & Pulp Dryers										
4	Coated paper - BK + SGW (70:30)	kg/ADTFP	2.2E-03	*1.8E-04*	*6.2E-03*	2.6E-02	*4.2E-05*	6.2E-04	3.1E-02	*6.2E-03*	*5.3E-03*
12	Bleached kraft paper	kg/ADTFP	7.6E-05	*1.4E-05*	1.0E-04	1.2E-04	1.8E-04		*1.4E-03*	4.5E-06	1.1E-04
6	Pulp Dryer - Bleached kraft	kg/ADTFP	*2.1E-03*	4.0E-04	1.2E-02	*2.0E-02*	*2.2E-02*	*9.2E-04*	*3.6E-02*	6.8E-02	*1.0E-02*
7	Pulp Dryer - Bleached kraft	kg/ADTFP	*4.3E-03*	*6.8E-05*	*3.3E-02*	1.6E-02	*2.2E-02*	*3.3E-04*	5.8E-03	*3.3E-02*	*3.3E-02*
9	Pulp Dryer - Bleached kraft	kg/ADTFP	*7.2E-03*	*2.4E-04*	1.8E-02	4.8E-03	*3.9E-02*	*1.2E-03*	1.4E-03	1.4E-02	*1.3E-02*
	Recovery Furnaces, DCE										
7	Recovery Furnace - DCE w/ESP + WS	kg/t BLS	*1.4E-03*	*1.9E-05*	*1.2E-02*	4.9E-03	*7.4E-03*	*9.2E-05*	*7.2E-03*	*1.2E-02*	*1.2E-02*
1	Recovery Furnace - DCE w/ESP	kg/t BLS	8.8E-02	1.1E-03	*3.0E-06*	6.0E-02	*1.1E-02*		*1.1E-02*	*3.0E-06*	*3.0E-06*
8	Recovery Furnace - DCE w/ESP	kg/t BLS	2.9E-02	*1.3E-04*	*4.4E-06*	2.2E-02	*1.6E-02*		*1.5E-02*	*4.4E-06*	*4.4E-06*
	Recovery Furnaces, NDCE										
9	Recovery Furnace - NDCE	kg/t BLS	*2.0E-03*	*6.8E-05*	6.0E-02	5.3E-03	*1.0E-02*	*3.4E-04*	*1.4E-02*	1.6E-02	*3.6E-03*
11	Recovery Furnace - NDCE	kg/t BLS	5.4E-03	*9.7E-05*	*2.8E-06*	*1.0E-02*	*1.0E-02*		1.4E-02	*2.8E-06*	*2.8E-06*
12	Recovery Furnace - NDCE	kg/t BLS	2.3E-02	*2.6E-05*	*8.1E-04*	*2.8E-03*	*2.8E-03*		*2.8E-03*	2.2E-03	*8.1E-04*
8	Recovery Furnace - NDCE	kg/t BLS	1.7E-02	1.5E-04	*0.0E+00*	*1.2E-02*	*1.3E-02*		*1.2E-02*	*0.0E+00*	*0.0E+00*
2	Recovery Furnace - NDCE	kg/t BLS	6.3E-03	7.7E-05	1.0E-03	1.2E-02	*9.9E-03*		*9.9E-03*	5.0E-04	7.5E-04
6	Recovery Furnace #3 - NDCE	kg/t BLS	1.1E-03	*5.6E-05*	*4.4E-03*	*7.8E-03*	*8.3E-03*	*2.8E-04*	*8.6E-03*	*4.4E-03*	*3.6E-03*
4	Recovery Furnace - NDCE	kg/t BLS	*1.5E-03*	*1.1E-04*	*3.6E-03*	*8.0E-03*	*9.1E-03*	*5.3E-04*	6.8E-03	*3.6E-03*	*3.1E-03*
6	Recovery Furnace #4 - NDCE	kg/t BLS	1.9E-03	*7.2E-05*	3.0E-03	*9.6E-03*	*1.0E-02*	6.3E-04	*1.2E-02*	3.0E-03	2.6E-03
1	Recovery Furnace - NDCE	kg/t BLS	9.1E-03	1.6E-03	*2.8E-06*	1.6E-02	*1.0E-02*		*9.9E-03*	*2.8E-06*	*2.8E-06*

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; FP - finished product; BLS – black liquor solids

Table A1 Continued

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
	Bleached Paper Machines & Pulp Dryers										
4	Coated paper - BK + SGW (70:30)	kg/ADTFP	6.7E-03	7.2E-04	*2.4E-04*	1.5E-06	*2.7E-04*	*1.8E-04*	*2.3E-04*	*2.5E-03*	7.8E-05
12	Bleached kraft paper	kg/ADTFP	*1.4E-03*	2.2E-06	*7.8E-04*	1.9E-06	*2.1E-05*	*2.1E-05*	1.5E-07	6.8E-06	*3.3E-05*
6	Pulp Dryer - Bleached kraft	kg/ADTFP	*2.0E-02*	*1.5E-04*	*2.6E-04*	1.8E-03	*2.9E-04*	*1.9E-04*	*2.5E-04*	*2.6E-03*	*3.8E-04*
7	Pulp Dryer - Bleached kraft	kg/ADTFP	*2.2E-02*	4.3E-05		6.7E-05	*1.9E-03*	*6.6E-05*	*9.0E-05*	*8.9E-04*	*1.4E-04*
9	Pulp Dryer - Bleached kraft	kg/ADTFP	*3.7E-02*	*1.9E-04*	*3.2E-04*	5.1E-04	*3.7E-04*	*2.5E-04*	*3.2E-04*	*3.3E-03*	*4.9E-04*
	Recovery Furnaces, DCE										
7	Recovery Furnace - DCE w/ESP + WS	kg/t BLS	*7.2E-03*	*1.5E-05*		6.4E-05	*2.9E-05*	*1.9E-05*	*2.4E-05*	*2.6E-04*	*4.2E-05*
1	Recovery Furnace - DCE w/ESP	kg/t BLS	*1.1E-02*	*1.3E-04*	*2.1E-04*	*1.2E-04*	*1.7E-04*	*1.7E-04*	*1.7E-04*	*2.3E-04*	*2.7E-04*
8	Recovery Furnace - DCE w/ESP	kg/t BLS	*1.5E-02*	*1.6E-04*	*2.5E-04*	7.8E-04	*2.0E-04*	*2.0E-04*	*2.0E-04*	*2.7E-04*	5.4E-04
	Recovery Furnaces, NDCE										
9	Recovery Furnace - NDCE	kg/t BLS	*1.0E-02*	*5.5E-05*	*9.3E-05*	*4.9E-05*	*1.1E-04*	*7.0E-05*	*9.0E-05*	*9.6E-04*	*1.0E-04*
11	Recovery Furnace - NDCE	kg/t BLS	*9.9E-03*	*1.2E-04*	*1.8E-04*	3.5E-04	*1.5E-04*	*1.5E-04*	*1.5E-04*	*2.0E-04*	*2.4E-04*
12	Recovery Furnace - NDCE	kg/t BLS	*2.8E-03*	6.8E-06	0.0000	2.8E-05	5.5E-06	1.2E-05	1.7E-05	2.1E-05	5.8E-06
8	Recovery Furnace - NDCE	kg/t BLS	*1.2E-02*	*1.3E-04*	*2.2E-04*	2.5E-04	*1.7E-04*	*1.7E-04*	*1.7E-04*	*2.4E-04*	*2.6E-04*
2	Recovery Furnace - NDCE	kg/t BLS	*9.9E-03*	*9.4E-05*	*1.5E-04*	1.8E-04	*1.2E-04*	*1.2E-04*	3.6E-05	7.6E-05	1.2E-05
6	Recovery Furnace #3 - NDCE	kg/t BLS	*7.9E-03*	*4.5E-05*	*7.5E-05*	4.6E-05	*8.6E-05*	*5.7E-05*	*7.3E-05*	*7.8E-04*	*1.1E-04*
4	Recovery Furnace - NDCE	kg/t BLS	*8.5E-03*	*8.7E-05*	*1.5E-04*	*7.7E-05*	*1.7E-04*	*1.1E-04*	*1.4E-04*	*1.5E-03*	*2.2E-04*
6	Recovery Furnace #4 - NDCE	kg/t BLS	5.1E-03	*5.8E-05*	*9.6E-05*	1.0E-04	*1.2E-04*	*8.0E-05*	*1.0E-03*	*1.1E-03*	1.6E-04
1	Recovery Furnace - NDCE	kg/t BLS	*9.9E-03*	*1.1E-04*	*1.7E-04*	*9.5E-05*	*1.4E-04*	*1.4E-04*	*1.4E-04*	*1.9E-04*	*2.2E-04*

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; FP - finished product; BLS – black liquor solids

Table A1 Continued

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon tetrachloride	3-Carene
	Slakers										
2	Lime Slaker	kg/t CaO	*9.0E-04*	*9.1E-04*	*7.3E-06*		*5.1E-06*	*9.1E-04*		*1.4E-05*	*2.6E-04*
9	Lime Slaker	kg/t CaO	1.2E-02	*1.9E-04*	1.0E-06	*8.9E-06*	*7.8E-07*	2.3E-03	1.2E-06	*1.3E-06*	3.4E-04
	Causticizers										
9	Causticizers	kg/t CaO	4.8E-04	*1.1E-04*	1.3E-05		*9.4E-07*	*1.2E-04*	8.4E-06	*1.6E-06*	*5.8E-05*
7	Causticizers	kg/t CaO	9.9E-06	*1.9E-05*		6.7E-08		*1.9E-05*	1.3E-07		*3.0E-05*
	Smelt Dissolving Tanks										
4	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	3.3E-03	5.9E-03	1.0E-05	2.9E-05		1.5E-03	1.1E-04	2.0E-06	
9	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	5.7E-04	*3.9E-04*	*1.6E-06*	*3.1E-05*	*2.7E-06*	*4.0E-04*	*3.8E-06*	*4.6E-06*	1.3E-03
11	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	5.8E-04	*1.2E-02*	*8.3E-06*		*5.5E-06*	*1.2E-03*		*1.7E-05*	*0.0E+00*
12	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	3.3E-04	*6.5E-04*	*5.0E-06*		*3.5E-06*	*6.5E-04*		*9.9E-06*	1.8E-04
1	Smelt Dissolving Tank #1 w/demister pads	kg/t BLS	*1.0E-03*	*1.0E-03*	*8.7E-06*		*5.8E-06*	*1.1E-03*		*1.5E-05*	*0.0E+00*
8	Smelt Dissolving Tank #1 w/scrubber	kg/t BLS	8.7E-04	*1.7E-03*	*1.4E-05*		*9.1E-06*	*1.7E-03*		*2.7E-05*	*0.0E+00*
8	Smelt Dissolving Tank #2 w/scrubber	kg/t BLS	5.5E-04	*1.1E-03*	1.1E-05		*7.6E-06*	*1.1E-03*		*1.5E-05*	*0.0E+00*
6	Smelt Dissolving Tank #3 w/scrubber	kg/t BLS	1.5E-03	*1.4E-03*	*5.4E-06*	*1.1E-04*	*9.3E-06*	*1.5E-03*	4.9E-05	*1.6E-05*	*8.0E-04*
6	Smelt Dissolving Tank #4 w/scrubber	kg/t BLS	7.8E-04	*1.1E-03*	1.7E-05	*1.6E-04*	*1.4E-05*	*1.1E-03*	3.5E-05	*2.4E-05*	5.1E-03
1	Smelt Dissolving Tank # 5 w/wet scrubber	kg/t BLS	*1.1E-03*	*1.1E-03*	*8.4E-06*		*5.6E-06*	5.7E-04		*1.7E-05*	*0.0E+00*

NOTE: All italicized numbers represent non-detects shown at the detection limit
BLS – black liquor solids

Table A1 Continued

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene (isopropylbenzene)	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane (Methylene Chloride)	1,2-dimethoxyethane	Ethylbenzene
	Slakers										
2	Lime Slaker	kg/t CaO	1.7E-06	*1.1E-05*	*2.3E-04*	*2.5E-04*	*9.1E-06*	*9.3E-06*	*8.0E-06*		*1.0E-05*
9	Lime Slaker	kg/t CaO	*6.5E-07*	*6.9E-07*	*4.6E-05*	1.5E-04	*5.6E-07*	*5.7E-07*	1.0E-02	*1.3E-06*	*9.2E-07*
	Causticizers										
9	Causticizers	kg/t CaO	*7.8E-07*	*8.3E-07*	*4.6E-05*	*6.5E-05*	*6.7E-07*	*6.9E-07*	1.6E-06	*1.6E-06*	*1.1E-06*
7	Causticizers	kg/t CaO	5.7E-08	3.8E-08	*2.6E-05*	*2.9E-05*	*0.0E+00*	4.2E-08	3.6E-06		
	Smelt Dissolving Tanks										
4	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	*3.6E-06*	1.3E-05				3.4E-06	5.1E-05		
9	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	*2.2E-06*	*2.4E-06*	*1.3E-04*	*1.8E-04*	*1.9E-06*	*2.0E-06*	3.3E-05	*4.5E-06*	*3.2E-06*
11	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	*1.1E-05*	*1.1E-05*	*0.0E+00*	*0.0E+00*	*1.1E-05*	*8.3E-06*	*8.3E-06*		*1.1E-05*
12	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	1.9E-06	*7.7E-06*	4.7E-05	*1.7E-04*	*6.2E-06*	*6.4E-06*	*5.5E-06*		5.4E-07
1	Smelt Dissolving Tank #1 w/demister pads	kg/t BLS	*1.2E-05*	*1.2E-05*	*0.0E+00*	*0.0E+00*	*8.7E-06*	*8.7E-06*	*8.7E-06*		*1.2E-05*
8	Smelt Dissolving Tank #1 w/scrubber	kg/t BLS	*1.8E-05*	*2.3E-05*	*0.0E+00*	*0.0E+00*	*1.8E-05*	*1.8E-05*	*1.4E-05*		*1.8E-05*
8	Smelt Dissolving Tank #2 w/scrubber	kg/t BLS	*1.5E-05*	*1.5E-05*	*0.0E+00*	*0.0E+00*	*7.6E-06*	*7.6E-06*	*7.6E-06*		*1.5E-05*
6	Smelt Dissolving Tank #3 w/scrubber	kg/t BLS	*7.8E-06*	*8.2E-06*	*7.5E-04*	*9.3E-04*	*6.8E-06*	*6.7E-06*	5.6E-05	*2.2E-05*	*1.1E-05*
6	Smelt Dissolving Tank #4 w/scrubber	kg/t BLS	1.8E-05	2.6E-05	*1.1E-03*	*1.3E-03*	2.2E-05	1.7E-05	8.0E-05	*3.3E-05*	*1.6E-05*
1	Smelt Dissolving Tank # 5 w/wet scrubber	kg/t BLS	*1.4E-05*	*1.4E-05*	*0.0E+00*	*0.0E+00*	*1.1E-05*	*1.1E-05*	*8.4E-06*		*1.1E-05*

NOTE: All italicized numbers represent non-detects shown at the detection limit
BLS – black liquor solids

Table A1 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
	Slakers										
2	Lime Slaker	kg/t CaO	*1.8E-04*	8.1E-06	*2.6E-04*	*9.0E-04*	*9.1E-04*		*9.1E-04*	*1.3E-05*	*1.3E-05*
9	Lime Slaker	kg/t CaO		*7.5E-07*	6.8E-04	1.8E+00	4.2E-04	*3.7E-06*	6.8E-04	2.9E-04	2.3E-04
	Causticizers										
9	Causticizers	kg/t CaO	2.3E-05	9.0E-07	*5.8E-05*	1.3E-01	*1.2E-04*	*4.5E-06*	*1.2E-04*	1.1E-04	9.2E-05
7	Causticizers	kg/t CaO	*3.9E-06*	*0.0E+00*	*3.0E-05*	1.8E-05	*2.0E-05*	3.1E-08	9.7E-06	*3.0E-05*	*3.0E-05*
	Smelt Dissolving Tanks										
4	Smelt Dissolving Tank w/wet scrubber	kg/t BLS				4.0E-02	1.5E-03	8.6E-07	*3.0E-03*		
9	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	*7.5E-05*	*2.6E-06*	2.8E-03	*3.8E-04*	*4.1E-04*	*1.4E-05*	1.0E-03	7.5E-04	4.5E-04
11	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	*2.3E-04*	2.1E-05	*0.0E+00*	1.4E-03	*1.2E-03*		*1.1E-03*	*0.0E+00*	*0.0E+00*
12	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	1.6E-04	*5.5E-06*	*1.8E-04*	7.4E-02	*6.6E-04*		*6.5E-04*	*1.8E-04*	*1.8E-04*
1	Smelt Dissolving Tank #1 w/demister pads	kg/t BLS	5.2E-04	7.8E-04	*0.0E+00*	4.2E-01	*1.1E-03*		*1.0E-03*	*0.0E+00*	*0.0E+00*
8	Smelt Dissolving Tank #1 w/scrubber	kg/t BLS	*3.4E-04*	*1.4E-05*	*0.0E+00*	*1.7E-03*	*1.7E-03*		*1.7E-03*	*0.0E+00*	*0.0E+00*
8	Smelt Dissolving Tank #2 w/scrubber	kg/t BLS	1.8E-03	1.5E-05	*0.0E+00*	*1.1E-03*	*1.1E-03*		*1.1E-03*	*0.0E+00*	*0.0E+00*
6	Smelt Dissolving Tank #3 w/scrubber	kg/t BLS	5.7E-04	4.2E-05	*8.0E-04*	2.2E-02	*1.5E-03*	*4.4E-05*	*1.5E-03*	*8.0E-04*	*6.7E-04*
6	Smelt Dissolving Tank #4 w/scrubber	kg/t BLS	*2.2E-04*	1.4E-05	1.3E-02	*1.1E-03*	*1.1E-03*	*6.6E-05*	*4.0E-03*	9.2E-03	*9.5E-04*
1	Smelt Dissolving Tank # 5 w/wet scrubber	kg/t BLS	*2.2E-04*	3.1E-04	*0.0E+00*	1.1E-01	*1.1E-03*		*1.1E-03*	*0.0E+00*	*0.0E+00*

