CRD-Victoria Biosolid Analyses, Combustion Study and Emission Profiling

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PROJECT SUMMARY

This project pertains to the Capital Regional District (CRD) – Victoria's McLoughlin Point' wastewater treatment and residual treatment facilities, which are currently under active development. CRD has banned the land application of sludge biosolids amid worries that farm land and the food grown on it could be polluted by pharmaceuticals and heavy metals, since 2011. To find a suitable usage for heat-dried biosolids, CRD explored cement kilns fuel markets, offering dried biosolids as an alternative biofuel, with limited success. Without a potential customer and with the current land ban in place, the only options available to CRD would be to landfill it, or to build a waste-to-energy facility. As part of its due diligence, CRD contracted InnoTech Alberta's Bio-ThermoChemical Processing Technologies team to conduct a combustion/incineration emission profiling and material characterization study. A representative 'heat dried biosolids' feedstock, which is marketed under the trade name 'Granulite – organic fertilizer' was sourced from Synagro's Florida facility and shipped to InnoTech Alberta for further testing.

As part of the exercise, InnoTech conducted a comprehensive assessment of as-received (AR) Bio-solids (Granulite) for composition, pathogens, organic and inorganic contaminants as well as ESOCs (Emerging Substances of Concern) verification purposes. The testing was conducted by standard ASTM and EPA methodologies as listed below.

Analyses	**Methodology**
Moisture	ASTM D3173
Proximate	ASTM D7582 (D3173,D3174,D3175)
Ultimate	ASTM D4239A/D5373
Heating Value	ASTM D5865
Metals	US EPA 200.2/6020A
PAHs (Polycyclic Aromatic Hydrocarbons)	US EPA 3540C, 3630C, 625, 8270
PCDDs/PCDFs (Dioxins/Furans)	US EPA 1613
PCBs (Polychlorinated Biphenyls)	US EPA 1668
Acidic Neutral Drugs	US EPA 1694
OC (Organochlorine) **Pesticides**	US EPA 1699
PBDEs (Polybrominated diphenyl ethers)	US EPA 1614
Pathogens (E coli, Salmonella, Coliforms)	TMECC 07.01/MFLP-75
Halide emissions	Method 26
Metal emissions	Method 29
LandFill suitability/Leachate Tests	TCLP/Method 1311

Based on the testing it was concluded that the Synagro heat-dried biosolids met all the specification of Class – A biosolids and was found to be a suitable feedstock for combustion/incineration for energy recovery purposes. The combustion of pulverized biosolids was carried out in a drop tube furnace at 1000 deg C to determine combustion efficiency, emissions and to generate combustion ash for further testing. The biosolids incineration was carried out in a drop tube furnace at 1000 deg C with 50 % excess air. The emission profile were recorded under steady state conditions using Testo 350XL analyzer for measuring CO, NOx, SOx, CxHy and O2. The halide and metal emissions were conducted by passing the flue gas through a series of impinger containing scrubber solutions as per Method 26 and 29 respectively. The solutions were subsequently analyzed by IC and ICP/MS for determining the halide and metal emissions per reference cubic meter of dry flue gas at standard conditions (25 deg C, 101 kPa, corrected to 11% balance O_2).

Based on the current investigation, the incineration of biosolids resulted in the formation of high concentrations of NOx and SOx emissions on account of its N- and S- rich composition.

Gaseous Emissions	Concentration (mg/Rm3)
CO	6
NOx	478
SO_2	994
HCl	9.29
HF	0.02
Particulate Emissions (TPM)	25
Metal Emissions	
Arsenic (As)	0.0027
Cadmium (Cd)	0.021
Chromium (Cr)	5.04
Lead (Pb)	0.03
Mercury (Hg)	0.0009

The emissions pertaining to NOx, SOx, particulates and Chromium were found to be in non-compliance with emissions standards of BC adopted air quality objectives and standards. Co-incineration with N- and S- lean feedstocks should be considered to mitigate the regulatory non-compliances associated with SOx, NOx, particulates (TPM) and Cr metal emissions.

The resulting ash was analyzed for organic, inorganic contaminants and ESOCs along with determination of landfill suitability by toxicity characteristic leaching procedures (TCLP). Based on the combustibility data and emission profile the CO and halide emissions were found to be compliant with the existing BC/MoE guideline for small incinerator emissions, however the SOx, NOx, Cr emissions were non-compliant with BC/MoE regulation. The ash contained high amounts of Cu, Co, Ni, Mo which made it unsuitable for land application, thus limiting its use to either cement manufacture or landfilling. During energy recovery, up to 75% volume reduction was be achieved, which would be advantageous for landfill space conservation.

PROJECT SCOPE & ACTIVITIES

Capital Regional District – Victoria (CRD) contracted InnoTech Alberta's Vegreville-based B-TCP team to conduct a comprehensive biosolids combustion and emission profiling study including characterization of biosolids and its resultant combustion ash products for toxicity verification purposes. As part of the exercise, InnoTech analyzed the biosolids and pre-processed the same for combustion test in a drop tube furnace (entrained flow regime) for emission profiling. The resultant ash was also tested for the presence of organic and inorganic constituents including landfill suitability through toxicity characteristic leaching procedures (TCLP).

