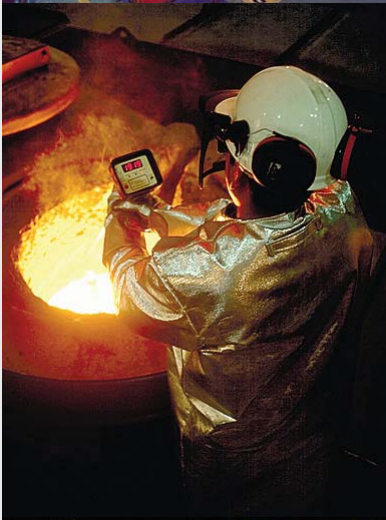




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5301 Price Avenue
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916-929-8001
www.technikonllc.com

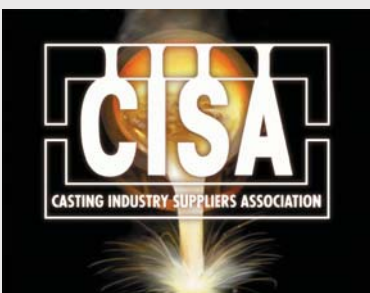
*US Army Contract W15QKN-05-D-0030
FY2006 Tasks
WBS # 2.2.1*

Sampling and Measurement of Methane from Metal Foundry Process Emissions

1413-221 NA

November 2007

(Revised for public distribution - May 2008)



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EXECUTIVE SUMMARY

This report is written to document the impetus and methodology for sampling and measurement of methane (CH_4) emitted from metal casting operations. The determination of methane is of interest to stationary sources for compliance with volatile organic carbon (VOC) permitting limits. Since methane is not considered a VOC by regulatory definition, subtraction of this compound from stack gas emissions ensures that only non-methane hydrocarbons (NMHC) are reported. While not regulated as VOCs, methane and other non-photochemically reactive compounds may also need to be estimated for certain modeling inventories or to meet certain state inventory requirements.

In metal casting applications, the amount of methane in process emissions can vary widely, making the measurement of methane critical to accurately determining NMHC emissions. For example, the shell core making process may involve the use of natural gas burners, which contribute the majority of hydrocarbon emissions in the form of methane to detectable emissions. The determination of NMHC emissions then becomes essential to avoid overestimation of the non-exempt emissions.

Currently, Method 25 is the only EPA method to determine NMHC from industrial stacks. There is no approved specific method for determining stack methane emissions using a flame ionization detector (FID), although Method 25 allows such a use under limited conditions. However, there are FID based EPA methods for other methane producing sources, including present in ambient air, emitted from internal combustion or spark ignition engines, and for sole stationary source types such as bakeries. Use of an FID for detection of hydrocarbons cannot differentiate NMHC from CH_4 and other exempt compounds such as ethane (C_2H_6) unless equipped with an oxidizing catalyst (methane cutter).

Methane and TGOC emissions were determined for metal casting processes, which included shell core making and storage, and combined pouring, cooling, and shakeout operations, through the use of two FID analyzers simultaneously run, one of which was equipped with an oxidizing catalyst. Determination of the associated NMHC was then based on calculations, including those from two of the existing EPA FID based methods that take catalyst

performance and efficiencies into account. Results indicated that the high efficiency of the cutter used for testing made the more complicated equations unnecessary, and a simple subtraction of CH_4 from TGOC was sufficient.

1.0 INTRODUCTION

1.1. Background

Technikon LLC is a privately held contract research organization located in McClellan, California, a suburb of Sacramento. Technikon offers emissions research services to industrial and government clients specializing in the metal casting and point source emissions areas. Technikon operates the Casting Emission Reduction Program (CERP). CERP is a cooperative initiative between the Department of Defense (US Army) and the United States Council for Automotive Research (USCAR). The parties to the CERP Cooperative Research and Development Agreement (CRADA) include The Environmental Leadership Council of USCAR, a Michigan partnership of Chrysler, LLC, Ford Motor Company, and General Motors Corporation; the U.S. Army Research, Development, and Engineering Command (RDECOM-ARDEC); the American Foundry Society (AFS); and the Casting Industry Suppliers Association (CISA). The US Environmental Protection Agency (US EPA) and the California Air Resources Board (CARB) also have been participants in the CERP program and rely on CERP published reports for regulatory compliance data. All published reports are available on the CERP web site at www.cerp-us.org.