NOTE: All italicized numbers represent non-detects shown at the detection limit
BLS – black liquor solids

Table A1 Continued

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
	Slakers										
2	Lime Slaker	kg/t CaO	*9.1E-04*	*9.8E-06*	*1.6E-05*	9.3E-05	*1.3E-05*	*1.3E-05*	2.4E-06	*1.7E-05*	1.1E-06
9	Lime Slaker	kg/t CaO	*1.9E-04*	5.0E-06	*1.0E-06*	1.8E-05	*1.2E-06*	*7.7E-07*	*9.9E-07*	*1.1E-05*	*1.1E-06*
	Causticizers										
9	Causticizers	kg/t CaO	6.2E-05	8.6E-07	*1.2E-06*	6.9E-06	*1.4E-06*	*9.3E-07*	*1.2E-06*	1.3E-05	*1.4E-06*
7	Causticizers	kg/t CaO	1.0E-05	8.3E-08		9.3E-08			1.0E-07	5.9E-08	
	Smelt Dissolving Tanks										
4	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	1.5E-03	4.5E-06		6.8E-06	2.8E-06	3.8E-06	5.2E-06		
9	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	*3.9E-04*	*2.1E-06*	*3.5E-06*	5.8E-05	*4.0E-06*	*2.7E-06*	*3.4E-06*	*3.6E-05*	*4.1E-06*
11	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	*1.1E-03*	*1.1E-05*	*1.7E-05*	2.6E-05	*1.4E-05*	*1.4E-05*	*1.4E-05*	*1.7E-05*	*2.2E-05*
12	Smelt Dissolving Tank w/wet scrubber	kg/t BLS	*6.5E-04*	1.9E-06	*3.7E-05*	1.2E-05	*8.6E-06*	1.4E-06	2.5E-06	1.9E-06	7.2E-07
1	Smelt Dissolving Tank #1 w/demister pads	kg/t BLS	*1.0E-03*	*1.2E-05*	*1.7E-05*	1.2E-05	*1.5E-05*	*1.5E-05*	*1.5E-05*	*1.7E-05*	*2.3E-05*
8	Smelt Dissolving Tank #1 w/scrubber	kg/t BLS	*1.7E-03*	*1.8E-05*	*2.7E-05*	*1.8E-05*	*2.3E-05*	*2.3E-05*	*2.3E-05*	*3.2E-05*	*3.6E-05*
8	Smelt Dissolving Tank #2 w/scrubber	kg/t BLS	*1.1E-03*	*7.6E-06*	*1.5E-05*	1.9E-05	*1.5E-05*	*1.5E-05*	*1.5E-05*	*2.3E-05*	*3.0E-05*
6	Smelt Dissolving Tank #3 w/scrubber	kg/t BLS	*1.5E-03*	*7.2E-06*	*1.2E-05*	2.5E-05	*1.4E-05*	*9.2E-06*	*1.2E-05*	*1.3E-04*	*1.8E-05*
6	Smelt Dissolving Tank #4 w/scrubber	kg/t BLS	*1.1E-03*	2.8E-05	2.9E-05	2.6E-05	2.4E-05	1.9E-05	2.8E-05	*1.9E-04*	*2.7E-05*
1	Smelt Dissolving Tank # 5 w/wet scrubber	kg/t BLS	*1.1E-03*	*1.1E-05*	*2.0E-05*	5.0E-05	*1.4E-05*	*1.4E-05*	*1.4E-05*	*2.0E-05*	*2.2E-05*

NOTE: All italicized numbers represent non-detects shown at the detection limit
BLS – black liquor solids

Table A2 Summary Speciated VOC Emission Data from FPAC 20 Mill Study – Miscellaneous Kraft Pulp Mill Operations

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon tetrachloride	3-Carene
	Weak Black Liquor Storage Tanks										
6	Weak Blk Liq Storage Tank	kg/hr/tank	8.8E-02	*9.1E-03*	1.2E-03	*1.9E-05*	*1.7E-03*	2.5E-02	2.3E-03	*2.9E-03*	8.2E-02
6	Weak Blk Liq Storage Tank	kg/hr/tank	3.9E-03	7.5E-06	3.3E-05		2.3E-05	1.8E-02	1.8E-01	*3.1E-06*	8.0E-02
7	Weak Blk Liq Storage Tank	kg/hr/tank	*3.4E-04*	*6.9E-04*	*3.2E-07*		*5.7E-07*	*6.9E-04*	1.2E-05	*1.0E-06*	*2.8E-04*
12	Weak Blk Liq Storage Tank	kg/hr/tank	8.0E-04	2.7E-04	1.1E-05		2.7E-05	9.7E-04		*6.7E-06*	5.2E-03
	Strong Black Liquor Storage Tanks										
6	Heavy/Strong Black Liquor Storage Vent	kg/hr/tank	1.0E-01	*5.9E-04*	1.4E-05	*1.2E-04*	*1.0E-05*	6.0E-02	1.7E-03	*1.8E-05*	4.9E-06
7	Strong Black Liquor Storage Vent	kg/hr/tank	6.6E-04	*9.1E-04*	*4.2E-07*		*7.6E-07*	*9.2E-04*	7.0E-05	*1.3E-06*	*3.7E-04*
12	Strong Black Liquor Storage Vent - 68%	kg/hr/tank	1.1E-01	*8.5E-04*	2.3E-04		5.0E-05	5.3E-02		*1.1E-05*	1.9E-05
12	Strong Black Liquor Storage Vent - 50%	kg/hr/tank	4.7E-05	*9.5E-05*	*8.2E-07*		*5.7E-07*	4.8E-05		*1.6E-06*	8.7E-06
7	Black Liquor Salt Cake Mix Tank Vent	kg/t BLS	2.2E-05	1.8E-05	1.8E-07	2.9E-07		*3.5E-05*	2.8E-06		*9.6E-05*
7	Black Liquor Filter	kg/ADTUBP	6.3E-05	*1.2E-04*	1.5E-06	1.4E-06	1.6E-06	6.5E-04	1.5E-05		*1.4E-04*
9	ESP Ash Tanks	kg/t BLS	2.1E-03	*9.7E-05*	*2.0E-06*		*3.5E-06*	5.2E-03	2.7E-06	*6.1E-06*	*3.3E-05*
	Mud Filter Hood Exhaust										
2	Mud Filter Hood Exhaust	kg/t CaO	7.7E-04	*7.6E-04*	*6.6E-06*		*4.6E-06*	*7.6E-04*		*1.3E-05*	*2.3E-04*
9	Mud Filter Hood Exhaust	kg/t CaO	*1.2E-03*	*1.2E-03*	6.0E-06		*1.0E-05*	1.1E-03	*1.4E-05*	*1.7E-05*	2.8E-03
9	Vacuum Filter Pump Exhaust	kg/t CaO	7.6E-03	*2.2E-04*	4.3E-06		*1.6E-06*	5.0E-03	1.9E-05	*2.7E-06*	5.6E-03

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; UBP – unbleached pulp; BLS – black liquor solids

Table A2 Continued

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane	1,2-dimethoxyethane	Ethylbenzene
	Weak Black Liquor Storage Tanks										
6	Weak Blk Liq Storage Tank	kg/hr/tnk	*1.4E-03*	*1.5E-03*	*1.4E-03*	1.0E-01	*1.2E-03*	*1.2E-02*	4.2E-03	*3.9E-03*	*2.0E-03*
6	Weak Blk Liq Storage Tank	kg/hr/tnk	*1.5E-06*	*1.6E-06*	*4.3E-05*	2.2E-02	*1.3E-06*	*1.3E-06*	1.0E-04	*4.3E-06*	1.7E-05
7	Weak Blk Liq Storage Tank	kg/hr/tnk	*4.6E-07*	*4.8E-07*	*2.4E-04*	*2.7E-04*	*3.9E-07*	*4.0E-07*	5.2E-06	*9.5E-07*	*6.9E-07*
12	Weak Blk Liq Storage Tank	kg/hr/tnk	4.0E-06	5.1E-07	8.3E-04	1.2E-03	*4.2E-06*	*4.3E-06*	1.5E-05		3.4E-06
	Strong Black Liquor Storage Tanks										
6	Heavy/Strong Black Liquor Storage Vent	kg/hr/tnk	*8.6E-06*	*9.1E-06*	4.9E-06	4.9E-06	*7.5E-06*	*7.4E-05*	1.0E-03	*2.4E-05*	3.9E-05
7	Strong Black Liquor Storage Vent	kg/hr/tnk	*6.1E-07*	2.4E-05	*3.2E-04*	*3.6E-04*	*5.2E-07*	*5.3E-07*	3.2E-05	*1.3E-06*	*9.2E-07*
12	Strong Black Liquor Storage Vent - 68%	kg/hr/tnk	3.6E-05	3.6E-06	*1.6E-04*	*1.8E-04*	5.4E-06	*6.8E-06*	*5.8E-06*		3.0E-05
12	Strong Black Liquor Storage Vent - 50%	kg/hr/tnk	1.2E-07	*1.3E-06*	2.6E-06	9.5E-06	*1.0E-06*	*1.0E-06*	1.8E-07		*1.1E-06*
7	Black Liquor Salt Cake Mix Tank Vent	kg/t BLS	2.3E-07	*0.0E+00*	*8.5E-05*	*9.5E-05*	*0.0E+00*	1.5E-07	2.9E-05		
7	Black Liquor Filter	kg/ADTUBP	3.9E-07	4.9E-07	*1.2E-04*	*1.4E-04*		*0.0E+00*	7.3E-05		1.9E-07
9	ESP Ash Tanks	kg/t BLS	*2.9E-06*	*3.1E-06*	*2.7E-05*	*3.8E-05*	*2.5E-06*	*2.6E-06*	1.1E-05	*5.9E-06*	*4.2E-06*
	Mud Filter Hood Exhaust										
2	Mud Filter Hood Exhaust	kg/t CaO	2.0E-06	4.3E-06	*2.0E-04*	*2.3E-04*	*8.2E-06*	*8.4E-06*	8.8E-06		2.5E-06
9	Mud Filter Hood Exhaust	kg/t CaO	8.1E-06	9.7E-06	*5.0E-04*	*7.1E-04*	*7.3E-06*	8.5E-06	2.1E-05	*1.7E-05*	*1.2E-05*
9	Vacuum Filter Pump Exhaust	kg/t CaO	*1.3E-06*	*1.4E-06*	*8.5E-05*	1.5E-03	*1.1E-06*	*1.2E-06*	1.3E-05	*2.7E-06*	*1.9E-06*

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; UBP – unbleached pulp; BLS – black liquor solids

Table A2 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
	Weak Black Liquor Storage Tanks										
6	Weak Blk Liq Storage Tank	kg/hr/tnk	7.7E-04	3.6E-06	1.5E-01	2.1E+00	2.6E-02	*7.9E-03*	*1.4E-02*	1.6E-01	5.7E-02
6	Weak Blk Liq Storage Tank	kg/hr/tnk	5.5E-05	*1.7E-06*	1.6E-01	1.6E-01	1.2E-03	*8.6E-06*	*2.0E-04*	1.2E-01	5.0E-02
7	Weak Blk Liq Storage Tank	kg/hr/tnk	*1.4E-04*	*5.6E-07*	*2.8E-04*	*7.0E-04*	*6.9E-04*	*2.7E-06*	*6.9E-04*	*2.8E-04*	*2.8E-04*
12	Weak Blk Liq Storage Tank	kg/hr/tnk	*9.6E-05*	*3.8E-06*	6.7E-03	1.9E-01	*4.8E-04*		*4.8E-04*	1.0E-01	3.5E-03
	Strong Black Liquor Storage Tanks										
6	Heavy/Strong Black Liquor Storage Vent	kg/hr/tnk	4.3E-03	1.6E-05	4.9E-06	6.7E-01	2.2E-03	*4.9E-06*	6.0E-03	4.9E-06	4.9E-06
7	Strong Black Liquor Storage Vent	kg/hr/tnk	*1.8E-04*	*7.4E-07*	*3.7E-04*	6.4E-04	*9.1E-04*	*3.6E-06*	*9.1E-04*	*3.7E-04*	*3.7E-04*
12	Strong Black Liquor Storage Vent - 68%	kg/hr/tnk	4.7E-04	*5.9E-06*	*1.9E-04*	3.5E-01	1.8E-02		1.8E-03	*1.9E-04*	1.9E-04
12	Strong Black Liquor Storage Vent - 50%	kg/hr/tnk	*1.9E-05*	*9.1E-07*	1.6E-05	7.1E-04	6.4E-05		*9.5E-05*	8.3E-05	1.3E-05
7	Black Liquor Salt Cake Mix Tank Vent	kg/t BLS	*8.1E-06*	*6.1E-08*	*9.6E-05*	2.9E-05	*3.6E-05*	*0.0E+00*	1.8E-05	*9.6E-05*	*9.6E-05*
7	Black Liquor Filter	kg/ADTUBP	8.6E-05		*1.4E-04*	1.1E-01	*1.2E-04*		*6.3E-05*	*1.4E-04*	*1.4E-04*
9	ESP Ash Tanks	kg/t BLS		*3.4E-06*	*3.3E-05*	2.7E-02	8.7E-05	*1.7E-05*	*9.2E-05*	*3.3E-05*	*2.8E-05*
	Mud Filter Hood Exhaust										
2	Mud Filter Hood Exhaust	kg/t CaO	*1.5E-04*	7.3E-06	*2.3E-04*	*7.6E-04*	*7.6E-04*		*7.6E-04*	*1.2E-05*	*1.2E-05*
9	Mud Filter Hood Exhaust	kg/t CaO		8.8E-06	4.8E-03	6.0E-01	*1.3E-03*	*4.8E-05*	*1.6E-03*	2.0E-03	1.4E-03
9	Vacuum Filter Pump Exhaust	kg/t CaO		*1.5E-06*	9.1E-03	4.2E-02	3.9E-04	*7.6E-06*	*2.6E-04*	4.0E-03	2.9E-03

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; UBP – unbleached pulp; BLS – black liquor solids

Table A2 Continued

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
	Weak Black Liquor Storage Tanks										
6	Weak Blk Liq Storage Tank	kg/hr/tnk	*9.3E-03*	4.8E-03	3.8E-03	2.3E-02	*2.5E-03*	*1.7E-03*	*2.1E-03*	*2.3E-02*	*1.5E-02*
6	Weak Blk Liq Storage Tank	kg/hr/tnk	4.5E-04	1.8E-04	*2.4E-06*	1.1E-03	*2.7E-06*	*1.8E-06*	*2.3E-06*	*2.4E-05*	4.9E-05
7	Weak Blk Liq Storage Tank	kg/hr/tnk	*6.9E-04*	*4.2E-07*		6.7E-07	*8.6E-07*	*5.4E-07*	*7.4E-07*	*7.3E-06*	*1.1E-06*
12	Weak Blk Liq Storage Tank	kg/hr/tnk	*4.8E-04*	3.6E-05	*1.7E-03*	7.5E-05	*5.8E-06*	1.2E-05	5.6E-06	2.8E-05	3.4E-06
	Strong Black Liquor Storage Tanks										
6	Heavy/Strong Black Liquor Storage Vent	kg/hr/tnk	4.0E-03	1.0E-04	*1.3E-05*	2.8E-03	*1.5E-05*	*1.0E-05*	*1.3E-05*	*1.4E-04*	1.3E-05
7	Strong Black Liquor Storage Vent	kg/hr/tnk	*9.1E-04*	1.6E-06		2.8E-05	*1.2E-06*	*7.2E-07*	*9.9E-07*	*9.8E-06*	*1.5E-06*
12	Strong Black Liquor Storage Vent - 68%	kg/hr/tnk	4.0E-03	1.8E-04	1.3E-05	6.3E-03	*9.1E-06*	4.1E-04	5.5E-05	6.4E-05	1.2E-05
12	Strong Black Liquor Storage Vent - 50%	kg/hr/tnk	*9.5E-05*	2.4E-07	*1.7E-03*	9.1E-07	*1.4E-06*	*1.4E-06*	1.3E-07	3.8E-07	*2.2E-06*
7	Black Liquor Salt Cake Mix Tank Vent	kg/t BLS	1.9E-05	3.0E-07		3.7E-07			3.5E-07		
7	Black Liquor Filter	kg/ADTUBP	6.0E-05	1.2E-05		5.6E-06		6.0E-05	5.0E-07	2.4E-07	4.0E-07
9	ESP Ash Tanks	kg/t BLS	1.6E-04	*3.5E-06*	*4.5E-06*	1.6E-04	*5.3E-06*	*3.4E-06*	*4.5E-06*	*4.7E-05*	*6.9E-06*
	Mud Filter Hood Exhaust										
2	Mud Filter Hood Exhaust	kg/t CaO	*7.6E-04*	2.3E-06	*1.4E-05*	2.3E-04	*1.1E-05*	*1.1E-05*	3.1E-06	5.1E-06	7.3E-06
9	Mud Filter Hood Exhaust	kg/t CaO	*1.1E-03*	*7.8E-06*	*1.3E-05*	1.2E-05	*1.5E-05*	*1.0E-05*	*1.3E-05*	*1.4E-04*	1.7E-05
9	Vacuum Filter Pump Exhaust	kg/t CaO	1.7E-04	6.9E-06	*2.1E-06*	4.4E-05	*2.4E-06*	*1.6E-06*	*2.0E-06*	*2.2E-05*	*3.1E-06*

