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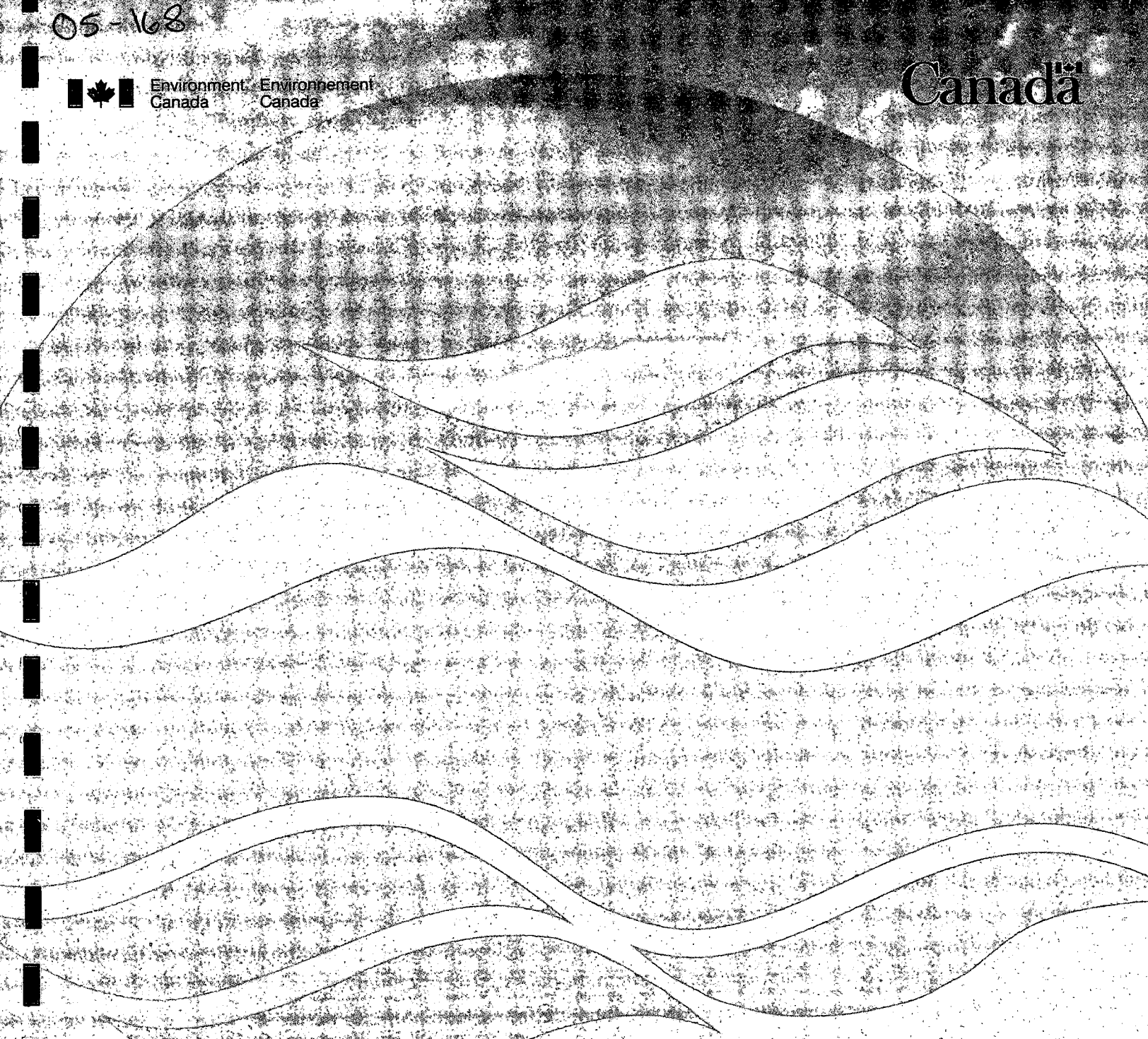

Analytical Approaches to Characterizing Fish Tainting Potential of Oil Sands Process Waters.

BY:

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Analytical Approaches to Characterizing Fish Tainting Potential of Oil Sands Process Waters.