1.2. CERP/Technikon Objectives

The primary objective of CERP is to evaluate materials, equipment, and processes used in the production of metal castings. Technikon's facility was designed to evaluate alternative materials and production processes while achieving significant air emission reductions. The facility's principal testing arena is designed to measure airborne emissions from individually poured molds. This testing facility enables the repeatable collection and evaluation of airborne emissions and associated process data.

1.3. Report Organization

This report has been written to document the methodology developed at Technikon for the sampling and measurement of methane and subsequent non-methane carbon emitted from a variety of metal casting processes. Section 2.0 of this report includes an explanation of and background for the concerns related to methane emissions and summarizes current research in developing and modifying sampling protocols for source methane. Section 3.0 provides details of methane results obtained from metal casting processes.

2.0 BACKGROUND

2.1. The Interest in Methane

Methane (CH_4) is a non-regulated gas. However, interest in methane emissions is growing, due to the fact that it is a potent greenhouse gas. Methane is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide (CO_2). When averaged over 100 years, each ton of CH_4 warms the Earth 25 times as much as the same mass of CO_2 . After emission, it may remain in the atmosphere for approximately 9-15 years. Methane is emitted from a variety of anthropogenic and biogenic sources.

Chemically, CH_4 is considered a volatile organic compound, but is excluded from this category in the Code of Federal Regulations (40 CFR 51.100(s)) by definition. The regulatory definition states that volatile organic compounds (VOC) are any compound of carbon excluding certain compounds such as carbon monoxide (CO) and CO_2 , which may participate in atmospheric photochemical reactions, or other such organic compounds such as CH_4 and C_2H_6 , which have been determined to have negligible photochemical reactivity.

While not regulated as VOCs, these compounds may need to be estimated for compliance purposes, certain modeling inventories or to meet specific state inventory requirements. Additionally, the use of some photochemical models requires estimation of CH_4 , C_2H_6 , and several other less photochemically reactive compounds. For this reason, the term total organic compounds (TOCs) or total gaseous organic compounds (TGOs) instead of the term VOCs are used to refer to a broader class of chemicals which includes exempt compounds.

2.2. Sampling and Measurement of Methane and Non-Methane Hydrocarbons

2.2.1. Instrumental Methodology

Methane is a permanent and low molecular weight gas. Compared with other straight chain hydrocarbons (alkanes), CH₄ has an unusually high carbon-hydrogen (C-H) bond strength, which means that it is normally the least reactive alkane in reactions. Because of its low mass and non-reactivity, the simplest sampling and measurement techniques are limited to the gas phase.

TGOCs (including exempt compounds) are emitted from a variety of sources and have traditionally been sampled using common collection methods followed by laboratory measurement techniques. TGOCs include a variety of chemical classes, and can be measured without the need for speciation using existing approved methods. NMHC is a convenient way of expressing TGOC emissions less the methane in terms of carbon; e.g. parts per million concentration (ppmc) or parts per billion concentration (ppbc). Since speciation of different components is not required, NMHC determination is fast and relatively inexpensive. The NMHC measurement also allows different emission sources to be compared in terms of total carbon irrespective of the specific compounds being emitted.

One way to measure NMHC is through the use of a methane cutter. A methane cutter is a heated oxidizing catalyst that removes non-methane hydrocarbons from the sample stream prior to the effluent entering an FID analyzer. This allows the methane concentration in the sample stream to be determined by the use of an FID placed after the catalyst to quantify all of the methane left uncombusted in the stream, while the oxidized hydrocarbons pass through the FID undetected. By taking the difference between the measured methane and the total hydrocarbon measurement, the non-methane hydrocarbon content can be determined.

Operation of the methane cutter is based upon the different combustion temperatures of methane compared to non-methane hydrocarbon compounds. The oxidizing catalyst of the methane cutter is maintained at a specific temperature for the catalyst used. The catalyst

selectively combusts the NMHC, while the methane content of the sample remains relatively unaffected. As the sample stream is passed through the cutter, hydrocarbons other than methane are oxidized to CO_2 and H_2O , which are not detected by the FID. The FID then measures the unreacted methane in the sample stream.