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; UBP – unbleached pulp; BLS – black liquor solids

Table A2 Continued

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon tetrachloride	3-Carene
	Dregs Filter Hood Exhaust										
2	Dregs filter Hood Exhaust	kg/t CaO	*6.9E-04*	*7.0E-04*	*6.3E-06*		*4.4E-06*	3.6E-04		*1.2E-05*	*2.2E-04*
9	Dregs Filter Hood Exhaust	kg/t CaO	1.8E-04	*1.8E-04*	*1.2E-05*		*2.0E-05*	*3.0E-04*	*2.8E-05*	*3.6E-05*	*4.7E-05*
	Kamyr Chip Bins										
6	Kamyr Chip Bin Vent	kg/t dry chips	2.9E-04	*1.2E-04*	3.7E-06	*1.2E-05*	2.2E-05	6.1E-03	2.3E-05	*1.8E-06*	5.0E-03
9	Kamyr Chip Bin Vent	kg/t dry chips	7.5E-04	*1.3E-03*	8.7E-07		*1.4E-06*	*1.3E-03*	1.1E-05	*2.2E-06*	6.9E-03
12	Kamyr Chip Bin Vent	kg/t dry chips	5.6E-04	*2.9E-04*	2.0E-06		1.2E-06	*2.9E-04*		1.2E-06	2.0E-05
9	Main NCG (after condenser)	kg/ADTUBP	2.7E-05	*1.9E-05*	*1.1E-07*		*1.8E-07*	*2.0E-05*	1.2E-06	*3.2E-07*	2.3E-04
12	Uncontrolled digester blow tank vent	kg/ADTUBP	1.3E-02	*6.6E-05*	8.2E-04		*3.8E-07*	9.8E-03		1.3E-06	6.5E-04
	Sludge Press or Blend Tanks										
4	Sludge Press - kraft pulp mill	kg/ADTUBP	*1.1E-02*	*1.1E-02*	*3.3E-05*		*4.3E-05*	*1.2E-02*	1.4E-04	*3.5E-05*	*1.5E-03*
6	Sludge Blend Tank - Kraft/DI/TMP mill	kg/ADTUBP	9.9E-06	*7.1E-06*	4.7E-08		*5.0E-08*	*7.5E-06*	1.2E-06	*8.5E-08*	2.4E-07
	Miscellaneous WTS Vents										
4	Primary Pumphouse - kraft pulp mill	kg/ADTUBP	*6.2E-04*	*6.3E-04*	*1.7E-06*		*2.5E-06*	*6.7E-04*	8.1E-06	*2.0E-06*	*8.2E-05*
6	Diversion Box at Effluent Tank[a]	kg/ADTUBP	7.9E-07	*1.4E-06*	*6.3E-09*		*1.1E-08*	*1.4E-06*	*1.5E-08*	*1.9E-08*	*6.6E-07*
6	General Effluent Tank - Kraft/DI/TMP mill	kg/ADTUBP	6.8E-04	*6.4E-04*	*3.1E-06*		*5.3E-06*	*6.8E-04*	1.1E-05	*9.1E-06*	*3.0E-04*
9	Effluent Foam Breaker Tank Vent	kg/ADTUBP	5.3E-06	*3.3E-06*	6.1E-08		9.7E-06	7.3E-06	2.3E-06	*3.6E-08*	

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT- air dry metric tonne; UBP – unbleached pulp; WTS – waste treatment system

[a] Kraft/DI/TMP mill

Table A2 Continued

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane	1,2-dimethoxyethane	Ethylbenzene
	Dregs Filter Hood Exhaust										
2	Dregs filter Hood Exhaust	kg/t CaO	*9.1E-06*	*9.6E-06*	*1.9E-04*	*2.2E-04*	*7.8E-06*	*8.0E-06*	*6.9E-06*		*8.6E-06*
9	Dregs Filter Hood Exhaust	kg/t CaO	*1.7E-05*	*1.8E-05*	*3.9E-05*	*5.4E-05*	*1.4E-05*	*1.5E-05*	2.3E-05	*3.3E-05*	*2.5E-05*
	Kamyr Chip Bins										
6	Kamyr Chip Bin Vent	kg/t dry chips	*8.8E-07*	*9.3E-07*	*2.5E-04*	3.4E-03	*7.7E-07*	*7.5E-07*	7.8E-05	*2.2E-06*	1.3E-06
9	Kamyr Chip Bin Vent	kg/t dry chips	*1.1E-06*	*1.1E-06*	*6.1E-04*	1.0E-03	*9.2E-07*	*9.4E-07*	2.0E-06	*2.3E-06*	*1.5E-06*
12	Kamyr Chip Bin Vent	kg/t dry chips	3.2E-07	4.1E-07	*1.8E-05*	*2.0E-05*	*7.3E-07*	*7.4E-07*	*6.4E-07*		1.4E-07
9	Main NCG (after condenser)	kg/ADTUBP	*1.5E-07*	*1.6E-07*	*4.1E-05*	*4.6E-05*	*1.3E-07*	*1.4E-07*	*1.7E-07*	*3.1E-07*	*2.2E-07*
12	Uncontrolled digester blow tank vent	kg/ADTUBP	1.4E-05	1.9E-06	*4.8E-05*	4.1E-05	*6.7E-07*	*6.9E-07*	*5.9E-07*		*1.9E-05*
	Sludge Press or Blend Tanks										
4	Sludge Press - kraft pulp mill	kg/ADTUBP	*3.5E-05*	1.1E-04	*1.3E-03*	*1.7E-03*	*3.0E-05*	*3.0E-05*	6.8E-05	*7.2E-05*	*8.7E-05*
6	Sludge Blend Tank - Kraft/DI/TMP mill	kg/ADTUBP	*4.1E-08*	1.1E-05	2.4E-07	2.4E-07	*3.6E-08*	*3.6E-08*	9.9E-06	*1.2E-07*	1.1E-07
	Miscellaneous WTS Vents										
4	Primary Pumphouse - kraft pulp mill	kg/ADTUBP	*2.0E-06*	7.6E-05	*6.3E-05*	*9.4E-05*	*1.7E-06*	*1.7E-06*	4.5E-06	*4.1E-06*	*5.0E-06*
6	Diversion Box at Effluent Tank[a]	kg/ADTUBP	*9.1E-09*	1.5E-07	*6.2E-07*	*7.6E-07*	*8.0E-09*	*7.9E-09*	4.1E-08	*2.6E-08*	*1.3E-08*
6	General Effluent Tank - Kraft/DI/TMP mill	kg/ADTUBP	*8.0E-06*	1.1E-05	*2.8E-04*	*3.5E-04*	*3.9E-06*	*3.8E-06*	1.3E-05	*1.3E-05*	*6.3E-06*
9	Effluent Foam Breaker Tank Vent	kg/ADTUBP	*1.8E-08*	6.8E-06	*3.1E-06*	5.7E-05	*1.5E-08*	*1.5E-08*	2.8E-07	*3.5E-08*	2.5E-08

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT- air dry metric tonne; UBP – unbleached pulp; WTS – waste treatment system

[a] Kraft/DI/TMP mill

Table A2 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
	Dregs Filter Hood Exhaust										
2	Dregs filter Hood Exhaust	kg/t CaO	*1.4E-04*	1.5E-05	*2.2E-04*	*6.9E-04*	*7.0E-04*		*7.0E-04*	*1.1E-05*	*1.1E-05*
9	Dregs Filter Hood Exhaust	kg/t CaO		*2.0E-05*	1.7E-04	1.9E-02	*3.3E-04*	*9.4E-05*	*1.6E-03*	*4.7E-05*	*3.9E-05*
	Kamyr Chip Bins										
6	Kamyr Chip Bin Vent	kg/t dry chips	1.9E-04	2.3E-06	8.4E-03	9.2E-02	4.5E-04	*5.0E-06*	*1.2E-04*	1.4E-01	2.9E-02
9	Kamyr Chip Bin Vent	kg/t dry chips	4.5E-02	2.5E-06	9.3E-03	9.8E-02	*1.3E-03*	*6.5E-06*	*1.7E-03*	3.0E-02	6.0E-03
12	Kamyr Chip Bin Vent	kg/t dry chips	3.6E-03	*6.4E-07*	*2.0E-05*	5.9E-02	*2.9E-04*		*2.9E-04*	6.6E-05	*2.0E-05*
9	Main NCG (after condenser)	kg/ADTUBP	4.5E-06	*1.8E-07*	3.7E-04	6.7E-05	*1.9E-05*	*8.7E-07*	*1.8E-05*	8.4E-05	7.6E-05
12	Uncontrolled digester blow tank vent	kg/ADTUBP	6.1E-05	5.5E-05	3.2E-04	3.6E-01	2.5E-02		*6.2E-05*	1.8E-02	*1.3E-03*
	Sludge Press or Blend Tanks										
4	Sludge Press - kraft pulp mill	kg/ADTUBP	*2.2E-03*	*4.0E-05*	*1.5E-03*	1.2E-02	*1.1E-02*	*2.0E-04*	6.0E-03	5.2E-03	3.6E-03
6	Sludge Blend Tank - Kraft/DI/TMP mill	kg/ADTUBP		*4.8E-08*	2.4E-07	1.9E-05	*7.5E-06*	*2.4E-07*	*7.3E-06*	2.4E-07	2.4E-07
	Miscellaneous WTS Vents										
4	Primary Pumphouse - kraft pulp mill	kg/ADTUBP	1.0E-04	*2.3E-06*	*8.2E-05*	1.7E-03	*6.5E-04*	*1.1E-05*	4.1E-04	1.4E-04	*6.7E-05*
6	Diversion Box at Effluent Tank[a]	kg/ADTUBP	*2.6E-07*	*1.1E-08*	*6.6E-07*	*1.3E-06*	*1.4E-06*	*5.2E-08*	*6.2E-06*	*6.6E-07*	*5.6E-07*
6	General Effluent Tank - Kraft/DI/TMP mill	kg/ADTUBP	*1.2E-04*	*5.1E-06*	*3.0E-04*	1.9E-03	*6.8E-04*	*2.5E-05*	*1.1E-03*	*3.0E-04*	*2.5E-04*
9	Effluent Foam Breaker Tank Vent	kg/ADTUBP	7.3E-06	9.0E-08	7.8E-06	2.7E-04	1.2E-06	*1.0E-07*	2.0E-06	7.1E-04	2.6E-04

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT- air dry metric tonne; UBP – unbleached pulp; WTS – waste treatment system

[a] Kraft/DI/TMP mill

Table A2 Continued

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
	Dregs Filter Hood Exhaust										
2	Dregs filter Hood Exhaust	kg/t CaO	*7.0E-04*	*8.4E-06*	*1.3E-05*	3.2E-05	*1.1E-05*	*1.1E-05*	2.3E-06	*1.5E-05*	8.8E-07
9	Dregs Filter Hood Exhaust	kg/t CaO	*2.0E-04*	*1.5E-05*	*2.6E-05*	*1.4E-05*	*3.1E-05*	*2.0E-05*	*2.5E-05*	*2.7E-04*	*4.0E-05*
	Kamyr Chip Bins										
6	Kamyr Chip Bin Vent	kg/t dry chips	*1.2E-04*	1.5E-05	*1.4E-06*	1.2E-04	*1.6E-06*	*1.0E-06*	*1.3E-06*	*1.4E-05*	2.6E-06
9	Kamyr Chip Bin Vent	kg/t dry chips	*1.3E-03*	8.6E-06	*1.8E-06*	2.5E-05	*1.9E-06*	*1.3E-06*	*1.7E-06*	*1.8E-05*	*2.5E-06*
12	Kamyr Chip Bin Vent	kg/t dry chips	*2.9E-04*	2.8E-06	2.3E-07	3.2E-06	9.5E-08	6.2E-06	4.2E-07	4.7E-07	1.9E-07
9	Main NCG (after condenser)	kg/ADTUBP	*1.9E-05*	*1.4E-07*	*2.4E-07*	7.5E-07	*2.7E-07*	*1.8E-07*	*2.3E-07*	*2.5E-06*	*3.7E-07*
12	Uncontrolled digester blow tank vent	kg/ADTUBP	4.6E-04	5.8E-04	8.4E-06	1.1E-03	2.6E-06	1.8E-03	2.0E-05	2.6E-05	2.0E-05
	Sludge Press or Blend Tanks										
4	Sludge Press - kraft pulp mill	kg/ADTUBP	*1.1E-02*	*3.2E-05*	*5.4E-05*	*2.8E-05*	*6.2E-05*	*4.1E-05*	*5.3E-05*	*5.6E-04*	*8.2E-05*
6	Sludge Blend Tank - Kraft/DI/TMP mill	kg/ADTUBP	*7.1E-06*	2.0E-07	*6.4E-08*	6.6E-06	*7.4E-08*	*4.9E-08*	*6.3E-08*	*6.7E-07*	3.8E-07
	Miscellaneous WTS Vents										
4	Primary Pumphouse - kraft pulp mill	kg/ADTUBP	*6.3E-04*	*1.8E-06*	*3.1E-06*	2.4E-06	*3.5E-06*	*2.3E-06*	*3.0E-06*	*3.2E-05*	*4.7E-06*
6	Diversion Box at Effluent Tank[a]	kg/ADTUBP	*1.4E-06*	*8.5E-09*	*1.4E-08*	4.5E-08	*1.6E-08*	*1.1E-08*	*1.4E-08*	*1.5E-07*	*2.2E-08*
6	General Effluent Tank - Kraft/DI/TMP mill	kg/ADTUBP	*6.4E-04*	*4.1E-06*	*6.9E-06*	3.9E-05	*7.9E-06*	*5.2E-06*	*6.8E-06*	*7.1E-05*	*1.0E-05*
9	Effluent Foam Breaker Tank Vent	kg/ADTUBP	*3.3E-06*	4.2E-07	*2.8E-08*	1.6E-06	*3.1E-08*	*2.1E-08*	3.2E-08	*2.8E-07*	1.5E-07

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADT- air dry metric tonne; UBP – unbleached pulp; WTS – waste treatment system

[a] Kraft/DI/TMP mill

Table A3 Summary Speciated VOC Emission Data from FPAC 20 Mill Study – Sulphite Pulp Mill Operations

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon tetrachloride	3-Carene
10	Recovery Furnace w/ wet scrubber	kg/t RLS	*5.6E-03*	*5.6E-03*	1.1E-03		*3.9E-06*	2.8E-03	3.6E-04	*6.7E-06*	2.8E-01
10	Recovery Furnace w/ wet scrubber	kg/t RLS	*9.0E-03*	*9.4E-03*	1.2E-04		*8.2E-05*	5.2E-03	*1.2E-04*	*1.4E-04*	*1.3E-02*
10	Bleach Plant	kg/ADTUBP	1.3E-02	5.3E-05	6.7E-05		*2.1E-05*	5.2E-03	5.9E-06	6.5E-06	*8.7E-03*
	Pulping & Recovery Operations										
10	Bisulphite Plant - Pulping & Recovery	kg/ADTUBP	6.9E-03	*1.9E-03*	1.6E-03		*1.0E-05*	4.5E-02	2.9E-05	*1.7E-05*	
18	Sulphite Pulping Operations (8 vents)	kg/ADTUBP	1.4E-02	*1.4E-02*	4.7E-05	*3.3E-03*	*3.2E-04*	6.1E-01	3.0E-04	8.5E-07	9.1E-02