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Abstract
A three-stage study has been carried out with rainbow trout (*Oncorhyncus mykiss*) to develop analytical approaches which can provide a fingerprint for tainting by oil sands chemicals from process-affected waters and natural sources. The objective is to find a simpler alternative to sensory evaluation. In the first stage, a set of seven test compounds was added to fish tissue which was analyzed by headspace and solvent (dichloromethane, DCM) extraction followed by gas chromatography-mass spectrometry (GC-MS). In the second stage, fingerlings (5-20 g) were exposed for 96 hours to the test compound mixture at 1.0 and 0.5 times the estimated tainting threshold concentrations. In the final stage, fingerlings were exposed for 96 hours to an oil sands process water at 5, 10, 20 and 50% concentrations in clean water. None of the test compounds was identified in DCM extracts of tissue from exposed fish. Two long-chain aldehydes, hexadecanal and 9-octadecenal, were tentatively identified in these extracts by matching of mass spectra with library spectra.

Keywords
Chemical analysis; oil sands; oil sands process waters; rainbow trout; tainting

INTRODUCTION

The vast oil sands deposits in northeastern Alberta are attracting international attention for their strategic and economic value in an era of tightening world crude oil supply. The surface mining operations near Fort McMurray store large quantities of oil sands process-affected waters (OSPW) which have the potential to taint fish, as shown by several sensory studies over the past two decades (Jardine and Hrudey, 1988; Diversified Research, 1992; Koning and Hrudey, 1992; Golder, 1996; LeBlanc *et al.*, 2000). Site reclamation and closure plans must take into account this potential for tainting of fish in the adjacent Athabasca River watershed. There is also the potential for tainting from natural sources because the Athabasca River and its tributaries erode oil sands deposits in the McMurray Formation. Sensory studies, based on challenging a test panel, are complex, subjective and costly. As a result, they are not good tools for tracking and delineating sources and extents of tainting potential. The Wetlands and Aquatics Working Group of CONRAD (Canadian Oilsands Network for Research and Development) has been working toward an analytical method for fingerprinting and defining tainting by chemicals from OSPW and natural erosion. An initial project has been completed at the Alberta Research Council, Vegreville, AB, to test analytical approaches with a suite of model compounds and OSPW using rainbow trout as test species.

History – sensory studies

In the mid-1980s concerns arose over the potential for oil sands chemicals to cause tainting of fish in the the Athabasca River and tributaries north of Fort McMurray. In addition there is a commercial fishery in Lake Athabasca into which the Athabasca River empties. Jardine and Hrudey (1988) established sensory detection thresholds for several oil sands chemicals in walleye tissue. Two of the more potent chemicals were naphthalene and benzothiophene with detection thresholds of 0.33 and 0.09 mg/kg, respectively. Koning and Hrudey (1992) exposed rainbow trout (*Oncorhyncus mykiss*) to a variety of OSPWs and reference waters. After exposure, fish tissue was

subsequently analyzed by a sensory panel. All of the process-affected waters produced significant taint. The authors also analyzed fish bile and tissue for phenol, methyl- and dimethyl phenols. Tissue and bile showed elevated levels of several phenols. The authors concluded that phenols contributed to the taint from the most tainting wastewater, treated tailings pond water.

In another study (Diversified Research, 1992), rainbow trout were exposed to water from five small test ponds on the Syncrude Canada site, and two reference waters. The fish tissue was assessed using the Double Triangle Difference Test. The only significant differences were control pond *vs.* a reference water, and the same control pond *vs.* two test ponds (with oil sands extraction material). Fish tissue was also analyzed for polycyclic aromatic compounds (PACs). Only a few PACs were at detectable levels, and the reference water fish had somewhat higher levels and more detections than fish exposed to water from the control or test ponds. In another study, also using the Double Triangle Difference Test, rainbow trout were exposed to 0.5% dike seepage water and 0.5% refinery effluent from the Suncor operation, and lab and field (caged fish) Athabasca River water (Golder, 1996). By the criteria of the testing, both dike seepage water and refinery water were different from lab and field river water; however they were not different from the time zero control.

In the most recent study (LeBlanc *et al.*, 2000), rainbow trout were exposed to fresh and aged CT water (water phase from production of consolidated or composite tailings). Three CT waters, one "aged" and two "fresh", were tested at 0.1-10% concentration. A screened, trained sensory panel from the local area was set up. Sensory analysis was by Difference-from-Control, and both flavour and aroma were evaluated. The lowest concentrations causing detectable taint were 0.1-1.0%. Tainting depended on the source of the CT water and whether it was picked up by changes to flavour or aroma.

By 2002, (TrueNorth, 2001; Golder 2002), fish tainting potential had become an important issue in environmental impact assessments of new oil sands projects. While these sensory studies have established that oil sands process-affected waters have the potential to cause fish tainting, the components responsible for the tainting are as yet unknown. Furthermore, the results have sometimes been internally inconsistent. Because sensory studies are expensive and complicated to conduct, chemical analysis may be a more practical means of screening and quantitating OSPWs for tainting potential.