In theory, all of the hydrocarbons in the effluent larger than CH_4 are oxidized to CO_2 . In practice, however, the catalyst has an operating efficiency that limits the amount of hydrocarbons larger than CH_4 that are oxidized within the catalyst bed, as well as, an amount of methane that passes undetected through the FID. Methane and ethane combustion efficiencies in the catalyst have been extensively studied, with results indicating that over 98% of the ethane present within a sample stream is combusted, increasing to 99% of propane and larger molecules. The most difficult separation within the catalyst is between methane and ethane, while molecules smaller than ethane (such as formaldehyde) would be readily combusted within the catalyst. Approximately 10% of the methane will be removed with the combusted hydrocarbons.

There are single detector/single amplifier instruments and dual detector/dual amplifier FID analyzers. Both types of instruments give measurements of TGOCs and measurements of CH_4 in the stream, and by difference measure NMHCs. From either of these types of instruments, the measurements of total hydrocarbons and measurements of methane are subtracted to give the NMHC result.

Use of a single FID for detection of hydrocarbons cannot differentiate NMHC from exempt compounds without the use of a preconditioning step via cryogenic concentration, or specially equipped instruments capable of alternately switching effluent from an oxidizing catalyst directly through the detector. With single detector/single amplifier instruments, the sample stream is alternately either passed through or around the selective catalytic combustion reactor before entering the FID, which then alternately measures either CH_4 or TGOC. It is possible to have instrument software which can control switching times (usually 1-minute cycles) and continuously display the TGOC, CH_4 and NMHC results.

With dual detector/dual amplifier instruments, the sample stream is continuously split. Part of the sample goes to an FID measuring TGOC. The other part of the sample passes through the methane cutter and then to a second FID, which continuously measures CH_4 . NMHCs

are then calculated internally and results are displayed on the instrument panel.

2.2.2. *Approved Analytical Methodologies*

Separate measurements for CH₄ and NMHC from TGOCs have been accomplished using several analytical methods from a variety of source types. Approved sampling and analysis methods include techniques for determining emissions from ambient air, from internal combustion or spark ignition engines, and from specific stationary source categories such as bakeries. Currently, Method 25 is the only EPA approved method to determine NMHC from generic industrial stacks. There is no approved specific method for determining stack methane emissions using an FID, although Method 25 allows such a use under limited conditions.

The method for the determination of NMHC from ambient air is EPA Method TO-12. For this method, a whole air sample is either extracted directly from the ambient air and analyzed on site by a gas chromatographic system or collected into a precleaned sample canister and analyzed off site. The analysis requires cryogenic preconcentration and a direct flame ionization detector. The cryogenic trap simultaneously collects and concentrates the NMHC (either via condensation or adsorption) while allowing the methane, nitrogen, oxygen, and other permanent gases to pass through the trap without retention.

EPA Standard Method 25, "Gaseous Nonmethane Organic Emissions," has been used to measure NMHC in air emissions from stationary sources. In this method, the gas samples are collected using a canister and are sent to the laboratory for analysis. The NMHC analyzer is designed to produce an equal response for each carbon atom. An aliquot of the air sample is injected into a gas chromatography (GC) column which separates the organics from CO₂ and CH₄. The principle of NMHC detection is to catalytically oxidize all organic compounds to CO₂, and then reduce the CO₂ to CH₄ which is measured by a conventional FID. The reduction step is necessary because CO₂ itself does not respond to detection using an FID.

In bakeries, between 50 to 1000 parts per million (ppm) of methane is detected in emis-

sion streams, which consist mainly of ethanol (in concentrations of 1,000 to 5,000 ppm) and methane. Moisture in these streams can range from 2 to 15%. For this specific source type, EPA CTM-042, "Use of Flame Ionization Detector-Methane Cutter Analysis Systems for VOC Compliance Testing of Bakeries," may be used to detect NMHC concentrations. The purpose of this conditional test method is to provide an alternate procedure for making real-time NMHC measurements for gaining immediate information regarding performance of the VOC destruction device. The method describes the use of an FID based instrument equipped with a catalytic methane cutter in conjunction with U.S. EPA Test Method 25A to provide real-time differential measurement of total hydrocarbons, methane, and by difference, non-methane hydrocarbons. The catalytic oxidizer in this application will destroy 95-99% of the NMHC, and reduce the ethanol to concentrations of 10 ppm to 250 ppm in the oxidizer effluent, while the other compounds virtually maintain their concentrations.