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane	1,2-dimethoxyethane	Ethylbenzene
10	Recovery Furnace w/ wet scrubber	kg/t RLS	6.5E-06	4.5E-05	7.1E-02	3.3E-01	*2.8E-06*	*2.9E-06*	6.1E-05	*6.5E-06*	1.4E-05
10	Recovery Furnace w/ wet scrubber	kg/t RLS	*6.8E-05*	9.7E-05	*1.1E-02*	2.8E-01	*5.9E-05*	*6.0E-05*	4.5E-04	*1.4E-04*	*9.6E-05*
10	Bleach Plant	kg/ADTUBP	*1.8E-05*	7.8E-03	*7.5E-03*	6.2E-01	2.0E-06	1.5E-06	3.1E-04		5.3E-05
	Pulping & Recovery Operations										
10	Bisulphite Plant - Pulping & Recovery	kg/ADTUBP	*9.0E-06*	1.5E-04	*3.2E-03*	3.8E+00	*7.2E-06*	2.5E-06	1.0E-04	*1.7E-05*	1.2E-04
18	Sulphite Pulping Operations (8 vents)	kg/ADTUBP	*2.8E-04*	1.5E-02	*2.8E-03*	6.3E-02	1.4E-04	5.8E-05	3.8E-04	*5.3E-04*	

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; UBP – unbleached pulp; RLS – red liquor solids

Table A3 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
10	Recovery Furnace w/ wet scrubber	kg/t RLS	*1.1E-03*	*2.6E-05*	3.3E-01	4.1E-01	*5.6E-03*	3.0E-05	*5.6E-03*	9.4E-02	1.7E-01
10	Recovery Furnace w/ wet scrubber	kg/t RLS	*1.8E-03*	*7.8E-05*	*1.3E-02*	8.8E-03	*1.0E-02*	*3.9E-04*	*9.6E-03*	*1.3E-02*	*1.3E-02*
10	Bleach Plant	kg/ADTUBP	2.8E-03	1.1E-04		2.6E-02	*6.5E-03*	*9.8E-05*			
	Pulping & Recovery Operations										
10	Bisulphite Plant - Pulping & Recovery	kg/ADTUBP	1.3E-03	*1.1E-05*	4.0E-02	8.5E-01	7.9E-04	8.4E-06	2.4E-05	4.1E-02	*3.6E-03*
18	Sulphite Pulping Operations (8 vents)	kg/ADTUBP	3.0E-03	6.7E-05	5.4E-02	1.3E+00	*1.5E-02*	2.5E-05	1.5E-02	1.1E-01	2.0E-02

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
10	Recovery Furnace w/ wet scrubber	kg/t RLS	*5.6E-03*	*3.0E-06*	*5.0E-06*	8.1E-05	*5.8E-06*	*3.9E-06*	*4.9E-07*	*5.2E-05*	5.5E-05
10	Recovery Furnace w/ wet scrubber	kg/t RLS	*9.3E-03*	*6.3E-05*	*1.1E-05*	1.3E-03	*1.2E-04*	*8.1E-05*	*1.0E-05*	*1.1E-03*	1.1E-04
10	Bleach Plant	kg/ADTUBP		6.9E-05	3.2E-05	4.2E-04	1.8E-06	1.9E-06	2.5E-06	*2.7E-04*	1.4E-04
	Pulping & Recovery Operations										
10	Bisulphite Plant - Pulping & Recovery	kg/ADTUBP	1.0E-03	3.0E-04	6.0E-06	8.5E-04	*1.4E-05*	2.3E-04	3.6E-06	*1.4E-04*	1.3E-04
18	Sulphite Pulping Operations (8 vents)	kg/ADTUBP	*1.3E-02*	2.4E-04	7.4E-05	3.0E-04	3.0E-06	1.1E-04	*4.1E-04*	1.9E-03	2.2E-04

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADT- air dry metric tonne; UBP – unbleached pulp; RLS – red liquor solids

Table A4 Summary Speciated VOC Emission Data from FPAC 20 Mill Study – Non-Chemical Pulp Mill Operations

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon tetrachloride	3-Carene
	Thermomechanical Pulping										
6	TMP Pulping Operations (3 vents)	kg/ADTP	1.1E-01	*2.8E-03*	*3.7E-06*	*4.5E-05*	9.0E-06	*2.8E-03*	8.3E-05	*1.1E-05*	*0.0E+00*
10	BCTMP Pulping Operations (5 vents)	kg/ADTP	3.8E-02	6.0E-04	1.0E-04		*9.5E-06*	9.7E-04	2.4E-05	*1.6E-05*	9.3E-04
15	TMP Pulping Operations (6 vents)	kg/ADTP	3.3E-03	2.2E-03	3.5E-06	4.5E-05	1.0E-05	8.5E-04	2.7E-06	*1.4E-06*	1.8E-02
16	TMP Pulping Operations (3 vents)	kg/ADTP	*8.3E-03*	*1.4E-02*	*9.6E-04*	*1.9E-02*	*1.7E-03*	*4.2E-02*	*2.4E-03*	*2.8E-03*	4.2E-01
18	TMP Pulping Operations (5 vents)		7.5E-03	3.8E-03	*4.8E-05*	*5.0E-04*	*4.5E-05*	*3.9E-03*	*1.0E-04*	*1.1E-04*	1.5E-02
20	TMP Pulping Operations (3 vents)	kg/ADTP	5.2E-03	1.2E-03	5.9E-06		3.5E-05	2.7E-03	*3.4E-05*	*4.1E-05*	3.6E-03
	Stone Groundwood Pulping										
14	Groundwood Operations (4 vents)	kg/ADTP	*4.0E-02*	*4.1E-02*	8.2E-05		*1.7E-04*	*4.4E-02*	*4.8E-04*	*1.4E-04*	8.8E-03
18	Groundwood Operations (4 vents)	kg/ADTP	2.3E-03	*1.2E-02*	*1.8E-04*	*2.1E-03*	*3.1E-04*	*1.6E-02*	*4.4E-04*	*5.4E-04*	4.6E-01
19	Groundwood Operations (8 vents)	kg/ADTP	5.8E-02	6.4E-03	*2.6E-04*		*4.6E-04*	2.7E-02	1.6E-03	*8.0E-04*	8.5E-02
6	Deinking Pulp Repulper	kg/ADTP	1.2E-04	*1.6E-04*	*1.1E-06*	*2.3E-05*	*2.0E-06*	*1.7E-04*	4.6E-06	*3.4E-06*	*1.1E-04*
	Paper Machines With Mostly Non-Chemical Furnishes										
	Paper Machines - Virgin Mechanical + Chemical Pulp Furnish										
6	Newsprint - DI, TMP, Kraft (51:33:16)[1]	kg/ADTFP	1.4E-03	*2.0E-02*	*1.0E-04*	*2.1E-03*	*1.8E-04*	*2.1E-02*	*2.6E-04*	*3.1E-04*	*1.0E-02*
10	Linerboard - BCTMP + Sulphite	kg/ADTFP	2.6E-02	*1.7E-02*	1.2E-03		*5.5E-05*	1.2E-02	*7.8E-05*	*9.4E-05*	*1.4E-02*
16	Newsprint – TMP	kg/ADTFP	*7.2E-03*	*8.3E-03*	*1.9E-04*	*3.7E-03*	*3.3E-04*	*1.4E-02*	*4.7E-04*	*5.4E-04*	2.2E-02
16	Newsprint – TMP	kg/ADTFP	*7.9E-03*	*1.4E-02*	4.6E-03	*2.0E-02*	*1.8E-03*	*4.2E-02*	*2.5E-03*	*2.9E-03*	3.8E+00
18	Newsprint - TMP/Gndwd/Sulphite	kg/ADTFP	*3.2E-02*	*3.3E-02*	1.7E-04	*1.4E-03*	*1.2E-04*	*3.3E-02*	1.9E-04	*2.6E-05*	2.5E-03
18	Newsprint - TMP/Gndwd/Sulphite	kg/ADTFP	*5.0E-02*	*5.4E-02*	*6.3E-04*	*4.7E-03*	*7.8E-04*	*6.0E-02*	1.3E-03	*8.0E-05*	7.7E-02
20	P&W Papers, uncoated gndwd	kg/ADTFP	1.6E-03	*1.7E-03*	*1.4E-05*		*2.4E-05*	*1.9E-03*	*3.4E-05*	*4.1E-05*	*4.7E-03*
	[1] dry end only										
10	BCTMP Pulp Dryer	kg/ADTFP	8.9E-02	3.1E-02	3.1E-03		4.7E-05	2.6E-02	5.0E-04	*4.8E-04*	5.5E-02

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADTP- air dry metric tonne of pulp; FP – finished product

Table A4 Continued

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane	1,2-dimethoxyethane	Ethylbenzene
	Thermomechanical Pulping										
6	TMP Pulping Operations (3 vents)	kg/ADTP	*5.4E-06*	5.1E-05	*0.0E+00*	*0.0E+00*	4.7E-06	4.6E-06	2.2E-02	*1.1E-05*	*7.6E-06*
10	BCTMP Pulping Operations (5 vents)	kg/ADTP	*7.9E-06*	2.2E-05	*1.3E-03*	4.5E-02	*6.8E-06*	*6.9E-06*	7.2E-05	*1.8E-05*	2.0E-05
15	TMP Pulping Operations (6 vents)	kg/ADTP	6.7E-06	2.3E-05	2.1E-05	1.5E-03	*5.8E-07*	*5.4E-06*	7.0E-05	*1.3E-06*	3.1E-06
16	TMP Pulping Operations (3 vents)	kg/ADTP	*1.4E-03*	6.0E-05	*1.5E-02*	2.0E-02	*1.2E-03*	7.7E-03	6.6E-03	*2.8E-03*	
18	TMP Pulping Operations (5 vents)		*6.4E-05*	2.2E-06	*4.2E-04*	1.6E-03	*3.2E-05*	1.0E-05	3.0E-04	*1.4E-04*	
20	TMP Pulping Operations (3 vents)	kg/ADTP	*2.0E-05*	4.3E-04	*4.1E-03*	*4.5E-03*	*1.7E-05*	*1.7E-05*	1.1E-04	*4.0E-05*	2.2E-05
	Stone Groundwood Pulping										
14	Groundwood Operations (4 vents)	kg/ADTP	*1.3E-04*	*1.4E-04*	*4.7E-03*	6.1E-03	*1.2E-04*	*1.2E-04*	3.9E-04	*2.8E-04*	*3.3E-04*
18	Groundwood Operations (4 vents)	kg/ADTP	*2.6E-04*	*2.8E-04*	*3.9E-03*	*5.1E-03*	*2.3E-04*	*2.4E-04*	*3.6E-04*	*5.2E-04*	
19	Groundwood Operations (8 vents)	kg/ADTP	*3.9E-04*	8.7E-04	*1.1E-01*	*1.2E-01*	*3.4E-04*	*3.4E-04*	5.1E-04	*7.6E-04*	*5.4E-04*
6	Deinking Pulp Repulper	kg/ADTP	*1.6E-06*	7.8E-06	*1.0E-04*	*1.3E-04*	*1.5E-06*	*1.4E-06*	1.8E-05	*3.3E-06*	*2.3E-06*
	Paper Machines With Mostly Non-Chemical Furnishes										
	Paper Machines - Virgin Mechanical + Chemical Pulp Furnish										
6	Newsprint - DI, TMP, Kraft (51:33:16)[1]	kg/ADTFP	*1.5E-04*	*1.6E-04*	*9.2E-03*	*1.2E-02*	*1.3E-04*	*1.6E-04*	1.1E-03	*4.3E-04*	*2.1E-04*
10	Linerboard - BCTMP + Sulphite	kg/ADTFP	*4.6E-05*	4.4E-04	*1.2E-02*	3.0E-01	*4.0E-05*	6.1E-05	4.5E-04	*9.2E-05*	*6.5E-05*
16	Newsprint – TMP	kg/ADTFP	*2.7E-04*	*2.9E-04*	*2.9E-03*	4.5E-03	*2.3E-04*	*3.5E-04*	*3.0E-04*	*5.5E-04*	
16	Newsprint – TMP	kg/ADTFP	*1.5E-03*	1.1E-03	*1.6E-02*	*1.7E-02*	*1.3E-03*	1.7E-01	1.5E-01	*3.0E-03*	
18	Newsprint - TMP/Gndwd/Sulphite	kg/ADTFP	2.8E-05	1.1E-04	*1.1E-03*	*1.2E-03*	*8.8E-05*	*1.2E-04*	*2.6E-04*	*2.1E-04*	
18	Newsprint - TMP/Gndwd/Sulphite	kg/ADTFP	*8.6E-04*	*8.2E-04*	*2.2E-02*	5.0E-02	*5.5E-04*	*4.3E-04*	*7.9E-04*	*1.3E-03*	
20	P&W Papers, uncoated gndwd	kg/ADTFP	*1.9E-05*	8.4E-05	*4.1E-03*	*4.6E-03*	*1.6E-05*	*1.7E-05*	1.7E-04	*3.9E-05*	*2.8E-05*
	[1]dry end only										
10	BCTMP Pulp Dryer	kg/ADTFP	*2.4E-04*	*2.5E-04*	*4.9E-02*	9.7E-01	*2.0E-04*	*2.1E-04*	6.8E-04	*4.7E-04*	*3.3E-04*

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADTP- air dry metric tonne of pulp; FP – finished product

Table A4 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
	Thermomechanical Pulping										
6	TMP Pulping Operations (3 vents)	kg/ADTP	8.6E-03	*6.2E-06*	*0.0E+00*	2.2E-02	*2.8E-03*	*6.1E-05*	*2.8E-03*	3.0E-03	1.4E-03
10	BCTMP Pulping Operations (5 vents)	kg/ADTP	5.5E-03	2.9E-05	3.1E-03	7.0E-01	*1.5E-03*	*5.2E-05*	*1.5E-03*	1.8E-02	1.6E-03
15	TMP Pulping Operations (6 vents)	kg/ADTP	1.6E-03	1.9E-05	1.1E-02	2.3E-02	5.3E-03	4.0E-06	1.6E-03	2.0E-01	7.6E-02
16	TMP Pulping Operations (3 vents)	kg/ADTP	*3.7E-03*	1.4E-03	*1.7E-02*	6.4E-02	*2.7E-02*	*7.9E-03*	*6.9E-03*	6.6E-04	7.6E-02
18	TMP Pulping Operations (5 vents)		2.0E-02	*4.1E-05*	2.2E-02	2.7E-01	3.2E-03	*4.0E-04*	*3.7E-03*	4.8E-03	3.8E-03
20	TMP Pulping Operations (3 vents)	kg/ADTP	2.7E-03	3.4E-05	*4.6E-03*	3.1E-02	3.6E-03	*1.1E-04*	4.0E-03	4.1E-02	1.6E-02
	Stone Groundwood Pulping										
14	Groundwood Operations (4 vents)	kg/ADTP	*8.1E-03*	*1.5E-04*	9.9E-03	3.3E-02	*4.2E-02*	*7.6E-04*	2.6E-02	4.8E-02	3.1E-02
18	Groundwood Operations (4 vents)	kg/ADTP	2.2E-03	*3.1E-04*	8.3E-02	*1.1E-02*	*1.3E-02*	*1.5E-03*	*1.1E-02*	6.9E-02	4.1E-02
19	Groundwood Operations (8 vents)	kg/ADTP	1.8E-02	*4.4E-04*	1.6E-02	3.9E-01	*8.2E-02*	*2.2E-03*	6.8E-02	3.6E-01	1.7E-01
6	Deinking Pulp Repulper	kg/ADTP	3.4E-05	*1.9E-06*	1.2E-03	9.3E-04	*1.7E-04*	*9.4E-06*	*4.8E-04*	7.2E-04	*1.4E-04*
	Paper Machines With Mostly Non-Chemical Furnishes										
	Paper Machines - Virgin Mechanical + Chemical Pulp Furnish										
6	Newsprint - DI, TMP, Kraft (51:33:16)[1]	kg/ADTFP	*5.2E-04*	*1.7E-04*	*1.0E-02*	*2.0E-02*	*2.1E-02*	*8.6E-04*	*2.1E-02*	*1.0E-02*	*8.6E-03*
10	Linerboard - BCTMP + Sulphite	kg/ADTFP	3.4E-03	1.7E-04	*2.0E-02*	7.4E-01	*1.7E-02*	*2.6E-04*	*2.1E-02*	5.6E-02	*1.4E-02*
16	Newsprint – TMP	kg/ADTFP	*1.4E-03*	*3.0E-04*	*3.3E-03*	*6.9E-03*	*1.1E-02*	*1.5E-03*	*6.9E-03*	8.4E-03	*3.3E-03*
16	Newsprint – TMP	kg/ADTFP	*4.1E-03*	2.6E-02	2.7E-01	*6.5E-03*	*2.7E-02*	*8.4E-03*	*6.5E-03*	*1.8E-02*	7.8E-01
18	Newsprint - TMP/Gndwd/Sulphite	kg/ADTFP	9.1E-03	2.0E-04	*1.3E-03*	*3.2E-02*	*3.3E-02*	*5.9E-04*	*3.2E-02*	7.7E-04	*1.3E-03*
18	Newsprint - TMP/Gndwd/Sulphite	kg/ADTFP	2.8E-02	*7.3E-04*	4.5E-02	3.0E-01	*5.8E-02*	*3.7E-03*	*9.7E-02*	6.7E-02	2.2E-02
20	P&W Papers, uncoated gndwd	kg/ADTFP	2.3E-04	3.9E-05	*4.7E-03*	3.2E-03	*1.9E-03*	*1.1E-04*	*1.8E-03*	4.5E-02	3.7E-03
	[1]dry end only										
10	BCTMP Pulp Dryer	kg/ADTFP	9.4E-02	3.4E-04	7.2E-03	6.1E+00	*4.5E-02*	*1.3E-03*	*4.3E-02*	1.3E-01	*5.5E-02*