METHODS

Experimental Outline

Rainbow trout fingerlings (5-20 g) were used. Both headspace and solvent (dichloromethane, DCM) extraction methods were used with analysis by gas chromatography-mass spectrometry (GC-MS) (ARC, 2005). The first step was to add a suite of model compounds to fish homogenate to determine analytical recovery. The model compounds were: 2,4-dimethylphenol, ethylbenzene, benzothiophene, naphthalene, quinoline, cyclohexane carboxylic acid, and nonane. They were chosen on the basis of earlier studies or reviews (Hydroqual and Dominion, 1986; Birkholz *et al.*, 1987; Jardine and Hrudey, 1988; Koning and Hrudey, 1992; Booty *et al.*, 1996; Golder, 2004). In the second stage (experiment I), fingerlings were exposed to the suite of model compounds added to clean water at 1 and 0.5 times the estimated tainting threshold concentrations, and were analyzed by DCM extraction and GC-MS.

In a second exposure experiment (II), fingerlings were exposed for 96 hours to Athabasca River water, both upstream and downstream from oil sands development, and to 5, 10, 20 and 50% of an

oil sands process water in dilution water (96-hour survival rates were 11, 13, 5 and 0, respectively, of the 15 original fingerlings at each exposure level). For the 50% exposure, fingerlings surviving at 72 hours were used for analysis. Fish were analyzed by both DCM extraction and headspace methods. Upstream river water was collected at the Fort McMurray water treatment plant (upstream from all oil sands development). Downstream river water was collected from Albian Sand's river intake station, the furthest downstream operation. Process water (release water) was from the Syncrude Mildred Lake Settling Basin. Waters were stored at 4 C and exposure experiments were carried out within two weeks of receipt of the waters. The exposures were static renewal tests.

Extraction and Analysis

A 1g sample of spiked fish homogenate was weighed into a 16 x 125 mm screw-cap test tube. The sample was then spiked with 8 µL of a surrogate standard spiking solution of n-decane-d22 and n-tetradecane-d30 at 1000 µg/mL. Five mL of Nanopure water was added to the tube, which was capped tightly and vortexed well to mix. The homogenate was then serially extracted three times with 5 mL aliquots of DCM with centrifugation at 2500 – 3000 rpm for 10 minutes to separate layers. The lower, organic layers were removed and combined using a Pasteur pipette and concentrated under nitrogen at 35°C to 1 mL. The final extract was passed through a 0.2 µm syringe filter into a 2 mL crimp-cap vial. Prior to analysis, 250 µL of final extract was transferred to a 2 mL vial with insert and combined with 2.5 µL of an internal standard mixture of 1,4-dichlorobenzene-d4 and acenapthene-d10.

The concentrated samples and tainting compound standards were loaded onto an automated liquid sampler (Agilent Technologies Model 7683) and analysed using a gas chromatograph (Agilent Technologies Model 6890) equipped with a split/splitless injector, a 30 m x 0.25 mm ID Rtx-5MS (crossbond 5% diphenyl, 95% dimethyl polysiloxane) capillary column, and a mass spectrometry detector (Agilent Technologies Model 5973). Gas chromatography was carried out with helium as a carrier gas, and programming of oven temperature (initial 50 °C; hold for 3 minutes; increase at 2°C/minute up to 125°C; 10°C/minute to a maximum of 320°C and hold for 10 minutes). Full scan mass spectrometry was conducted over a mass range of *m/z* 38-300. Identification of the tainting compounds was by comparison of retention time and peak area with calibration standards. The identity of an observed analyte was confirmed using mass spectra ion chromatograms of the analyte's quantification ions and the mass spectral library database. The chromatogram for the DCM extract of undiluted process water is shown in Figure 1 where the retention times for internal and surrogate standards, and the test compounds are shown.

Fish tissue was analyzed for more volatile compounds by headspace analysis. Briefly, a 2 g sample of tissue was placed in a 1050 mL bottle and sealed with cap and septa. After warming at 30 C for at least 20 min a 50 mL aliquot of the headspace was withdrawn and analyzed by GC-MS (Agilent 6890 gas chromatograph and 5973 mass spectrometer). Column: 0.32 mm by 50 m fused silica coated with 0.52 µm of 5% cross-linked phenyl methyl silicone. Temperature program: 1 C for 1 min, then programmed at 15 C per min to 265 C and hold for 0.4 min. Mass scan from *m/z* 33-300.