The use of CTM-042 must be approved as an alternative method before a source may employ it to meet Federal requirements under 40 CFR Part 60, 61, and 63. This method and other CTMs have been evaluated by the EPA and may be applicable to one or more categories of stationary sources.

The application of a methane cutter in conjunction with an FID based instrument is also the basis for NMHC determination in some heavy duty and non-road diesel and spark ignition engines following the requirements in CFR Part 1065—Engine-Testing. The FID analyzer is used to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. In this method, a sample of the engine exhaust is routed to the catalyst equipped FID through a heated transfer line. To determine NMHC, CH₄ must be quantified, either with a methane cutter and an FID analyzer, or with a gas chromatograph. The NMHC concentration is determined by calculations which take the cutter's efficiency of CH₄ and C₂H₆ into account, as well as background concentrations, before subtracting the adjusted CH₄ amount from TGOC results.

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3.0 METHANE AND NON-METHANE HYDROCARBON TESTING

3.1. Scope of Testing

In metal foundry applications, the amount of CH₄ emissions produced from the diversity of casting related processes can vary widely, making the measurement of methane fundamental to determining appropriate NMHC emissions. The determination of NMHC emissions becomes essential to avoid overestimation of the non-exempt emissions from a process. For example, as in the case of certain shell core making processes, a majority of the total hydrocarbon emissions are composed of CH₄, which is a result of the use of natural gas burners for providing heat to the shell core machine core box.

The use of an FID based instrument equipped with a catalytic methane cutter in conjunction with U.S. EPA Test Method 25A can provide real-time measurement of total hydrocarbons, methane and, by difference, NMHC in a manner similar to that described for CTM-042.

For the testing undertaken for the determination of NMHC from metal casting processes, two totally automated continuous FID analyzers were interfaced directly to the source stack of the Research Foundry. Sampling was accomplished by extracting a gas stream from the stack effluent and transferring it via heated non-reactive tubing to the FID analyzers under very controlled temperature and pressure conditions. Methane was determined by one FID equipped with a methane cutter that oxidizes the NMHC. The calibration gas for this FID was CH₄. The second FID was used to detect TGOCS in accordance with EPA Method 25A. For Method 25A, the quantity of carbon containing molecules was calibrated by propane (C₃H₈). The FIDs gave a response relative to the calibration standard and results were expressed in terms of the gas used for calibration. The two FIDs were run simultaneously, and data was collected every second. NMHC results were then determined by several methods.

The most straightforward determination of NMHC was achieved by taking a simple difference between the detected CH₄ and TGOCS results after determining concentrations on a per carbon basis. The efficiencies for propane and ethane and the penetration factor for

methane in the oxidizing catalyst were taken into account through the use of the equations given in EPA CTM-042 and EPA CFR Part 1065.

Methane, TGOc, and NMHC concentrations were determined for metal casting pouring, cooling, and shakeout processes for 7 emission tests encompassing 11 different resin binder systems using 4 metals. In addition, emissions were determined for 2 shell core making and storage tests on 2 different binder systems.

3.2. Test Results

Three calculations methods were used for determining NMHC from the measured CH₄ and TGOc results. The most uncomplicated calculation method was a direct subtraction of the CH₄ from the TGOc results to provide NMHC values. The second method used Equation 1, which is the equation used in CTM-042, and takes instrument response and cutter efficiencies into account.

$$C_c = K C_{\text{meas}} / \varepsilon$$

Equation 1

Where:

C_c	= NMHC concentration
C_{meas}	= $\text{THC}_{\text{meas}} - M_{\text{meas}}$
K	= Response Factor for the NMHC
ε	= Determined efficiency fraction of the methane cutter. This value is 1.0 if no methane is present, as in a calibrated gas cylinder containing only ethanol in air
M_{meas}	= Methane concentration as directly measured on the methane channel
THC_{meas}	= Measurement on the total hydrocarbon channel, calibrated to methane

Methane cutter efficiency can be determined by testing a certified mixture of methane and the NMHC of interest (ethanol for example). The equation for the methane cutter efficiency is as follows:

$$\varepsilon = \mathbf{K} C_{\text{meas NMHC}} / C_{\text{cert NMHC}}$$

Note: the cutter is cutting NMHC, not methane. Therefore the efficiency is calculated by the non-methane components.