Project Name:	**Heat-Dried Bio-solids Analyses, Combustion Study and Emission Profiling**
Item	*Description*
Bio-Solids Testing	Composition verification (CHNS, ash, moisture, volatile matter), inorganic contaminants (Chlorine, Heavy metals (Pb, Cd, Cr, Cu, Ni, Hg, Zn), trace organic contaminants (PAHs/PCDD/PCDF/PCBs/HCB), Emerging Substances of Concern (ESOCs) - Pharmaceuticals, Herbicides, OC Pesticides, BDEs; ash fusion temperature, pathogen tests (Listeria, Salmonella, Fecal Coliform)
Set-up and Calibration	Combustion Equipment set-up, gas analyzer recalibration and impinger train set-up for capture of contaminants and particulates
Feedstock Pre-Processing	Drying, Grinding, Screening/Sieving as required, Pulverizing
Combustion Testing	Combustion test at a specified operating condition (temperature, stoichiometry) will be conducted in a drop tube furnace (entrained flow regime)
Emission Profiling	In-line measurement of flue gas for (O2, CO, CO2, NO, NO2 and SO2), particulate matter, Canister Analyses, halides and halogens (method 26), metal emissions (method 29),
Ash Testing	Ash composition, stability, landfill suitability-leachate testing (as TCLP guidelines), inorganic contaminants (Chlorine, Heavy metals (Pb, Cd, Cr, Cu, Ni, Hg, Zn), trace organic contaminants (PAHs/PCDD/PCDF/PCBs/HCB), Emerging Substances of Concern (ESOCs) - Pharmaceuticals, Herbicides, OC Pesticides, BDEs – fire extinguishers;
Regulatory Guidance	Document existing CCME and provincial code of practices and associated regulatory guidelines associated with biosolids handling and combustion processes for energy recovery
Project co-ordination & Reporting	Project planning, co-ordination, Data acquisition, Data Analyses, Interpretation, Compliance and Reporting

INTRODUCTION

Biosolids are a solid by-product of municipal wastewater treatment plants. Biosolids are a by-product of municipal wastewater treatment, which are stabilized by various treatment processes. Biosolids are rich in both organic matter and plant nutrients and have been historically used as soil amendment and fertilizers. Biosolids also contain various organic substances, which could exert hormonal effects, various infectious agents, heavy metals, and residues of pharmaceutical drugs. An important factor influencing the end use of biosolids is public perception, particularly in the areas where biosolids are land applied. There is considerable odor and contaminant concerns associated with biosolids application or end use.

Biosolids are processed to one of two levels: Class B and Class A. Processing involves various levels of time and temperature to significantly reduce or eliminate pathogenic organisms and protect public health. Class B biosolids are typically the product of aerobic or mesophilic anaerobic digestion and pathogen indicators are significantly reduced but not eliminated. As a result, Class B biosolids have restricted uses and are generally applied to areas where there will be no unintentional contact by the public. Example uses include agricultural fertilizer and soil amendment and mine reclamation. Class A biosolids products have undergone additional processing at high temperatures (55ºC minimum). These products are essentially pathogen-free and suitable for application to areas where public access is more common like golf courses and urban landscape projects.

For the current project, CRD-Victoria sourced the biosolids samples through Synagro from their South Cross Bayou WRF Pelletizing Facility, Pinellas, Florida. Synagro markets the granular (pelletized) heat-dried biosolids product under the trade name of 'Granulite – an Organic Fertilizer'. The product is composed of 90 wt.% biosolids with ≤ 10 wt.% moisture. It is considered as a non-hazardous chemical as per OSHA 29 CFR 1910.1200. The Granulite MSDS is provided as an appendix in this report. As per its MSDS, Synagro supplied heat-dried biosolids 'Granulite' meets with Class A Biosolids quality criterion.

Product Trade Name: Granulite
Product Origin: Heat-Dried Biosolids, Organic Fertilizer

Figure 1: Synagro's Heat-Dried Biosolids - 'Granulite'

In recent years, a variety of ESOCs (emerging substances of concern) including pharmaceuticals, personal care products, plasticizers, surfactants, pesticides, and fire retardants were detected in municipal waste waters and biosolids (Kolpin et al., 2002). The impacts of these compounds in the environment are currently under extensive investigation although leading research indicates little threat to public health through biosolids use (OACWA, 2009).

In 2011, CRD banned use of biosolids sludge on land over concerns that farmland and the food grown on it could be polluted by pharmaceuticals and heavy metals. Subsequently CRD explored the options of marketing the heat-dried biosolids to the cement production sector with limited success. International jurisdictions such as Denmark, Japan, USA, and Switzerland have successfully demonstrated the use of heat dried biosolids as a fuel source in cement kilns and use of the resultant ash in cement production [G. Vasileski, 2007]. In these applications, careful attention is paid to chemical composition of biosolids to ensure compliance with the existing emission guidelines.