RESULTS AND DISCUSSION

In the pilot study, the model compounds were added to homogenized fish tissue using both fillets and whole (non-eviscerated) fish followed by DCM extraction. Recoveries were 50-128% with detection limits of 0.07-1.00 µg/g (Table 1). In an exposure experiment using this set of model compounds all of the test compounds were measurable in the homogenized fish tissue (Table 2). The tissue had distinct odours (naphthalene and benzothiophene being most prominent). Tissue

concentrations and bioconcentration factors are given in Table 2. None of the test compounds was detectable in the DCM extract of undiluted process water (Figure 1).

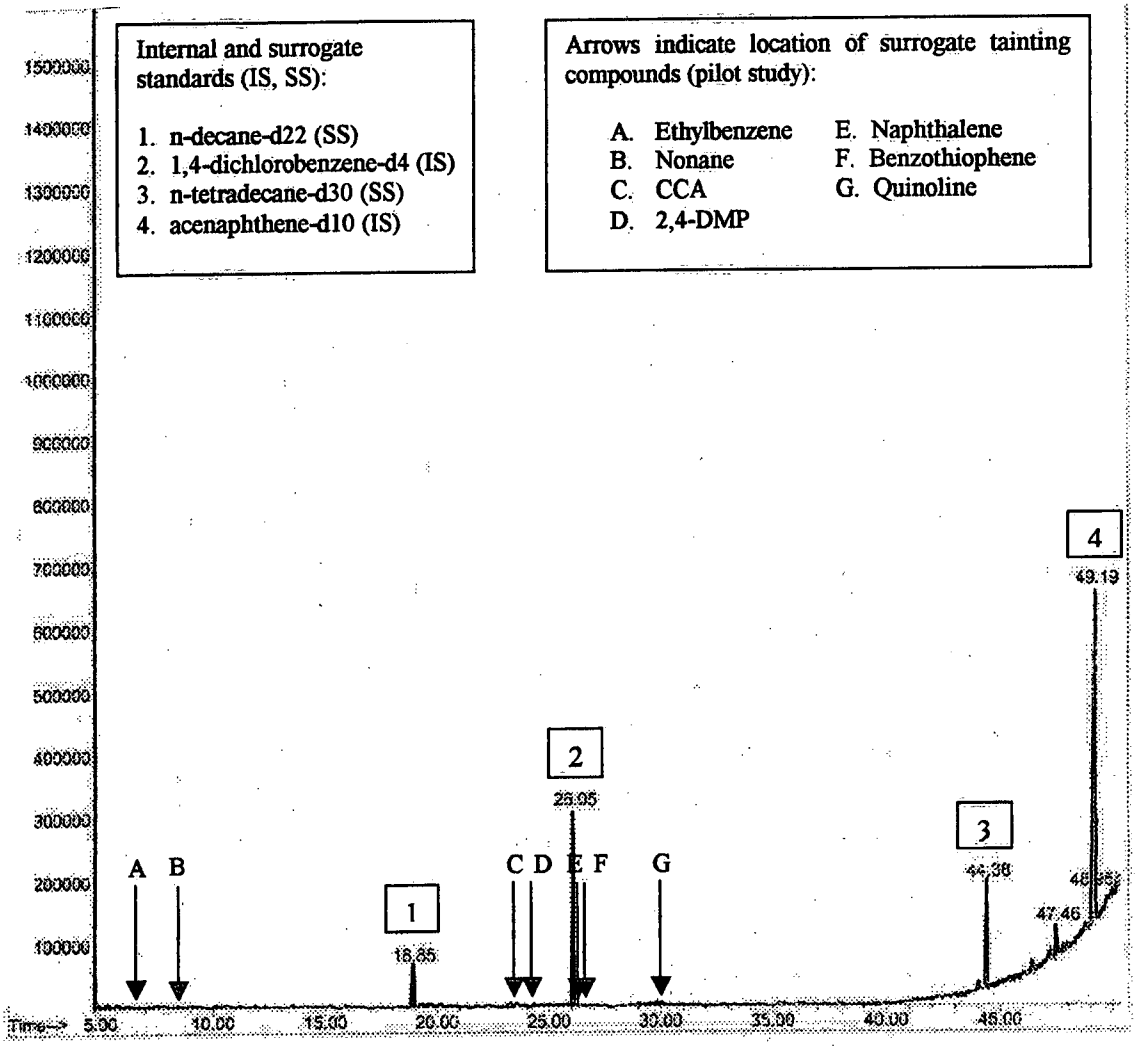

Figure 1. GC-MS chromatogram of the DCM extract of undiluted process water showing the peaks for surrogate and internal standards (1-4), and elution times of the test compounds (A-G).