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADTP- air dry metric tonne of pulp; FP – finished product

Table A4 Continued

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
	Thermomechanical Pulping										
6	TMP Pulping Operations (3 vents)	kg/ADTP	*2.8E-03*	6.9E-06	*8.2E-06*	4.5E-03	*9.6E-06*	*6.4E-06*	*8.2E-06*	*8.7E-05*	*1.3E-05*
10	BCTMP Pulping Operations (5 vents)	kg/ADTP	9.9E-05	1.7E-04	*1.2E-05*	1.1E-04	*1.4E-05*	*9.3E-06*	*1.2E-05*	*1.3E-04*	2.6E-05
15	TMP Pulping Operations (6 vents)	kg/ADTP	1.4E-03	9.6E-05	4.7E-07	1.2E-04	*1.2E-06*	2.5E-07	8.4E-06	6.6E-06	2.1E-08
16	TMP Pulping Operations (3 vents)	kg/ADTP	*1.1E-02*	*1.3E-03*		*1.2E-03*	*2.4E-03*	*1.6E-03*	*2.1E-03*	*2.2E-02*	*3.2E-03*
18	TMP Pulping Operations (5 vents)		*4.0E-03*	8.1E-05	*5.4E-05*	9.1E-05	*7.0E-05*	*5.0E-05*	*7.3E-05*	*5.9E-04*	*8.5E-05*
20	TMP Pulping Operations (3 vents)	kg/ADTP	1.7E-03	5.2E-05	*3.1E-05*	3.0E-04	*3.5E-05*	*2.3E-05*	*3.0E-05*	*3.2E-04*	4.7E-05
	Stone Groundwood Pulping										
14	Groundwood Operations (4 vents)	kg/ADTP	2.1E-02	*1.6E-04*	*2.1E-04*	5.4E-04	*2.4E-04*	*1.6E-04*	*2.0E-04*	*2.2E-03*	*3.2E-04*
18	Groundwood Operations (4 vents)	kg/ADTP	*1.1E-02*	9.5E-05	*4.0E-04*	5.0E-04	*4.7E-04*	*3.2E-04*	*4.0E-04*	*4.2E-03*	*4.6E-04*
19	Groundwood Operations (8 vents)	kg/ADTP	1.8E-02	8.9E-05	8.8E-06	2.1E-02	*6.8E-04*	*4.5E-04*	1.2E-03	*6.2E-03*	4.6E-05
6	Deinking Pulp Repulper	kg/ADTP	*1.6E-04*	3.2E-05	*2.6E-06*	2.9E-06	*2.9E-06*	*2.0E-06*	*2.5E-06*	*2.7E-05*	*3.9E-06*
	Paper Machines With Mostly Non-Chemical Furnishes										
	Paper Machines - Virgin Mechanical + Chemical Pulp Furnish										
6	Newsprint - DI, TMP, Kraft (51:33:16)[1]	kg/ADTFP	*2.0E-02*	*1.4E-04*	*2.3E-04*	8.8E-04	*2.7E-04*	*1.8E-04*	*2.3E-04*	*2.4E-03*	*3.6E-04*
10	Linerboard - BCTMP + Sulphite	kg/ADTFP	1.1E-02	2.0E-04	*7.1E-05*	4.9E-04	*8.2E-05*	*5.5E-05*	*7.0E-05*	*7.4E-04*	6.6E-05
16	Newsprint – TMP	kg/ADTFP	*6.9E-03*	*2.5E-04*		*2.3E-04*	*4.7E-04*	*3.2E-04*	*4.1E-04*	*4.4E-03*	*6.3E-04*
16	Newsprint – TMP	kg/ADTFP	*8.0E-03*	1.0E-01		*1.3E-03*	*2.5E-03*	*1.7E-03*	*2.2E-03*	*2.3E-02*	*3.1E-03*
18	Newsprint - TMP/Gndwd/Sulphite	kg/ADTFP	*3.2E-02*	1.2E-04	3.9E-05	5.6E-04	*2.4E-04*	*1.6E-04*	*2.4E-04*	5.8E-04	2.6E-04
18	Newsprint - TMP/Gndwd/Sulphite	kg/ADTFP	*5.1E-02*	9.3E-04	*1.2E-03*	7.4E-04	*1.5E-03*	9.8E-04	*1.3E-03*	*1.0E-02*	1.2E-03
20	P&W Papers, uncoated gndwd	kg/ADTFP	7.5E-04	2.1E-04	*3.1E-05*	3.2E-04	*3.5E-05*	2.3E-05	3.0E-05	3.2E-04	2.2E-05
	[1] dry end only										
10	BCTMP Pulp Dryer	kg/ADTFP	2.1E-02	1.1E-02	*3.6E-04*	1.8E-03	*4.2E-04*	*2.8E-04*	*3.6E-04*	*3.8E-03*	4.3E-04

NOTE: All italicized numbers represent non-detects shown at the detection limit
ADTP- air dry metric tonne of pulp; FP – finished product

Table A5 Summary Speciated VOC Emission Data from FPAC 20 Mill Study – Other Pulp Mill Sources

Mill No.	Unit Operation	Units	Acetaldehyde	Acrolein	Benzene	Biphenyl	1,3-butadiene	2-Butanone (MEK)	Carbon Disulphide	Carbon tetrachloride	3-Carene
4	CLO_2 Generator Vent Gas Scrubber	kg/ADTBP	*1.2E-05*	*1.4E-05*	*2.3E-07*		*4.2E-07*	*2.0E-05*	1.4E-06	*3.4E-07*	*1.1E-05*
4	CLO_2 Generator Tail Gas Scrubber	kg/ADTBP	1.0E-01	*4.5E-02*	4.4E-06		*4.0E-06*	*4.5E-02*	1.1E-05	*3.2E-06*	*1.4E-04*
4	Cooling Tower - kraft pulp mill[a]	kg/ADTUBP	*4.8E-01*	*4.8E-01*	*1.5E-03*		*1.9E-03*	*5.1E-01*	*5.3E-03*	*1.5E-03*	*6.5E-02*
18	Cooling Tower - TMP/Gndwd/Sulphite mill	kg/ADTP	3.7E-03	*2.7E-03*	*1.4E-05*	*1.8E-04*	*2.4E-05*	9.9E-02	*3.4E-05*	*4.1E-05*	*4.0E-05*
19	Cooling Tower No. 1 - TMP Mill	kg/ADTP	4.4E-03	*8.5E-03*	1.5E-05		*7.1E-06*	*8.6E-03*	9.8E-05	*1.0E-05*	1.7E-02
19	Cooling Tower No. 3 - TMP Mill	kg/ADTP	4.6E-03	*9.0E-03*	1.4E-05		*8.2E-06*	*9.0E-03*	6.9E-05	*1.0E-05*	1.7E-02
14	Bark Pile Flux (mg/s/m2)	$mg/s/m^2$	*1.1E-03*	*1.1E-03*	8.2E-06		*8.2E-06*	*1.2E-03*	*3.3E-05*	*8.2E-06*	*3.4E-04*
2	Chip Pile Flux ($mg/s/m^2$)	$mg/s/m^2$	1.9E-05	ND	ND		ND	7.0E-06		ND	3.5E+00
14	Chip Pile Flux ($mg/s/m^2$)	$mg/s/m^2$	*1.0E-03*	*1.0E-03*	*5.5E-06*		*5.5E-06*	*1.1E-03*	*2.2E-05*	*5.5E-06*	*2.6E-04*
18	Chip Pile Flux ($mg/s/m^2$)	$mg/s/m^2$	*1.1E-03*	*1.1E-03*	6.2E-06	*6.9E-05*	*6.2E-06*	*1.1E-03*	8.3E-06	*5.5E-06*	9.0E-05
9	Chip Handling	kg/t dry chips	*1.9E-03*	*2.0E-03*	*1.1E-05*		*1.9E-05*	*2.1E-03*	6.9E-05	*3.2E-05*	*1.0E-03*
16	Bark Cyclone	kg/t dry bark	*3.3E-05*	*3.8E-05*	*9.3E-07*	*1.8E-05*	*1.6E-06*	*6.5E-05*	*2.3E-06*	*2.7E-06*	3.5E-04
16	Chip Cyclone	kg/t dry chips	*8.9E-03*	*3.4E-02*	*4.3E-03*	*8.5E-02*	*7.5E-03*	*1.6E-01*	*1.1E-02*	*1.2E-02*	*7.5E-02*
18	Chip Conveyor System	kg/t dry chips	1.2E-01	1.8E-03	*1.4E-05*	*2.9E-04*	*2.5E-05*	*1.4E-03*	*3.6E-05*	4.2E-05	5.4E-03
20	Chip Silo B (High Efficiency Cyclone)	kg/t dry chips	1.4E-03	*9.0E-04*	*5.7E-06*		*9.8E-06*	*9.6E-04*	1.1E-05	*1.7E-05*	*2.2E-03*
20	Chip Screening & Washing Vent	kg/t dry chips	8.3E-04	*9.6E-04*	*6.0E-06*		*1.0E-05*	*1.0E-03*	*1.5E-05*	*1.8E-05*	*1.9E-03*
20	Chip Conveyor System - TMP	kg/t dry chips	3.1E-05	*4.7E-05*	*1.3E-07*		*2.2E-07*	*4.9E-05*	*3.1E-07*	*3.7E-07*	*5.5E-05*
16	Dye room – TMP	kg/ADTP	*1.7E-07*		*2.9E-07*		*5.1E-07*	*1.0E-05*	*7.1E-07*	*8.7E-07*	
20	PM Coating Preparation Room Vent - TMP	kg/ADTP	1.1E-06	*1.4E-06*	*6.3E-09*		*1.1E-08*	*1.5E-06*	*1.5E-08*	*1.9E-08*	*2.7E-06*
19	Paper Coater 9 First Heads - Newsprint	kg/ADTFP	2.7E-03	*1.1E-03*	*8.9E-05*		*1.5E-04*	*2.1E-03*	*2.2E-04*	*2.6E-04*	1.5E-03
19	Sludge Press Vent – TMP Mill	kg/ADTP	2.1E-05	*3.5E-05*	8.9E-08		2.2E-07	*3.5E-05*	4.3E-06	*4.4E-08*	7.7E-05

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADTP- air dry metric tonne of pulp; BP & UBP – bleached & unbleached pulp; FP – finished product

[a] Some non-detects for this cooling tower, especially for water-soluble VOCs, are suspect due to high detection limits.

Table A5 Continued

Mill No.	Unit Operation	Units	Chlorobenzene	Chloroform	Cumene	para-Cymene	1,2-dichloroethylene	1,2-dichloroethane	Dichloromethane	1,2-dimethoxyethane	Ethylbenzene
4	CLO_2 Generator Vent Gas Scrubber	kg/ADTBP	*3.3E-07*	1.9E-05	*9.3E-06*	*1.4E-05*	*2.9E-07*	*2.9E-07*	1.0E-06	*6.9E-07*	*8.4E-07*
4	CLO_2 Generator Tail Gas Scrubber	kg/ADTBP	1.8E-05	2.0E-04	*1.2E-04*	*1.6E-04*	*2.7E-06*	*2.8E-06*	8.6E-06	*6.6E-06*	*8.0E-06*
4	Cooling Tower - kraft pulp mill[a]	kg/ADTUBP	*1.5E-03*	3.0E-03	*5.4E-02*	*7.5E-02*	*1.3E-03*	*1.3E-03*	4.5E-03	*3.1E-03*	*3.7E-03*
18	Cooling Tower - TMP/Gndwd/Sulphite mill	kg/ADTP	*2.0E-05*	*2.1E-05*	*1.4E-04*	*1.6E-04*	*1.7E-05*	*1.8E-05*	*3.2E-05*	*4.0E-05*	
19	Cooling Tower No. 1 - TMP Mill	kg/ADTP	*4.9E-06*	5.4E-05	*1.3E-02*	*1.5E-02*	*4.2E-06*	*4.3E-06*	3.7E-04	*1.4E-05*	*6.9E-06*
19	Cooling Tower No. 3 - TMP Mill	kg/ADTP	*4.9E-06*	1.9E-04	*1.3E-02*	*1.5E-02*	*4.2E-06*	*4.3E-06*	4.6E-04	*1.4E-05*	*9.2E-06*
14	Bark Pile Flux (mg/s/m2)	mg/s/m^2	*8.2E-06*	*8.2E-06*	*2.7E-04*	*4.0E-04*	*8.2E-06*	*8.2E-06*	4.1E-05	*1.6E-05*	
2	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	3.0E-06	1.1E-05	ND	3.9E-01	ND	ND	5.0E-06		1.4E-05
14	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	*5.5E-06*	*5.5E-06*	*2.0E-04*	*3.1E-04*	*5.5E-06*	*5.5E-06*	3.4E-04	*1.3E-05*	
18	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	*1.4E-05*	*2.8E-06*	*6.9E-05*	*1.5E-04*	*2.1E-06*	2.1E-06	9.0E-06	*6.2E-06*	
9	Chip Handling	kg/t dry chips	*1.6E-05*	*1.7E-05*	*8.4E-04*	*1.2E-03*	*1.3E-05*	*1.4E-05*	9.4E-05	*3.1E-05*	*3.0E-05*
16	Bark Cyclone	kg/t dry bark	*1.3E-06*	*1.4E-06*	*1.4E-05*	5.8E-05	*1.2E-06*	*1.7E-06*	*1.5E-06*	*2.7E-06*	
16	Chip Cyclone	kg/t dry chips	*6.2E-03*	*6.6E-03*	*6.6E-02*	*7.4E-02*	*5.3E-03*	3.6E-02	3.1E-02	*1.3E-02*	
18	Chip Conveyor System	kg/t dry chips	*2.1E-05*	*2.2E-05*	*2.2E-04*	8.9E-04	*1.8E-05*	*1.8E-05*	*2.3E-05*	*4.2E-05*	
20	Chip Silo B (High Efficiency Cyclone)	kg/t dry chips	*8.2E-06*	1.5E-05	*1.9E-03*	*2.1E-03*	*7.0E-06*	*7.2E-06*	2.7E-05	*1.6E-05*	*1.2E-05*
20	Chip Screening & Washing Vent	kg/t dry chips	*8.7E-06*	*9.2E-06*	*1.7E-03*	*1.9E-03*	*7.5E-06*	*7.6E-06*	3.1E-05	*1.7E-05*	*1.2E-05*
20	Chip Conveyor System – TMP	kg/t dry chips	*1.8E-07*	9.6E-07	*4.9E-05*	*5.4E-05*	*1.6E-07*	*1.6E-07*	8.9E-06	*3.6E-07*	*2.6E-07*
16	Dye room – TMP	kg/ADTP	*4.3E-07*	*4.5E-07*	*4.5E-06*	*5.1E-06*	*3.7E-07*	*3.7E-07*	1.2E-05		
20	PM Coating Preparation Room Vent - TMP	kg/ADTP	*9.1E-09*	1.3E-06	*2.4E-06*	*2.7E-06*	*7.8E-09*	*8.0E-09*	4.1E-07	*1.8E-08*	*1.3E-08*
19	Paper Coater 9 First Heads - Newsprint	kg/ADTFP	*1.3E-04*	*1.4E-04*	*1.1E-03*	*1.3E-03*	*1.1E-04*	*1.1E-04*	4.5E-04	*2.6E-04*	*1.8E-04*
19	Sludge Press Vent – TMP Mill	kg/ADTP	*2.1E-08*	8.2E-07	*5.7E-05*	*6.4E-05*	*1.8E-08*	*1.9E-08*	5.0E-07	*6.0E-08*	8.1E-08

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADTP- air dry metric tonne of pulp; BP & UBP – bleached & unbleached pulp; FP – finished product

[a] Some non-detects for this cooling tower, especially for water-soluble VOCs, are suspect due to high detection limits.