Where:

ε	= Efficiency of the methane cutter
$C_{\text{cert NMHC}}$	= Certified concentration of NMHC (for example 90% ethanol/10% acetaldehyde) with a balance of air in a mixture of methane and NMHC
$C_{\text{meas NMHC}}$	= measured NMHC (ethanol) concentration on the methane channel

The third calculation method for determining NMHC was through the use of Equation 2, which is the equation used in CFR Part 1065, and takes cutter efficiencies, instrument response, penetration of methane and ethane, and methane background concentrations into account.

$$x_{\text{NMHC}} = \frac{PF_{\text{CH}_4} \cdot x_{\text{THC}} - RF_{\text{CH}_4} \cdot x_{\text{CH}_4}}{PF_{\text{CH}_4} - PF_{\text{C}_2\text{H}_6}} - x_{\text{NMHC}_{\text{init}}}$$

Equation 2

Where:

x_{NMHC}	= Non-methane hydrocarbon concentration, ppm (on C_1 basis)
x_{THC}	= Total hydrocarbon concentration, ppm (on C_1 basis)
RF_{CH_4}	= Response factor of methane, refer to Federal Register Vol. 70, No 133. Wed July 13, 2005, Rules and Regulations (1065.360)
x_{CH_4}	= Methane concentration, ppm (on C_1 basis)
PF_{CH_4}	= Penetration fraction for methane, defined in Federal Register Vol. 70, No 133. Wed July 13, 2005, Rules and Regulations (1065.365)
$PF_{\text{C}_2\text{H}_6}$	= Penetration fraction for ethane, defined in Federal Register Vol. 70, No 133. Wed July 13, 2005, Rules and Regulations (1065.365)

$\chi_{NMHC_{init}}$ = Initial NMHC contamination concentration defined in Federal Register Vol 70, No 133, Wed July 13, 2005, Rules and Regulations (1065.520)

Tested cutter efficiencies were above 99% for propane (C_3), which was consistent with the manufacture stated cutter efficiency for compounds above C_2 . The stated efficiency of 98% for ethane was not tested. The catalyst was also specified to remove approximately 10% of CH_4 with hydrocarbons above C_3 . The high efficiencies of the catalyst meant that the manner of calculation only affected results within a few percent. Table 3-1 presents comparison results (from Test HL as an example) for the determination of NMHC using direct CH_4 subtraction from TGOc results and from the equations contained in EPA CTM-042 and CFR Part 1065.

Table 3-1 Example of Results Obtained from Three Calculation Methods for Total Hydrocarbons, Methane, and Non-Methane Hydrocarbons Using Data from Test HL

	Analyte	Uncoated Cores		Rheotec-XL		Rheotec-204P		
		ppm	lb/ton	ppm	lb/ton	ppm	lb/ton	
Measured	THC (as C3)	1.46E+01	1.35E+00	7.63E+00	6.59E-01	7.19E+00	6.19E-01	
	THC (as C1)	4.06E+01	1.37E+00	2.12E+01	6.66E-01	2.00E+01	6.28E-01	
	Methane	4.79E+00	1.61E-01	3.38E+00	1.06E-01	2.94E+00	9.21E-02	
	% Methane		12		16		15	
Calculated	Direct Subtraction	NMHC	3.58E+01	1.20E+00	1.78E+01	5.60E-01	1.70E+01	5.35E-01
	CFR 1065	NMHC	3.46E+01	1.17E+00	1.65E+01	5.19E-01	1.58E+01	4.97E-01
	CTM 042	NMHC	3.78E+01	1.27E+00	1.88E+01	5.91E-01	1.80E+01	5.65E-01

Data summarizing methane results to date for both PCS and shell core making and storage are given in Table 3-2 as lb/ton metal and lb/lb binder. Figure 3-1 presents the same CH_4 and NMHC data as a relative percentage of total measured hydrocarbons. Data show that both binder composition and concentration, and to a lesser extent metal type, are influential on CH_4 and NMHC emissions from PCS processes.