Table 1. Percent Recoveries and Detection Limits for Model Tainting Compounds Using the DCM Extraction Method.

Compound	Percent Recovery		Detection Limit
	Fillets	Whole Fish	MDL (µg/g)
2,4-Dimethylphenol	80	62	0.20
Ethylbenzene	82	128	0.07
Benzothiophene	93	94	0.25
Naphthalene	98	90	0.03
Quinoline	108	94	0.07
Cyclohexane carboxylic acid	61	74	1.00
Nonane	50	51	0.15

Table 2. Concentrations and Calculated Bioconcentration Factors of the Model Tainting Compounds after 96-Hour Exposure and Analysis by DCM Extraction.				
Compound	1.0 Times Est. Threshold		0.5 Times Est. Threshold	
	Conc. µg/g	BCF	Conc. µg/g	BCF
2,4-Dimethylphenol	13.5	13	6.1	12
Ethylbenzene	12.0	34	8.1	46
Benzothiophene	103	103	58	117
Naphthalene	161	88	96	105
Quinoline	4.1	5.8	3.5	9.9
Cyclohexane carboxylic acid	6.5	0.7	6.5	1.3
Nonane	48	16	35	23

In the exposure experiment using the OSPW, by headspace, no discernable compounds were identified in the Athabasca River water-exposed fish nor at the 5, 10 and 20% exposures. 3-Methylbutanal and 2-methylbutanal were tentatively identified at the 50% exposure. DCM extraction showed a number of compounds, tentatively identified as alkanals or alkenals, in increasing concentration from upstream river water, downstream river water and increasing percentages of process water. The total ion chromatogram for the DCM extract at the 50% exposure level is presented in Figure 2. The peaks at 52.91 and 54.90 minutes have been tentatively identified as hexadecanal and 9-octadecenal, respectively, by matching with library spectra. The match quality was 95 for hexadecanal and 99 for 9-octadececanal. The peaks at 47.15 and 50.22 minutes gave library matches for pentadecane and heptadecane, respectively. None of the model compounds was detected in OSPW-exposed fish. Later peaks, not shown in Figure 2, were indicative of alkyl phthalates and adipates (plasticizers, origin unknown) and possibly other aldehydes and hydrocarbons.

The two peaks assigned to hexadecanal and 9-octadecenal were detected in DCM extracts of all fish exposures: upstream Athabasca River water, downstream Athabasca River water, and 5, 10, 20 and 50% OSPW. There was an approximate "dose-uptake" relationship, i.e., yields of these two aldehydes increased in order from upstream river water, downstream river water, and 5, 10, 20 and 50% of OSPW (Table 3). The origin of these compounds is as yet unclear. They could arise by (1) uptake from the water, (2) uptake of some precursor from the water, or (3) be produced by the fish as a physiological response to stress. The first two would be more immediately consistent with the observations, but we cannot rule out the last pathway since the stress to the fish also increased in the order that concentration in tissue did.

Table 3. Relative Yields of the Two Aldehydes at the Different Exposures.		
Exposure Water[a]	"Hexadecanal" Yield[b]	"9-Octadecenal" Yield[b]
U/S ARW	0.14	0.10
D/S ARW	0.33	0.23
OSPW, 5%	0.46	0.32
OSPW, 10%	0.74	0.48
OSPW, 20%	0.83	0.56
OSPW, 50%	1.44	0.81
[a] U/S ARW, D/S ARW=upstream and downstream Athabasca River water; OSPW=process water		
[b] Calculated from the ratio of peak heights to that of the internal standard, acenaphthene-d_{10}		