Table A5 Continued

Mill No.	Unit Operation	Units	Formaldehyde	n-Hexane	Limonene	Methanol	Methyl isobutyl ketone (MIBK)	Naphthalene	Phenol	alpha-pinene	bata-pinene
4	CLO$_2$ Generator Vent Gas Scrubber	kg/ADTBP	*2.9E-06*	*3.8E-07*	*1.1E-05*	5.3E-05	*1.7E-05*	*1.9E-06*	4.0E-05	*1.1E-05*	*9.7E-06*
4	CLO$_2$ Generator Tail Gas Scrubber	kg/ADTBP	*1.4E-03*	*3.6E-06*	*1.4E-04*	1.2E-01	*2.6E-02*	*1.8E-05*	*5.9E-02*	*1.4E-04*	*1.2E-04*
4	Cooling Tower - kraft pulp mill[a]	kg/ADTUBP	*9.5E-02*	*1.7E-03*	*6.5E-02*	4.1E-01	*5.0E-01*	*8.5E-03*	4.5E-01	*5.4E-02*	*6.5E-02*
18	Cooling Tower - TMP/Gndwd/Sulphite mill	kg/ADTP	2.2E-03	*2.2E-05*	*1.6E-04*	*2.5E-03*	*2.6E-03*	*1.1E-04*	*2.5E-03*	*1.6E-04*	*1.6E-04*
19	Cooling Tower No. 1 - TMP Mill	kg/ADTP	*1.7E-03*	8.2E-05	*1.5E-02*	4.3E-03	*8.6E-03*	*3.6E-05*	*8.5E-03*	1.0E-01	5.0E-02
19	Cooling Tower No. 3 - TMP Mill	kg/ADTP	*1.8E-03*	1.1E-04	*1.5E-02*	4.6E-03	*9.0E-03*	*3.6E-05*	*9.0E-03*	1.0E-01	5.0E-02
14	Bark Pile Flux (mg/s/m2)	mg/s/m^2	*2.6E-04*	*8.2E-06*	*3.4E-04*	2.3E-03	*1.2E-03*	*4.9E-05*	1.2E-04	8.9E-04	*2.9E-04*
2	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	ND	ND	6.7E+00	4.6E-03	ND		ND	ND	ND
14	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	*2.4E-04*	*7.1E-06*	*2.6E-04*	7.6E-04	*1.0E-03*	*3.7E-05*	1.0E-03	*2.6E-04*	*2.2E-04*
18	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	7.5E-04	*4.1E-06*	*6.9E-05*	*1.1E-03*	*1.1E-03*	*6.9E-06*	*1.1E-03*	*6.9E-05*	*6.9E-05*
9	Chip Handling	kg/t dry chips	4.1E-04	2.2E-05	7.3E-03	4.7E-03	*2.2E-03*	*8.9E-05*	*4.8E-02*	4.2E-03	*8.4E-04*
16	Bark Cyclone	kg/t dry bark	*6.3E-06*	*1.5E-06*	*1.6E-05*	*3.1E-05*	*5.0E-05*	*7.7E-06*	*3.1E-05*	*1.6E-05*	*1.6E-05*
16	Chip Cyclone	kg/t dry chips	*1.7E-02*	2.3E-02	*7.5E-02*	*2.7E-03*	*9.1E-02*	*3.6E-02*	*2.7E-03*	1.1E-01	*7.5E-02*
18	Chip Conveyor System	kg/t dry chips	7.3E-03	*2.3E-05*	*2.5E-04*	3.7E-01	*1.2E-03*	*1.2E-04*	*9.2E-04*	*2.5E-04*	*2.5E-04*
20	Chip Silo B (High Efficiency Cyclone)	kg/t dry chips	*1.7E-04*	4.9E-05	1.1E-03	9.7E-04	*9.7E-04*	*4.7E-05*	*9.3E-04*	9.5E-03	2.1E-03
20	Chip Screening & Washing Vent	kg/t dry chips	*1.8E-04*	2.0E-05	*1.9E-03*	*9.3E-04*	*1.0E-03*	*4.9E-05*	*9.8E-04*	4.7E-03	1.9E-02
20	Chip Conveyor System - TMP	kg/t dry chips	*9.3E-06*	2.2E-07	*5.5E-05*	*4.7E-05*	*4.9E-05*	*1.0E-06*	4.8E-05	*5.5E-05*	*5.5E-05*
16	Dye room – TMP	kg/ADTP		3.7E-06			*6.0E-06*	*2.4E-06*		5.4E-05	1.9E-05
20	PM Coating Preparation Room Vent - TMP	kg/ADTP	*2.7E-07*	3.0E-08	*2.7E-06*	1.6E-06	*1.5E-06*	*5.2E-08*	1.3E-06	*2.7E-06*	*2.7E-06*
19	Paper Coater 9 First Heads - Newsprint	kg/ADTFP	*9.2E-05*	*1.5E-04*	*1.3E-03*	*3.0E-03*	*2.3E-03*	*7.3E-04*	*1.5E-03*	9.1E-03	4.4E-03
19	Sludge Press Vent – TMP Mill	kg/ADTP	*6.9E-06*	6.7E-07	*6.5E-05*	*3.5E-05*	*3.5E-05*	*1.6E-07*	*3.5E-05*	4.5E-04	2.2E-04

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADTP- air dry metric tonne of pulp; BP & UBP – bleached & unbleached pulp; FP – finished product

[a] Some non-detects for this cooling tower, especially for water-soluble VOCs, are suspect due to high detection limits.

Table A5 Continued

Mill No.	Unit Operation	Units	Propionaldehyde	Styrene	Tetrachloro-ethylene	Toluene	1,1,1-trichloroethane	1,1,2-trichloroethane	trichloroethylene	1,2,4-trichlorobenzene	Xylenes (mixed isomers)
4	CLO$_2$ Generator Vent Gas Scrubber	kg/ADTBP	*1.4E-05*	*3.1E-07*	*5.2E-07*	5.2E-07	*5.9E-07*	*4.0E-07*	*5.1E-07*	*5.4E-06*	*7.9E-07*
4	CLO$_2$ Generator Tail Gas Scrubber	kg/ADTBP	*5.1E-02*	*2.9E-06*	*5.0E-06*	2.6E-06	*5.6E-06*	*3.8E-06*	*4.8E-06*	*5.1E-05*	*7.5E-06*
4	Cooling Tower - kraft pulp mill[a]	kg/ADTUBP	*4.8E-01*	*1.4E-03*	*2.3E-03*	1.5E-03	*2.6E-03*	*1.8E-03*	*2.3E-03*	*2.4E-02*	*3.5E-03*
18	Cooling Tower - TMP/Gndwd/Sulphite mill	kg/ADTP	*2.6E-03*	*1.8E-05*	*3.1E-05*	1.8E-05	*3.4E-05*	*2.5E-05*	*3.2E-05*	*4.3E-04*	*4.6E-05*
19	Cooling Tower No. 1 - TMP Mill	kg/ADTP	*8.5E-03*	4.1E-05	*9.7E-06*	2.4E-03	*8.7E-06*	*5.8E-06*	*9.7E-06*	*1.0E-04*	3.2E-05
19	Cooling Tower No. 3 - TMP Mill	kg/ADTP	*8.9E-03*	2.5E-05	*9.7E-06*	2.4E-03	*8.7E-06*	*5.8E-06*	*9.7E-06*	*1.0E-04*	3.2E-05
14	Bark Pile Flux (mg/s/m2)	mg/s/m^2	*1.1E-03*	*8.2E-06*	*1.6E-05*	8.2E-06	*1.6E-05*	*8.2E-06*	*1.6E-05*	*1.3E-04*	*1.6E-05*
2	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	ND	8.0E-06		9.0E-05	ND	ND	5.0E-06	1.0E-05	4.4E-05
14	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	*1.0E-03*	*6.0E-06*	*9.8E-06*	*5.5E-06*	*1.1E-05*	*7.7E-06*	*9.8E-06*	*1.0E-04*	*1.5E-05*
18	Chip Pile Flux (mg/s/m^2)	mg/s/m^2	*1.1E-03*	*4.1E-05*	6.9E-06	3.2E-05	*6.9E-06*	6.2E-06	*6.9E-06*	*6.9E-05*	3.3E-05
9	Chip Handling	kg/t dry chips	*2.0E-03*	4.7E-05	*2.4E-05*	1.8E-03	*2.8E-05*	*1.9E-05*	*2.4E-05*	*2.5E-04*	*3.7E-05*
16	Bark Cyclone	kg/t dry bark	*3.1E-05*	*1.2E-06*		*1.2E-06*	*2.3E-06*	*1.6E-06*	*2.0E-06*	*2.2E-05*	*1.3E-06*
16	Chip Cyclone	kg/t dry chips	*3.3E-02*	*5.7E-03*		*5.3E-03*	*1.1E-02*	*7.3E-03*	*9.5E-03*	*1.0E-01*	*5.8E-03*
18	Chip Conveyor System	kg/t dry chips	4.1E-03	*2.1E-05*	*3.2E-05*	*1.8E-05*	*3.6E-05*	*2.6E-05*	*3.2E-05*	*3.4E-04*	*3.7E-05*
20	Chip Silo B (High Efficiency Cyclone)	kg/t dry chips	5.2E-04	*7.6E-06*	*1.3E-05*	1.8E-04	*1.5E-05*	*9.7E-06*	*1.2E-05*	*1.3E-04*	*1.4E-05*
20	Chip Screening & Washing Vent	kg/t dry chips	5.3E-04	*8.0E-06*	*1.3E-05*	7.4E-05	*1.2E-05*	*1.3E-05*	*1.3E-05*	*1.4E-04*	*1.5E-05*
20	Chip Conveyor System - TMP	kg/t dry chips	2.5E-05	*1.7E-07*	*2.9E-07*	6.9E-06	*3.2E-07*	*2.2E-07*	*2.8E-07*	*2.9E-06*	*3.2E-07*
16	Dye room – TMP	kg/ADTP		*3.9E-07*		*3.5E-07*	*7.5E-07*	*5.0E-07*	*7.4E-07*	*6.8E-06*	*1.0E-06*
20	PM Coating Preparation Room Vent - TMP	kg/ADTP	*1.4E-06*	*8.4E-09*	*1.5E-08*	5.2E-07	*1.6E-08*	*1.1E-08*	*1.4E-08*	*1.5E-07*	*1.6E-08*
19	Paper Coater 9 First Heads - Newsprint	kg/ADTFP	*1.1E-03*	1.2E-04	*2.0E-04*	3.3E-04	*2.3E-04*	*1.5E-04*	*2.0E-04*	*2.1E-03*	*2.2E-04*
19	Sludge Press Vent – TMP Mill	kg/ADTP	*3.5E-05*	3.0E-07	*4.3E-08*	1.1E-05	*3.8E-08*	*2.5E-08*	*4.3E-08*	*4.5E-07*	2.1E-07

NOTE: All italicized numbers represent non-detects shown at the detection limit

ADTP- air dry metric tonne of pulp; BP & UBP – bleached & unbleached pulp; FP – finished product

[a] Some non-detects for this cooling tower, especially for water-soluble VOCs, are suspect due to high detection limits.

APPENDIX B

SUMMARY OF AIR EMISSION DATA FOR CRITERIA AIR CONTAMINANT EMISSIONS DURING THE FPAC 20 MILL STUDY

The following tables summarize the criteria air contaminant emission data generated for various combustion and non-combustion sources during the 20-mill FPAC study. The unit operations tested include boilers burning coal, oil, gas and wood residues exclusively, combination wood-oil, wood-gas, wood-coal, and wood-sludge boilers, one thermal oxidizer burning concentrated NCGs, DCE and non-DCE recovery furnaces, smelt dissolving tanks, lime kilns, and sulphite recovery furnaces.

Table B1 Summary Data for Criteria Air Contaminant Emissions in FPAC 20 Mill Study

Mill No.	Fuel	Control Device	Source & Control Device Description	Unit Capacity	In Units of	Emission Units, x	TPM	
							mg/m^3	x
17	C	MC	PBs 2,3,4,5 coal - stoker - combined stacks - MCs	478.1	GJ/hr	kg/GJ	739.0	0.285
19	G	None	PB #7 - Gas only	173.3	GJ/hr	kg/GJ	5.0	0.002
19	G	None	PB #8 - Gas only	202.4	GJ/hr	kg/GJ	31.6	0.009
2	G	None	Gas Only - #1 Power Boiler	208.2	GJ/hr	kg/GJ		
10	G	None	Boiler #1 - Natural Gas	147.2	GJ/hr	kg/GJ		
10	G	None	Boiler #8 - Natural Gas	183.6	GJ/hr	kg/GJ		
15	G	None	PB - Gas only	233.7	GJ/hr	kg/GJ	3.1	0.001
4	O	None	Oil only - Power Boiler #6	135.4	GJ/hr	kg/GJ	66.8	0.052
16	O	None	PB 4 oil	207.0	GJ/hr	kg/GJ	181.5	0.133
16	O	None	PB 1 oil	177.6	GJ/hr	kg/GJ	262.5	0.075
19	O	None	PB #8 - Oil only	202.5	GJ/hr	kg/GJ	130.3	0.038
19	O	None	PB #7 - Oil only	164.5	GJ/hr	kg/GJ	177.1	0.054
20	O	None	PB - 100% oil - no external emission controls	577.2	GJ/hr	kg/GJ	91.0	0.034
15	O	None	PB oil	233.6	GJ/hr	kg/GJ	34.2	0.014
11	W	ESP	PB - 92.2% hog fuel, rest gas, CTO - ESP	291.2	GJ/hr	kg/GJ	7.5	0.004
12	W	ESP	PB - 97.9% hog fuel, 2.1% gas - ESP	524.9	GJ/hr	kg/GJ	12.0	0.006
18	W	ESP	PB #3 - almost 100% hog fuel - ESP	368.4	GJ/hr	kg/GJ		
5	W	ESP/WS	PB #5 - hog fuel - WS + WESP - some sludge & oil	280.6	GJ/hr	kg/GJ	162.0	0.196
1	W	MC	#4 Power Boiler - 1982; MC only; 97% hog fuel, 3% gas	365.7	GJ/hr	kg/GJ	151.2	0.062
19	W	MC	PB #1 - MCs only - Hog only	170.3	GJ/hr	kg/GJ	98.1	0.042
4	W/O	ESP	Power Boiler #4 - 49% hog fuel, 51% oil - ESP	523.7	GJ/hr	kg/GJ	31.8	0.013
7	W/O	ESP	PB 1 - 80% hog fuel, 20% oil - MCs & ESP	331.1	GJ/hr	kg/GJ	7.8	0.006
5	W/O	ESP/WS	PB #5 - WS+WESP - salty hog fuel w/bunker C oil	280.6	GJ/hr	kg/GJ	154.5	0.215
16	W/O	MC	PB 4 - average of 32.4% bark, rest oil - MCs only	234.6	GJ/hr	kg/GJ	1033.9	0.696
20	W/O	MC	PB (86% oil, 14% sawdust) - MCs only	662.0	GJ/hr	kg/GJ	206.0	0.090
21	W/O	ESP	PB #3 - ESP/MC - 83.3% hog fuel, 14.3% oil, 2.5% gas	487.2	GJ/hr	kg/GJ	56.3	0.022

Table B1 Continued

Mill No.	Fuel	Control Device	Source & Control Device Description	Unit Capacity	In Units of	Emission Units, x	TPM	
							mg/m^3	x
6	W/G	ESP	PB #4 - ESP - 83.4% hog fuel, rest gas	690.4	GJ/hr	kg/GJ	43.7	0.023
1	W/G	MC	#2 Power Boiler - 1966; MC only; 63% hog fuel, 37% gas	409.9	GJ/hr	kg/GJ	145.0	0.058
8	W/G	MC	PB - hog fuel 49.0%, gas 50.4% - MCs only	209.0	GJ/hr	kg/GJ	137.2	0.073
2	W/G	ESP	#3 Power Boiler - ESP - 80.0% hog fuel, 20.0% gas	108.8	GJ/hr	kg/GJ		
9	W/G	WS	PB (75.3% hog fuel, 17.3% gas) w WS	404.4	GJ/hr	kg/GJ		
5	W/G	WS/ESP	PB #5 - WS + WESP - low salt hog fuel with natural gas	280.6	GJ/hr	kg/GJ	36.6	0.048
5	W/G	WS/ESP	PB #5 - WS + WESP - salty hog fuel with natural gas	280.6	GJ/hr	kg/GJ	157.5	0.204
5	W/C	WS/ESP	PB #5 - WS + WESP - low salt hog fuel with coal	280.6	GJ/hr	kg/GJ	58.4	0.075
5	W/C	WS/ESP	PB #5 - WS + WESP - salty hog fuel with coal	280.6	GJ/hr	kg/GJ	170.0	0.207
10	W/S	ESP	Boiler #4 - ESP (82.5% hog fuel, 14.3% sludge)	373.9	GJ/hr	kg/GJ	36.4	0.017
22	W/S	ESP	Boiler - ESP (wood, sludge, oil, knots)	373.9	GJ/hr	kg/GJ		
12		TO	CNCG Scrubber after Thermal Oxidizer	1,200.0	Tubp/day	kg/mtubp		
1	BLS	ESP	DCE - #1 Recovery, 1966, CE, ESP - 3 chamber	1,595.7	Tbls/day	kg/mt bls	135.8	0.639
8	BLS	ESP	DCE - RB #1 w/ESP	1,122.2	Tbls/day	kg/mt bls	247.3	1.290
7	BLS	WS/ESP	DCE - RB w/ESP + WS	1,154.0	Tbls/day	kg/mt bls	170.4	0.745
1	BLS	ESP	NDCE - # 5 Recovery, 1981, CE, ESP - 2 chamber	1,734.3	Tbls/day	kg/mt bls	53.6	0.213
4	BLS	ESP	NDCE - RB #4	1,261.7	Tbls/day	kg/mt bls	154.0	0.657
6	BLS	ESP	NDCE - RB #4 - 1990s	1,642.9	Tbls/day	kg/mt bls	27.0	0.130
6	BLS	ESP	NDCE - RB #3 - 1970/1990	1,140.6	Tbls/day	kg/mt bls	109.0	0.570
8	BLS	ESP	NDCE - RB #2 w/ESP	474.3	Tbls/day	kg/mt bls	117.2	0.485
11	BLS	ESP	NDCE - RB - ESP	1,740.2	Tbls/day	kg/mt bls	25.7	0.094
12	BLS	ESP	NDCE - RB w/ESP	1,070.4	Tbls/day	kg/mt bls	16.0	0.089
13	BLS	ESP	NDCE - RB w/ESP	889.2	Tbls/day	kg/mt bls	80.0	0.412
21	BLS	WS/ESP	NDCE - RB w/Teller Scrubber & ESP	1,573.9	Tbls/day	kg/mt bls	37.0	0.203
2	BLS	ESP	NDCE - RB #3 w/ESP	1,270.0	Tbls/day	kg/mt bls		
9	BLS	ESP	NDCE - RB w 2 ESPs	1,860.0	Tbls/day	kg/mt bls		