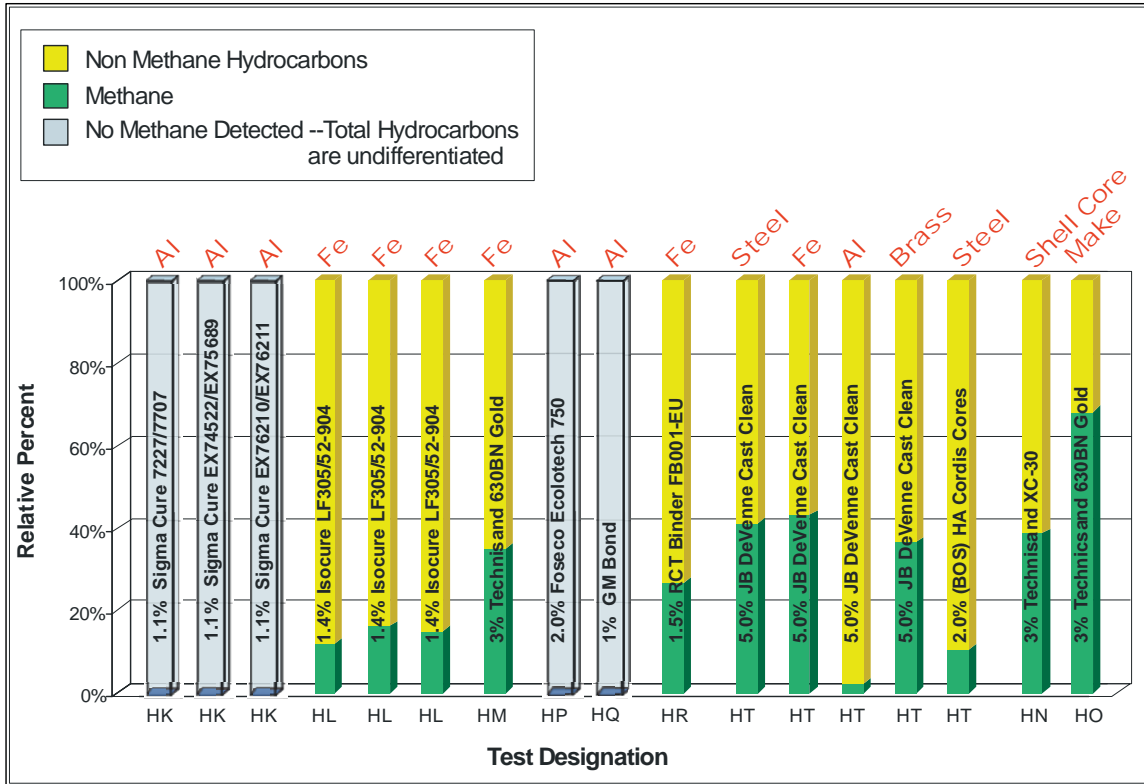
Table 3-2 Total Hydrocarbons, Methane, and Non-Methane Hydrocarbon Results for PCS and Shell Core Making Tests