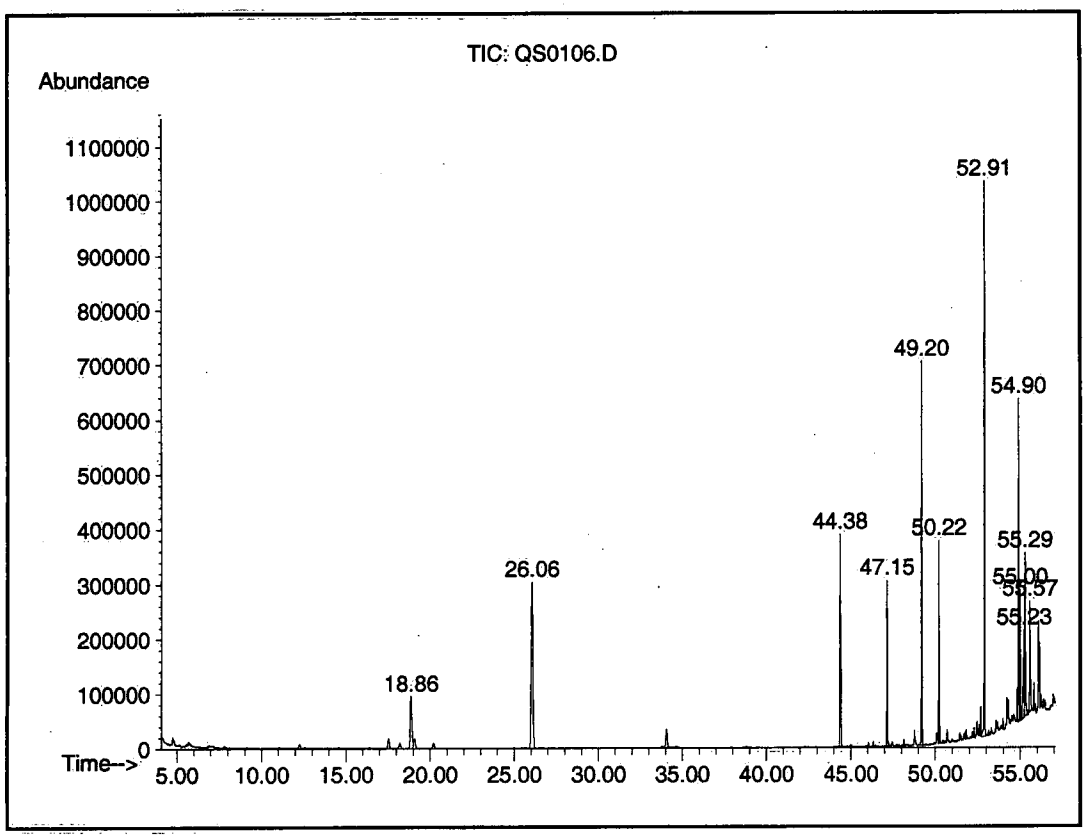

Figure 2. Total ion chromatogram of DCM extract of rainbow trout after 72 hours of exposure to 50% oil sands process water. Peaks at 18.86, 26.06, 44.38 and 49.20 minutes are surrogate or internal standards.

The analytical experiments described here have not yielded an obvious chemical "fingerprint" of tainting by OSPW. The finding (tentative) that aldehydes were major compounds in exposed fish was unanticipated. Studies on these these aldehydes are continuing and will initially focus on the synthesis of standards to test the tentative identifications and to determine their odour potencies. If the identification is confirmed, their origin needs to be determined. Furthermore, the possibility that tainting is a result of tens or even hundreds of compounds contributing to the overall tainting load suggests a modification to the GC-MS analysis to use selective ion monitoring for families of compounds such as alkyl naphthalenes, benzothiophenes, quinolines and dibenzothiophenes. Another possibility to explore is the metabolic conversion of alkylbenzenes (BTEX) into phenols with a higher tainting potential (e.g., Koning and Hrudey, 1992).

ACKNOWLEDGEMENTS

We thank Jackie Dobson (Toxicology, ARC) and the Trace Organics Department (Environmental Monitoring, ARC) who performed the fish exposures, extractions and analyses. We are grateful to the members of the CONRAD Fish Tainting Committee for encouragement and guidance, and to the industrial members of the committee for funding this research.

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Analytical Approaches to Characterizing Fish Tainting Potential of Oil Sands Process Waters.