Table B1 Continued

Mill No.	Fuel	Control Device	Source & Control Device Description	Unit Capacity	In Units of	Emission Units, x	TPM	
							mg/m^3	x
1		WS	#5 Smelt Stack - ducon scrubber (1981)	1,734	Tbls/day	kg/mt bls	350.8	0.147
1		WS	#1 Smelt Stack - chevrons w/cond. showers (Munters)	1,596	Tbls/day	kg/mt bls	838.7	0.322
4		WS	Smelt Dissolving Tank	1,262	Tbls/day	kg/mt bls	175.5	0.100
6		WS	Smelt Dissol. Tank #3 (wet scrubber)	887	Tbls/day	kg/mt bls	67.6	0.044
6		WS	Smelt Dissol. Tank #4 (wet scrubber)	1,503	Tbls/day	kg/mt bls	99.6	0.038
8		WS	Smelt Dissol. Tank #1 - turbotak, 0.5% caustic	1,122	Tbls/day	kg/mt bls	53.6	0.030
8		WS	Smelt Dissol. Tank #2 - turbotak, 0.5% caustic	474	Tbls/day	kg/mt bls	166.7	0.073
11		WS	Smelt Dissol. Tank w turbo tank scrubber	1,740	Tbls/day	kg/mt bls	266.6	0.093
12		WS	Smelt Dissol. Tank - scrubber	1,070	Tbls/day	kg/mt bls	207.0	0.109
13		WS	Smelt Dissol. Tank	889	Tbls/day	kg/mt bls	186.0	0.072
2		WS	Smelt Tank No. 3 - Scrubber	1,270	Tbls/day	kg/mt bls		
9		WS	Smelt Dissolving Tank w/dynamic scrubber	RB	Tbls/day	kg/mt bls		
4	O	WS	Lime Kiln #2 - No. 6 oil - Venturi Scrubber - Smidth	117.0	tCaO/d	kg/mt CaO	168.1	0.797
13	O	WS	LK w/Venturi Scrubber - No. 6 oil	144.0	tCaO/d	kg/mt CaO	166.0	0.996
4	O	WS	Lime Kiln #1 - No. 6 oil - Venturi Scrubber - Traylor	59.0	tCaO/d	kg/mt CaO	118.4	0.722
7	O	WS	Lime Kiln - WS - No. 6 oil	145.0	tCaO/d	kg/mt CaO	467.2	1.668
8	G	WS	LK - Venturi Scrubber - Fuller Schmidt - Gas	203.2	tCaO/d	kg/mt CaO	83.5	0.352
11	G/CTO	WS	LK w/Venturi Scrubber - Gas & CTO	241.1	tCaO/d	kg/mt CaO	190.0	0.641
21a	O	WS	LK1 w/Venturi Scrubber - No. 6 oil	251	tCaO/d	kg/mt CaO	792.0	1.386
21b	O	WS	LK2 w/Venturi Scrubber - No. 6 oil	248	tCaO/d	kg/mt CaO	604.0	1.183
9	G/CTO	WS	Lime Kiln with VS - Gas & CTO	LK	tCaO/d	kg/mt CaO		
1a	G	ESP	LK w/ESP East Stack - gas	476.1	tCaO/d	kg/mt CaO	8.30	0.056
1b	G	ESP	LK w/ESP West Stack - gas - Traylor, 1981	476.1	tCaO/d	kg/mt CaO	17.00	
6	G/O	ESP	LK w/ESP (gas & oil)	356.4	tCaO/d	kg/mt CaO	76.2	0.262
12	G	ESP	LK w/ESP - gas	246.0	tCaO/d	kg/mt CaO	18.0	0.044
10	RLS	ESP	Red liquor recovery boiler - #9 - NH_3 bisulphite	702	Trls/day	kg/mt rls	296.6	1.053
10	RLS	ESP	Red liquor recovery boiler - #2 - NH_3 bisulphite	210	Trls/day	kg/mt rls	146.8	0.854
10	RLS	ESP	Red liquor recovery boiler - #3 - NH_3 bisulphite	210	Trls/day	kg/mt rls	337.4	1.594
22	RLS	WS	Red liquor recovery boiler - Mg sulphite	528	Trls/day	kg/mt rls		

Table B1 Continued

Mill No.	Fuel	TPM/M201		$PM_{2.5}$		% of TPM	PM_{10}		% of TPM	CPM	
		mg/m^3	x	mg/m^3	x		mg/m^3	x		mg/m^3	x
17	C	670.0	0.264	229.0	0.088	**34.2%**	418.0	0.161	**62.4%**		
19	G	5.0	0.002	0.4	0.000	**8.6%**	2.2	0.001	**44.4%**		
19	G	31.6	0.009	1.0	0.000	**3.1%**	4.1	0.001	**13.1%**		
2	G										
10	G										
10	G										
15	G										
4	O	95.6	0.066	46.9	0.032	**49.0%**	62.9	0.044	**65.8%**		
16	O	73.8	0.047	55.1	0.035	**74.7%**	71.3	0.046	**96.7%**	74.7	0.062
16	O	115.4	0.036	61.0	0.019	**52.9%**	82.1	0.025	**71.1%**	68.8	0.021
19	O	130.3	0.038	21.1	0.006	**16.2%**	40.2	0.012	**30.8%**		
19	O	177.1	0.054	4.4	0.001	**2.5%**	21.1	0.006	**11.9%**		
20	O	91.0	0.034	30.8	0.017	**33.8%**	52.5	0.030	**57.7%**		
15	O										
11	W	6.5	0.003	0.0	0.000	**0.0%**	3.3	0.002	**50.0%**		
12	W									6.0	0.003
18	W	44.9	0.035	8.5	0.008	**18.9%**	24.8	0.021	**55.3%**	71.7	0.053
5	W										
1	W	159.0	0.068	91.4	0.039	**57.5%**	146.0	0.062	**91.8%**		
19	W										
4	W/O	31.7	0.013	12.3	0.005	**38.8%**	15.0	0.006	**47.5%**		
7	W/O	6.3	0.004	0.5	0.001	**8.3%**	2.3	0.001	**35.8%**	32.0	0.017
5	W/O										
16	W/O	524.9	0.383	122.3	0.089	**23.3%**	260.4	0.190	**49.6%**	102.7	0.075
20	W/O	206.0	0.090	45.0	0.050	**21.8%**	80.2	0.089	**38.9%**		
21	W/O	17.86	0.011	8.92	0.006	**49.9%**	13.14	0.008	**73.6%**		

Table B1 Continued

Mill No.	Fuel	TPM/M201		$PM_{2.5}$		% of TPM	PM_{10}		% of TPM	CPM	
		mg/m^3	x	mg/m^3	x		mg/m^3	x		mg/m^3	x
6	W/G	43.7	0.023	24.9	0.013	**57.0%**	35.8	0.018	**82.0%**		
1	W/G	146.0	0.062	36.7	0.016	**25.1%**	75.2	0.032	**51.5%**		
8	W/G	418.0	0.322	309.0	0.238	**73.9%**	377.0	0.291	**90.2%**		
2	W/G			1.5	6.3E-04		9.3	3.8E-03			
9	W/G										
5	W/G										
5	W/G										
5	W/C										
5	W/C										
10	W/S	38.7	0.019	18.9	0.009	**48.8%**	27.8	0.013	**71.8%**		
22	W/S										
12											
1	BLS	57.1	0.223	30.8	0.120	**53.9%**	44.5	0.174	**77.9%**		
8	BLS	183.0	0.946	106.0	0.548	**57.9%**	141.0	0.729	**77.0%**		
7	BLS										
1	BLS	36.7	0.142	15.9	0.062	**43.3%**	29.4	0.114	**80.1%**		
4	BLS	145.0	0.615	75.9	0.323	**52.4%**	106.6	0.45	**73.5%**		
6	BLS	27.0	0.141	18.9	0.099	**70.0%**	25.4	0.133	**94.1%**		
6	BLS	107.1	0.550	61.6	0.316	**57.5%**	96.5	0.496	**90.1%**		
8	BLS										
11	BLS	24.2	0.084	19.7	0.069	**81.4%**	23.2	0.081	**95.9%**		
12	BLS	7.6	0.055	4.2	0.030	**55.3%**	4.6	0.033	**60.5%**	7.0	0.089
13	BLS										
21	BLS	37.0	0.203	8.0	0.038	**21.5%**	9.1	0.043	**24.5%**		
2	BLS			24.8	0.11		47.3	0.21			
9	BLS			0.0	4.812		0.0	7.467			

Table B1 Continued

Mill No.	Fuel	TPM/M201		$PM_{2.5}$		% of TPM	PM_{10}		% of TPM	CPM	
		mg/m^3	x	mg/m^3	x		mg/m^3	x		mg/m^3	x
1											
1											
4											
6											
6											
8											
8											
11											
12										29.0	0.015
13											
2											
9											
4	O										
13	O										
4	O										
7	O										
8	G										
11	G/CTO										
21a	O	792.0	1.386	547.1	0.689	**69.1%**	707.0	0.890	**89.3%**		
21b	O	604.0	1.183	375.6	0.517	**62.2%**	517.3	0.711	**85.6%**		
9	G/CTO										
1a	G	3.26	0.011	0.0	0.000	**0.0%**	1.04	0.006	**31.9%**		
1b	G	3.39	0.000	0.0		**0.0%**	2.35		**69.3%**		
6	G/O	76.3	0.268	14.5	0.051	**19.0%**	53.3	0.187	**69.8%**		
12	G									36.0	0.089
10	RLS										
10	RLS										
10	RLS										
22	RLS	29.0	0.161	21.0	0.118	**73.7%**	26.0	0.146	**90.7%**		

Table B1 Continued

Mill No.	Fuel	SO_2		NO_x		CO		VOC		NH_3	
		mg/m^3	x	mg/m^3	x	mg/m^3	x	mg/m^3	x	mg/m^3	x
17	C	157.3	0.062	157.8	0.062	739.0	0.285				
19	G	17.5	0.005	210.4	0.061	4.0	0.002				
19	G	33.2	0.010	212.7	0.063	2.0	0.001				
2	G			90.0	0.029	340.0	0.102				
10	G			150.5	0.043	40.0	0.013				
10	G			141.0	0.115	0.5	1.2E-04				
15	G			131.3	0.043						
4	O	1864.7	1.52	592.86	0.417	1.16	5.3E-04				
16	O			245.0	0.211						
16	O	3496.7	1.007	660.0	0.190						
19	O	2424.0	0.709	588.8	0.172	4.0	0.001				
19	O	2334.0	0.714	623.2	0.190	5.0	0.002				
20	O	1620.6	0.611	404.6	0.152	4.0	0.002				
15	O			384.1	0.153						
11	W										
12	W	1.4	0.001	80.3	0.041						
18	W	89.0	0.066	156.0	0.116	162.7	0.121				
5	W	53.3	0.064	164.0	0.199						
1	W										
19	W	122.0	0.052	273.4	0.116	744.0	0.287				
4	W/O	973.0	0.43	205.13	0.082	208.80	0.085				
7	W/O	945.2	0.485	644.9	0.338						
5	W/O	63.0	0.088	180.0	0.250						
16	W/O	131.0	0.088	193.9	0.131	0.0	0.000				
20	W/O	1083.2	0.463	331.7	0.142	30.0	0.015	8.8	0.002		
21	W/O	2287.6	1.047	324.6	0.150	177.5	0.075				

Table B1 Continued

Mill No.	Fuel	SO_2		NO_x		CO		VOC		NH_3	
		mg/m^3	x	mg/m^3	x	mg/m^3	x	mg/m^3	x	mg/m^3	x
6	W/G	112.0	0.060	174.0	0.093						
1	W/G										
8	W/G										
2	W/G			170.0	0.071	150.0	0.063				
9	W/G	0.0	47.470	0.0	0.000						
5	W/G	20.0	0.026	232.0	0.304	126.0	0.165				
5	W/G	21.0	0.027	171.0	0.222	347.0	0.450				
5	W/C	39.0	0.050	195.0	0.249	238.0	0.304				
5	W/C	56.0	0.068	162.0	0.197	263.0	0.321				
10	W/S	246.4	0.145	355.3	0.209	183.0	0.098	355.3	0.005		
22	W/S										
12		239.2	0.036	1005.9	1.4E-01	22.5	0.003				
1	BLS										
8	BLS										
7	BLS									59.3	0.260
1	BLS										
4	BLS	0.27	0.001	137.90	0.582	245.92	1.035				
6	BLS	90.3	0.435	98.9	0.476						
6	BLS	209.0	1.097	97.9	0.514						
8	BLS										
11	BLS										
12	BLS	8.5	0.046	132.8	0.720						
13	BLS	308.0	1.603	114.0	0.587						
21	BLS	2.0	0.008	175.9	0.730	519.9	2.506				
2	BLS					90.0	0.396				
9	BLS			0.0	0.000						

Table B1 Continued

Mill No.	Fuel	SO_2		NO_x		CO		VOC		NH_3	
		mg/m^3	x	mg/m^3	x	mg/m^3	x	mg/m^3	x	mg/m^3	x
1											
1											
4						7.31	4.1E-03				
6										35.0	0.032
6										113.0	0.053
8											
8											
11											
12											
13											
2										0.0	0.000
9										0.0	0.000
4	O	400.3	0.71	40.30	0.100						
13	O	191.0	1.146	248.0	1.488						
4	O			14.33	0.046						
7	O										
8	G										
11	G/CTO										
21a	O			282.7	0.373	114.8	0.179				
21b	O			305.6	0.388	23.0	0.031				
9	G/CTO										
1a	G										
1b	G										
6	G/O	779.0	4.625	78.1	0.466						
12	G	12.9	0.032	352.6	0.868						
10	RLS	782.2	3.218	230.0	0.814	743.6	2.650	47.5	0.195	90.0	0.370
10	RLS	582.7	3.482	559.7	3.345	4.6	0.027	8.0	0.048		
10	RLS	803.3	3.937	673.6	3.302	138.0	0.659	7.0	0.034	14.1	0.069
22	RLS	41.0	0.768	63.3	0.421	4.8	0.030	12.4	0.082		

APPENDIX C

SUMMARY OF AIR EMISSION DATA FOR REDUCED SULPHUR COMPOUND EMISSIONS DURING THE FPAC 20 MILL STUDY

Table C1 summarizes the reduced sulphur compound and total reduced sulphur (TRS) emission data generated for various combustion and non-combustion sources during the 20-mill FPAC study. The unit operations tested include one bleach plant, one brownstock washer system, five lime kilns, three non-contact recovery furnaces, four smelt dissolving tanks, one strong black liquor storage tank, one tall oil scrubber, one thermal oxidizer, one chip bin, two causticizing units, and one lime slaker.