Test Series	Binder		Test Parameters						Results			
	Binder Concentration (BOS)	Binder Description	Test Type	Metal	Number of Molds	Mold Type	Seacoal	Lb/Ton of Metal		Lb/Lb of Binder		
								TGOOC	Methane	TGOOC	Methane	Non-Methane HC
HK	1.1	Sigma Cure 72277707	PCS	Aluminum	6	Greensand	No	1.10E+00	≤PQL	7.65E-02	≤PQL	NA
	1.1	Sigma Cure EX74522/EX75689	PCS	Aluminum	3	Greensand	No	1.07E+00	≤PQL	7.42E-02	≤PQL	NA
	1.1	Sigma Cure EX76210/EX76211	PCS	Aluminum	3	Greensand	No	1.12E+00	≤PQL	8.08E-02	≤PQL	NA
HL	1.4	Isocure LF305/52-904 (No Coating)	PCS	Iron	8	Greensand	No	1.23E+00	1.46E-01	1.99E-01	2.37E-02	1.75E-01
	1.4	Isocure LF305/52-904 (RHEOTEC-XL Coating)	PCS	Iron	3	Greensand	No	6.59E-01	1.06E-01	1.03E-01	1.65E-02	8.62E-02
	1.4	Isocure LF305/52-904 (RHEOTEC-204P Coating)	PCS	Iron	3	Greensand	No	6.19E-01	9.21E-02	9.71E-02	1.44E-02	8.27E-02
HIM	3	Technisand 630BN Gold	PCS	Iron	9	Greensand	No	6.07E-01	2.12E-01	3.95E-01	5.42E-02	1.89E-02
HP	2	Foseco Ecolotech 750	PCS	Aluminum	9	Greensand	No	2.33E-01	≤PQL	1.04E-02	≤PQL	NA
HO	1	GM Bond (Low Aroma)	PCS	Aluminum	9	Greensand	No	2.19E-01	≤PQL	1.63E-02	≤PQL	NA
HR(b)	1.5	Prometal RCT Binder FB001-EU	PCS	Iron	9	Printed Mold	NA	2.15E+00	5.73E-01	1.57E+00	3.11E-02	8.30E-03
HT	5	JB DeVenne Cast Clean	PCS	Steel	1	No Bake	NA	1.55E+00	6.36E-01	9.10E-01	6.29E-03	2.59E-03
	5	JB DeVenne Cast Clean	PCS	Iron	3	No Bake	NA	1.73E+00	7.46E-01	9.88E-01	6.79E-03	2.92E-03
	5	JB DeVenne Cast Clean	PCS	Aluminum	2	No Bake	NA	1.14E+00	2.50E-02	1.12E+00	1.71E-03	2.73E-05
	5	JB DeVenne Cast Clean	PCS	Brass	2	No Bake	NA	1.15E+00	4.20E-01	7.29E-01	5.28E-03	1.93E-03
	2	HA Cordis Cores	PCS	Steel	3	Greensand	No	1.63E-01	2.10E-02	1.42E-01	1.56E-02	2.00E-03
HN ^f	3	Technisand XC-30	Shell Core Make/Storage	NA	6 Runs @ 15 cores	NA	NA	5.34E-01	2.06E-01	3.28E-01	9.16E-03	3.54E-03
	3	Technisand XC-30	Shell Core Make/Storage	NA	1 Run @ 30 cores	NA	NA	8.21E-01	3.48E-01	4.72E-01	1.41E-02	5.97E-03
HO ^f	3	Technisand 630BN Gold	Shell Core Make/Storage	NA	6 Runs @ 15 cores	NA	NA	9.34E-01	6.38E-01	2.96E-01	1.60E-02	1.10E-02

^fSystem Blank Background Corrected Data

NA = Not Applicable

Figure 3-1 Percent Comparison of Total Hydrocarbon, Methane, and Non-Methane Fractions of Metal Foundry Tests by Metal and Binder Type



Tested aluminum PCS operations generated near non-detectable quantities of methane, whereas the methane generated from iron and steel ranged from 10 to 40% of total measured hydrocarbons. Shell core making and storage generated 40 to 60% of total measured hydrocarbons, even after accounting for the contribution of methane from the gas-fired burners used in core manufacture.

APPENDIX A

ACRONYMS AND ABBREVIATIONS

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ACRONYMS AND ABBREVIATIONS

AFS	American Foundry Society
ARDEC	(US) Army Armament Research, Development and Engineering Center
C₂H₆	Ethane
CERP	Casting Emission Reduction Program
CFR	Code of Federal Regulations
CH₄	Methane
CISA	Casting Industry Suppliers Association
CO	Carbon Monoxide
CO₂	Carbon dioxide
CRADA	Cooperative Research and Development Agreement
CTM-042	(EPA) Conditional Test Method 042
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FID	Flame Ionization Detector
GC	Gas Chromatography
Lb/Lb	Pound per pound of binder used
Lb/Tn	Pound per ton of metal poured
NMHC	Non-Methane Hydrocarbon
PCS	Pouring, Cooling, Shakeout
ppbc	Part per Billion Concentration
ppm	Parts per Million
ppmc	Part per Million Concentration
PTE	Potential to Emit
TGOC	Total Gaseous Organic Concentration
THC	Total Hydrocarbon Concentration
TOC	Total Organic Compound
US EPA	United States Environmental Protection Agency
USCAR	United States Council for Automotive Research
VOC	Volatile Organic Compound
WBS	Work Breakdown Structure