V. Rogers*, M. MacKinnon**, and B. Brownlee***

ABSTRACT

The vast oil sands deposits in northeastern Alberta are attracting international attention for their strategic and economic value in an era of tightening world crude oil supply. The surface mining operations store large quantities of oil sands process-affected waters (OSPW) which have the potential to taint fish, as shown by several sensory studies over the past two decades. Site reclamation and closure plans must take into account this potential for tainting of fish in the adjacent Athabasca River watershed. There is also the potential for tainting from natural sources because the Athabasca River and its tributaries erode oil sands deposits in the McMurray Formation. Sensory studies, based on challenging a test panel, are complex, subjective and costly. As a result, they are not good tools for tracking and delineating sources and extents of tainting potential. The Wetlands and Aquatics Working Group of CONRAD (Canadian Oilsands Network for Research and Development) has been working toward an analytical method for fingerprinting and defining tainting by chemicals from OSPW and natural erosion. An initial three-phase project has been completed at the Alberta Research Council. Rainbow trout (*Oncorhyncus mykiss*) fingerlings (5-20 g) were used. Both headspace and solvent (dichloromethane, DCM) extraction methods were used with analysis by gas chromatography-mass spectrometry (GC-MS). The first step was to add a suite of model compounds to fish homogenate to determine analytical recovery. The model compounds were: 2,4-dimethylphenol, ethylbenzene, benzothiophene, naphthalene, quinoline, cyclohexane carboxylic acid, and nonane. Recoveries by DCM extraction were 50-120%. In the second stage, fingerlings were exposed to the suite of model compounds added to clean water at 1 and 0.5 times the estimated tainting threshold concentrations, and were analyzed by DCM extraction and GC-MS. All of the test compounds were measurable in the homogenized fish tissue which also had distinct odours (naphthalene and benzothiophene being most prominent). In a second exposure experiment, fingerlings were exposed for 96 hours to Athabasca River water, both upstream and downstream from oil sands development, and to 5, 10, 20 and 50% of an oil sands process water in dilution water (96-hour survival rates were 11, 13, 5 and 0, respectively, of the 15 original fingerlings at each exposure level). For the 50% exposure, fingerlings surviving at 72 hours were used for analysis. Fish were analyzed by both DCM extraction and headspace methods. By headspace, no discernable compounds were identified in the Athabasca River water-exposed fish nor at the 5, 10 and 20% exposures. 3-Methylbutanal and 2-methylbutanal were tentatively identified at the 50% exposure. DCM extraction showed a number of compounds, tentatively identified as alkanals, in increasing concentration from upstream river water, downstream river water and increasing percentages of process water, suggestive of a dose-response relationship. More sensitive methods are being assessed so that this analytical tainting evaluation technique will identify exposure level thresholds where tainting is occurring in test or indigenous fish.

NWRI RESEARCH SUMMARY

Plain language title

What is the potential for oil sands process waters to taint fish in the Athabasca River?

What is the problem and what do scientists already know about it?

Oil sands operations in northeastern Alberta are generating large quantities of process water which will be stored until the projects are wound up and the sites reclaimed. Site reclamation and closure plans must take into account the potential for tainting of fish on the adjacent Athabasca River watershed. Since 2002, environmental impact assessments have identified the need for in-depth research to understand the potential (if any) for tainting to occur and to distinguish between tainting potential from both industrial and natural origins.

Why did NWRI do this study?

NWRI had been contributing scientific leadership to the industry-sponsored research program since it began in 2002. Research is overseen by a committee of CONRAD (Canadian Oil Sands Network for Research and Development) and thus far has been carried out at Alberta Research Council, Vegreville, AB.

What were the results?

A protocol has been developed to expose rainbow trout fingerlings to oil sands process water and to analyze them chemically for suspected tainting compounds. The objective is to be able to define tainting by chemical analysis as a simpler alternative to the traditional method of sensory analysis by a flavour panel.

How will these results be used?

This pilot study will be used to design further experiments planned for 2005 and 2006.

Who were our main partners in the study?

Alberta Research Council, Vegreville, AB (V. Rogers); Syncrude Canada Limited, Edmonton Research Centre (M. MacKinnon); CONRAD Wetlands and Aquatics Working Group – Fish Tainting Committee.

Approches analytiques de caractérisation du potentiel d'altération du poisson des eaux de traitement des sables bitumineux