Table C1 Summary Kraft Pulp Mill TRS Emission Data from FPAC 20-Mill Study[a]

Mill No.	Unit Operation	Units	H_2S	CH_3SH	$(CH_3)_2S$	$(CH_3)_2S_2$	TRS
Mill 12	Bleach Plant	kg/mtbp	0.0E+00	1.4E-04	6.2E-05	6.2E-05	1.8E-04
Mill 6	Bleach Plant	kg/mtbp					1.1E-02
Mill 13	Brownstock Washer Vents	kg/mtubp	9.5E-04	1.7E-03	6.9E-04	5.8E-03	6.9E-03
Mill 12	Lime Kiln w/ESP	kg/mt CaO	2.7E-02	2.9E-03	2.0E-04	2.9E-04	3.0E-02
Mill 13	Lime Kiln w/Wet Scrubber	kg/mt CaO	8.4E-03	1.2E-04	1.8E-04	2.4E-04	8.4E-03
Mill 4	Lime Kiln w/Wet Scrubber	kg/mt CaO					5.6E-02
Mill 4	Lime Kiln w/Wet Scrubber	kg/mt CaO					2.2E-01
Mill 9	Lime Kiln w/Wet Scrubber	kg/mt CaO					6.7E-03
Mill 13	Recovery Boiler - NDCE	kg/mt bls	4.5E-03	7.6E-03	4.0E-03	3.6E-03	1.5E-02
Mill 4	Recovery Boiler - NDCE	kg/mt bls					2.3E-03
Mill 9	Recovery Boiler - NDCE	kg/mt bls					*2.2E-03*
Mill 12	Smelt Dissolving Tank	kg/mt bls	1.3E-02	4.6E-03	6.7E-04	3.6E-04	1.7E-02
Mill 13	Smelt Dissolving Tank	kg/mt bls	1.2E-02	3.8E-02	6.2E-03	4.7E-03	4.6E-02
Mill 4	Smelt Dissolving Tank	kg/mt bls					1.6E-02
Mill 9	Smelt Dissolving Tank	kg/mt bls					3.2E-02
Mill 13	Strong Black Liquor Storage Tank	kg/hr/tnk	3.1E-04	5.4E-03	1.1E-02	5.0E-02	4.7E-02
Mill 13	Tall Oil Scrubber	kg/mtubp	3.2E-03	1.6E-03	1.2E-03	3.8E-04	4.7E-03
Mill 12	Thermal Oxidizer	kg/mtubp	0.0E+00	2.8E-05	1.4E-05	8.0E-06	3.3E-05
Mill 12	Chip Bins	kg/mt chips	3.3E-04	6.0E-03	8.8E-03	2.2E-04	9.6E-03
Mill 7	Caustisizing Unit Vent No. 1	kg/mt CaO					1.3E-04
Mill 9	Recausticizers	kg/mt CaO					2.9E-03
Mill 9	Slaker	kg/mt CaO					2.7E-02

mt – metric tonne; bp - bleached pulp; ubp – unbleached pulp; bls – black liquor solids

[a] does not include wastewater treatment plant emissions;

APPENDIX D

SUMMARY OF AIR EMISSION DATA FOR TRACE METAL EMISSIONS DURING THE FPAC 20 MILL STUDY

Tables D1, D2, D3, and D4 summarize emissions of trace and heavy metals from two direct contact (DCE), three non-direct contact (NDCE) kraft recovery furnaces, five smelt dissolving tanks, and three lime kilns, respectively.

Table D1 Summary of Trace and Heavy Metal Emissions from DCE Kraft Recovery Furnaces

Trace Metal	KRFC1	KRFC8	Mean
	kg/Tbls	kg/Tbls	kg/Tbls
Sb	1.0E-07	1.6E-07	1.3E-07
As	1.7E-06	2.1E-06	1.9E-06
Be	4.2E-07	1.2E-06	7.9E-07
Cd	6.4E-07	1.2E-06	9.3E-07
Cr	7.0E-06	8.5E-06	7.7E-06
Co	2.6E-07	4.4E-07	3.5E-07
Pb	9.1E-06	2.7E-06	5.9E-06
Mn	4.5E-05	2.7E-04	1.6E-04
Hg	1.4E-05	1.4E-05	1.4E-05
Ni	3.9E-06	4.8E-06	4.4E-06
Se	2.5E-06	3.2E-06	2.8E-06
P	5.1E-04	4.3E-04	4.7E-04
Ba	7.1E-06	5.5E-06	6.3E-06
Cu	2.5E-05	2.7E-05	2.6E-05
Zn	2.8E-05	3.0E-05	2.9E-05
Ag	3.2E-08	2.3E-07	1.3E-07
Th	-3.1E-09	5.7E-09	1.3E-09
Al	7.1E-05	7.0E-05	7.1E-05
B	1.0E-03	9.0E-04	9.7E-04
Bi	8.8E-08	3.8E-08	6.3E-08
Ca	7.6E-04	8.7E-04	8.2E-04
Cl	7.5E-02	3.8E-02	5.6E-02
Fe	9.2E-05	1.3E-04	1.1E-04
K	9.7E-03	4.4E-02	2.7E-02
Li	2.3E-07	9.9E-07	6.1E-07
Mg	6.6E-05	6.0E-05	6.3E-05
Mo	1.3E-06	1.7E-06	1.5E-06
Na	6.0E-02	2.6E-01	1.6E-01
S	8.2E-01	6.9E-01	7.5E-01
Si	2.5E-03	1.6E-03	2.1E-03
Sn	1.5E-06	1.3E-06	1.4E-06
Sr	1.7E-06	4.5E-06	3.1E-06
Ti	1.1E-05	4.7E-06	7.8E-06
Tl	1.9E-08	3.2E-08	2.6E-08
U	1.9E-10	1.5E-09	8.7E-10
V	6.5E-07	1.1E-06	8.7E-07

Tbls – tonne black liquor solids

Table D2 Summary of Trace and Heavy Metal Emissions from NDCE Kraft Recovery Furnaces

Trace Metal	KRFC1	KRFC8	KRFC11	Median	Mean
	kg/Tbls	kg/Tbls	kg/Tbls	kg/Tbls	kg/Tbls
Sb	8.6E-08	1.6E-07	9.0E-08	9.0E-08	1.1E-07
As	1.6E-07	1.7E-06	2.8E-08	1.6E-07	6.4E-07
Be	6.3E-07	3.4E-07	1.8E-07	3.4E-07	3.9E-07
Cd	3.8E-07	9.5E-07	3.6E-07	3.8E-07	5.6E-07
Cr	4.4E-06	6.9E-06	3.8E-06	4.4E-06	5.0E-06
Co	1.9E-07	2.2E-07	2.2E-07	2.2E-07	2.1E-07
Pb	4.7E-06	1.4E-06	1.3E-06	1.4E-06	2.5E-06
Mn	3.6E-05	2.2E-04	9.6E-05	9.6E-05	1.2E-04
Hg	5.4E-06	1.2E-05	7.1E-06	7.1E-06	8.2E-06
Ni	2.1E-06	7.9E-06	2.2E-06	2.2E-06	4.0E-06
Se	1.4E-06	7.0E-06	1.0E-06	1.4E-06	3.1E-06
P	9.8E-05	1.3E-03	5.6E-05	9.8E-05	4.9E-04
Ba	5.1E-06	1.0E-05	2.8E-06	5.1E-06	6.1E-06
Cu	1.0E-05	2.4E-05	5.2E-06	1.0E-05	1.3E-05
Zn	1.4E-05	2.9E-05	1.1E-05	1.4E-05	1.8E-05
Ag	3.1E-08	2.0E-07	3.2E-08	3.2E-08	8.6E-08
Th	-4.4E-09	4.2E-08	6.3E-08	4.2E-08	3.4E-08
Al	4.9E-05	7.8E-05	5.9E-05	5.9E-05	6.2E-05
B	2.9E-03	1.5E-03	1.4E-03	1.5E-03	1.9E-03
Bi	2.6E-07	7.1E-08	9.3E-09	7.1E-08	1.1E-07
Ca	4.6E-04	1.2E-03	3.5E-04	4.6E-04	6.6E-04
Cl	1.1E-03	3.9E-01	1.7E-03	1.7E-03	1.3E-01
Fe	8.2E-05	1.5E-04	1.1E-04	1.1E-04	1.1E-04
K	4.9E-03	2.0E-03	1.2E-03	2.0E-03	2.7E-03
Li	2.0E-07	8.2E-08	7.8E-08	8.2E-08	1.2E-07
Mg	3.1E-05	4.4E-04	4.2E-05	4.2E-05	1.7E-04
Mo	8.9E-07	1.3E-06	1.3E-06	1.3E-06	1.1E-06
Na	3.5E-02	1.4E-02	6.0E-03	1.4E-02	1.8E-02
S	9.2E-02	2.2E+00	4.2E-03	9.2E-02	7.5E-01
Si	4.1E-04	1.2E-03	2.1E-03	1.2E-03	1.2E-03
Sn	2.2E-07	4.3E-06	8.4E-07	8.4E-07	1.8E-06
Sr	1.2E-06	4.3E-06	2.8E-06	2.8E-06	2.8E-06
Ti	3.4E-06	9.2E-06	2.6E-06	3.4E-06	5.1E-06
Tl	4.7E-10	2.0E-08	1.6E-09	1.6E-09	7.4E-09
U	2.8E-11	7.4E-09	2.2E-09	2.2E-09	3.2E-09
V	2.1E-07	2.7E-07	9.1E-08	2.1E-07	1.9E-07

Tbls – tonne black liquor solids

Table D3 Summary of Trace and Heavy Metal Emissions from Smelt Dissolving Tanks

Trace Metal	SDTC1a	SDTC1b	SDTC8a	SDTC8b	SDTC11	Median	Mean
	kg/Tbls	kg/Tbls	kg/Tbls	kg/Tbls	kg/Tbls	kg/Tbls	kg/Tbls
Sb	6.4E-08	2.9E-08	2.9E-08	3.9E-08	1.1E-08	2.9E-08	3.5E-08
As	1.3E-07	5.0E-08	8.1E-08	7.2E-08	3.3E-08	7.2E-08	7.3E-08
Be	5.6E-08	2.5E-08	1.0E-07	8.6E-08	4.4E-08	5.6E-08	6.3E-08
Cd	8.8E-08	4.1E-08	8.2E-08	1.8E-07	6.1E-08	8.2E-08	9.0E-08
Cr	1.1E-06	6.8E-07	9.7E-07	9.7E-07	7.4E-07	9.7E-07	8.9E-07
Co	6.5E-08	1.8E-08	6.5E-08	3.8E-08	3.4E-08	3.8E-08	4.4E-08
Pb	3.5E-07	3.0E-07	2.8E-07	2.1E-07	9.5E-08	2.8E-07	2.5E-07
Mn	2.0E-05	7.7E-06	1.5E-05	3.0E-05	8.0E-06	1.5E-05	1.6E-05
Hg	1.1E-06	5.3E-07	8.9E-07	1.3E-07	2.3E-07	5.3E-07	5.6E-07
Ni	7.6E-07	3.3E-07	4.7E-07	6.7E-07	8.4E-07	6.7E-07	6.1E-07
Se	3.9E-07	1.9E-07	1.1E-07	1.6E-07	1.6E-07	1.6E-07	2.0E-07
P	2.8E-05	1.5E-05	2.0E-05	2.0E-05	1.0E-05	2.0E-05	1.9E-05
Ba	1.8E-06	9.5E-07	1.6E-06	1.3E-06	6.6E-07	1.3E-06	1.3E-06
Cu	2.4E-06	1.9E-06	1.3E-06	1.7E-06	8.6E-07	1.7E-06	1.6E-06
Zn	5.5E-06	1.1E-06	4.0E-06	3.0E-06	1.5E-06	3.0E-06	3.0E-06
Ag	2.3E-08	8.2E-09	1.5E-08	4.6E-09	1.0E-08	1.0E-08	1.2E-08
Th	4.4E-10	1.1E-09	3.6E-09	3.8E-09	5.6E-09	3.6E-09	2.9E-09
Al	2.1E-05	9.2E-06	1.6E-05	1.3E-05	1.2E-05	1.3E-05	1.4E-05
B	3.8E-05	1.2E-05	1.3E-05	8.8E-06	7.4E-06	1.2E-05	1.6E-05
Bi	1.5E-09	6.6E-09	2.2E-09	7.1E-09	3.5E-08	6.6E-09	1.0E-08
Ca	1.2E-04	7.6E-05	2.0E-04	1.7E-04	4.0E-05	1.2E-04	1.2E-04
Cl	2.2E-03	9.2E-04	1.0E-03	9.5E-04	9.2E-04	9.5E-04	1.2E-03
Fe	2.7E-05	2.3E-05	2.2E-05	1.5E-05	7.9E-06	2.2E-05	1.9E-05
K	7.4E-03	3.3E-03	5.1E-03	3.9E-03	2.3E-03	3.9E-03	4.4E-03
Li	1.4E-07	5.6E-08	1.2E-07	8.7E-08	4.9E-08	8.7E-08	9.2E-08
Mg	2.4E-05	1.5E-05	3.7E-05	3.3E-05	7.7E-06	2.4E-05	2.3E-05
Mo	7.3E-07	3.8E-07	8.0E-07	4.5E-07	3.6E-07	4.5E-07	5.5E-07
Na	6.0E-02	2.6E-02	3.0E-02	2.2E-02	1.2E-02	2.6E-02	3.0E-02
S	1.6E-02	4.8E-03	6.5E-03	9.2E-03	3.3E-03	6.5E-03	7.9E-03
Si	1.0E-03	2.0E-04	2.6E-03	3.0E-03	2.3E-03	2.3E-03	1.8E-03
Sn	7.6E-08	1.4E-07	2.6E-07	1.4E-07	1.1E-07	1.4E-07	1.4E-07
Sr	1.2E-06	6.9E-07	1.3E-06	8.9E-07	2.7E-07	8.9E-07	8.6E-07
Ti	1.2E-06	4.6E-07	1.1E-06	1.4E-06	6.2E-07	1.1E-06	9.4E-07
Tl	3.0E-09	2.7E-09	8.2E-10	5.1E-09	3.3E-09	3.0E-09	3.0E-09
U	1.6E-09	1.2E-09	7.5E-09	3.7E-09	4.3E-09	3.7E-09	3.7E-09
V	2.1E-07	8.0E-08	1.1E-07	6.9E-08	7.1E-08	8.0E-08	1.1E-07

Tbls – tonne black liquor solids

Table D4 Summary of Trace and Heavy Metal Emissions from Lime Kilns

Trace Metal	LK w/ESP		Lime Kilns w/Wet Scrubbers		
	LKC1		LKC8	LKC11	Mean
	kg/T CaO		kg/T CaO	kg/T CaO	kg/T CaO
Sb	1.3E-07		1.2E-07	9.7E-08	1.1E-07
As	2.5E-07		6.7E-07	1.4E-06	1.0E-06
Be	1.9E-07		2.9E-07	2.9E-07	2.9E-07
Cd	1.1E-06		2.4E-06	2.2E-06	2.3E-06
Cr	7.9E-06		8.4E-05	1.6E-04	1.2E-04
Co	3.0E-07		4.6E-07	1.4E-07	3.0E-07
Pb	8.0E-06		1.8E-06	1.1E-06	1.4E-06
Mn	1.9E-04		1.9E-03	4.0E-04	1.2E-03
Hg	8.4E-06		1.9E-06	2.0E-06	1.9E-06
Ni	4.8E-06		1.7E-05	7.3E-06	1.2E-05
Se	1.0E-07		1.7E-06	1.5E-06	1.6E-06
P	5.7E-04		9.0E-03	3.1E-03	6.0E-03
Ba	2.1E-05		7.2E-04	5.4E-04	6.3E-04
Cu	2.3E-05		1.0E-05	6.0E-06	8.0E-06
Zn	5.4E-05		4.9E-05	2.9E-05	3.9E-05
Ag	2.8E-08		1.1E-07	1.4E-07	1.3E-07
Th	1.9E-08		4.0E-07	4.5E-08	2.2E-07
Al	9.2E-05		4.4E-04	1.5E-04	2.9E-04
B	1.2E-04		6.5E-05	3.7E-05	5.1E-05
Bi	2.2E-07		8.2E-07	0.0E+00	4.1E-07
Ca	2.9E-03		5.1E-02	2.9E-02	4.0E-02
Cl	3.9E-05		3.9E-03	3.6E-03	3.8E-03
Fe	1.0E-04		2.0E-03	9.1E-04	1.4E-03
K	5.4E-04		1.4E-03	1.1E-02	6.3E-03
Li	2.5E-07		2.4E-06	4.4E-06	3.4E-06
Mg	3.3E-04		1.2E-02	3.6E-03	7.8E-03
Mo	1.3E-06		2.5E-06	1.8E-06	2.1E-06
Na	5.2E-03		4.6E-02	2.3E-01	1.4E-01
S	7.9E-01		1.8E-02	1.5E-01	8.2E-02
Si	5.0E-04		1.4E-02	5.2E-03	9.8E-03
Sn	1.3E-06		2.7E-06	1.9E-06	2.3E-06
Sr	7.5E-06		1.5E-04	1.1E-04	1.3E-04
Ti	6.1E-06		1.3E-04	3.1E-05	8.3E-05
Tl	3.2E-08		2.9E-07	5.3E-07	4.1E-07
U	1.2E-09		2.0E-08	3.3E-08	2.6E-08
V	5.8E-07		5.0E-07	1.5E-06	1.0E-06

T CaO – tonne reburned lime product