V. Rogers*, M. MacKinnon** et B. Brownlee***

RÉSUMÉ

Les vastes gisements de sables bitumineux du nord-est de l'Alberta attirent l'attention du monde entier en raison de leur valeur stratégique et économique dans une période où l'approvisionnement mondial en pétrole brut se réduit. Les opérations d'exploitation à ciel ouvert stockent de grandes quantités d'eaux contaminées par le traitement des sables bitumineux (ECTSB), lesquelles peuvent altérer le poisson comme l'ont montré plusieurs études au cours des deux dernières décennies. Les plans de remise en état et de fermeture des sites doivent tenir compte de ce potentiel d'altération du poisson dans le bassin hydrologique de la rivière Athabasca voisine. Il y a également un potentiel d'altération par des sources naturelles, puisque cette rivière et ses tributaires érodent les dépôts de sables bitumineux dans la formation de McMurray. Les études sensorielles, qui font intervenir un groupe témoin , sont complexes, subjectives et onéreuses. Ce ne sont donc pas de bons outils pour suivre et délimiter les sources et la portée du potentiel d'altération. Le groupe de travail de CONRAD (Réseau canadien pour la recherche-développement sur les sables pétrolifères) a cherché une méthode analytique pour caractériser et définir l'altération par des substances chimiques provenant des ECTSB et par l'érosion naturelle. Un projet initial en trois phases a été parachevé par l'Alberta Research Council. Des alevins d'un an (5-20 g) de truites arc-en-ciel (*Oncorhyncus mykiss*) ont été utilisés. On a utilisé l'extraction à partir de l'espace de tête et l'extraction par solvant (dichlorométhane, DCM) avec une analyse par chromatographie en phase gazeuse et spectrométrie de masse (CG-SM). La première étape a consisté à ajouter une série de composés expérimentaux à l'homogénat de poisson pour déterminer la récupération analytique. Ces composés étaient le 2,4-diméthylphénol, l'éthylbenzène, le benzothiophène, le naphthalène, la quinoline, l'acide hexahydrobenzoïque et le nonane. Les récupérations par extraction avec le DCM variaient de 50 à 120 %. À la deuxième étape, des alevins d'un an ont été exposés à la série de composés expérimentaux ajoutés à de l'eau propre à 1 et 0,5 fois les concentrations d'altération seuils estimées et ont été analysés par extraction du DCM et par CG-SM. Tous les composés d'essais étaient mesurables dans les tissus de poisson homogénéisés qui, par ailleurs, avaient des odeurs distinctes (celles du naphthalène et du benzothiophène étant les plus fortes). Dans une seconde expérience d'exposition, des alevins d'un an ont été exposés durant 96 heures à l'eau de la rivière Athabasca, en amont et en aval de l'exploitation de sables bitumineux, et à 5, 10, 20 et 50 % d'une eau de traitement de sables bitumineux dans une eau de dilution (les taux de survie après 96 heures furent de 11, 13, 5 et 0 respectivement pour les 15 alevins originels à chaque niveau d'exposition). Pour l'exposition à 50 %, les alevins vivants après 72 heures ont été soumis à des analyses par extraction au DCM et par extraction à partir de l'espace de tête. Avec l'extraction à partir de l'espace de tête, aucun composé n'a pu être identifié dans le poisson exposé à l'eau de la rivière à hauteur de 5, 10 et 20 %. Le 3-méthylbutanal et le 2-méthylbutanal ont été provisoirement identifiés à l'exposition de 50 %. L'extraction au DCM a révélé un certain nombre de composés, provisoirement identifiés comme des alcanals, en concentration croissante dans l'eau de la rivière, en amont et en aval, et à des pourcentages croissants d'eau de traitement, ce qui porte à croire à un lien dose-réponse. Des méthodes plus sensibles sont en cours

d'évaluation afin que cette méthode d'évaluation analytique de l'altération puisse déterminer à quels seuils d'exposition commence l'altération dans le poisson d'essai ou le poisson indigène.

Sommaire des recherches de l'INRE

Titre en langage clair

Quel est le potentiel d'altération du poisson de la rivière Athabasca par les eaux de traitement des sables bitumineux?

Quel est le problème et que savent les chercheurs à ce sujet?

Les exploitations de sables bitumineux du nord-est de l'Alberta produisent de grandes quantités d'eau de traitement qui seront stockées jusqu'à l'achèvement des projets et la récupération des sites. Les plans de récupération et de fermeture des sites doivent tenir compte du potentiel d'altération du poisson dans le bassin hydrologique de la rivière Athabasca. Depuis 2002, les études d'impact ont déterminé qu'il fallait des recherches approfondies pour comprendre l'apparition éventuelle du potentiel d'altération et en distinguer les origines industrielles et naturelles.

Pourquoi l'INRE a-t-il effectué cette étude?

L'INRE a apporté son leadership scientifique au programme de recherche parrainé par l'industrie depuis son lancement en 2002. La recherche est supervisée par un comité de CONRAD (Réseau canadien pour la recherche-développement sur les sables pétrolifères) et jusqu'ici a été menée à l'Alberta Research Council, à Vegreville (Alberta).

Quels sont les résultats?

Un protocole a été élaboré pour exposer des alevins d'un an de truite arc-en-ciel aux eaux de traitement des sables bitumineux et les soumettre à une analyse chimique en vue de détecter les composés d'altérations présumées. L'objectif est de parvenir à définir l'altération par une analyse chimique, ce qui serait plus simple que la méthode traditionnelle d'analyse sensorielle par un groupe témoin.

Comment ces résultats seront-ils utilisés?

Cette étude pilote sera utilisée pour élaborer de nouvelles expériences prévues pour 2005 et 2006.

Quels étaient nos principaux partenaires dans cette étude?

Alberta Research Council, Vegreville (Alberta) (V. Rogers); Syncrude Canada Limited, Edmonton Research Centre (M. MacKinnon); Comité sur l'altération du poisson du groupe de travail sur les terres humides et les milieux aquatiques de CONRAD.

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