Without a prospective buyer, and with the land ban, the CRD has few options at its disposal. One option would be to landfill it, or to build a waste-to-energy plant based on incineration/combustion of biosolids. Incineration of biosolids has been carried out by a range of technologies including rotary kilns, fixed hearth, moving hearth, circulating fluidized bed, entrained flow regimes [G. Vasileski, 2007]. Among them, the circulating fluidized bed and moving hearth are very common. The advantage of incineration of biosolids would be two fold waste-to-energy generation and waste volume reduction. In the current constrained scenario, the municipality of the Victoria is considering the option of incinerating its heat-dried biosolids for energy generation or district heating.

As per the RTA, InnoTech Alberta conducted testing on the AR biosolids and its combustion ash for both organic and inorganic contaminants, ESOCs, pathogens, and chemical composition. The analytical data obtained from this exhaustive exercise is summarized in this report.

CRD WASTEWATER TREATMENT PROJECT

Capital Regional District (CRD) – Victoria is expected to commission its 'McLoughlin Point' waste water treatment plant in 2020 and commissioned a jurisdictional review through EDI (Environmental Dynamics Inc.) in 2017. The jurisdictional review of biosolids beneficial reuse identified a range of technology options including incineration for energy recovery. The Wastewater Treatment Project is being built to meet the provincial and federal regulations for treatment by December 31, 2020. The overall cost of the project is estimated to be $765 million and is supported through both federal and provincial government funding. The Project consists of three main components:

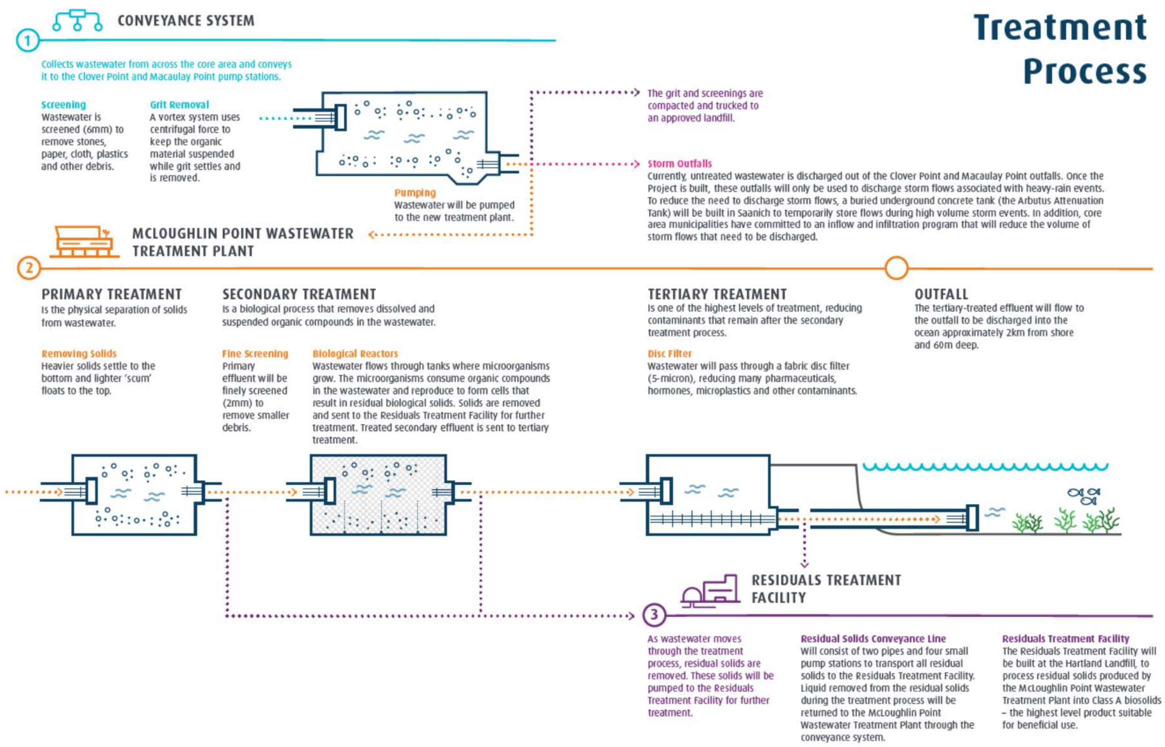
McLoughlin Point Wastewater Treatment Plant: Located at McLoughlin Point in Esquimalt, the treatment plant will provide tertiary treatment to the core area's wastewater.

Residuals Treatment Facility: Residual solids from the wastewater treatment plant will be piped to a Residuals Treatment Facility at Hartland Landfill. Here they will be treated and turned to Class A biosolids.

Conveyance System: The conveyance system refers to the 'pumps and pipes' of the Wastewater Treatment Project. This system will carry wastewater from across the core area to the treatment plant, and residual solids to the Residuals Treatment Facility at Hartland Landfill.

Anaerobic Digestion: The wet biosolids will be subjected via anaerobic digestion to generate biogas for energy recovery applications.

Post treatment, the waters will be released into open oceans and the sewage sludge will be treated to class A biosolids for high value beneficial use including incineration for energy recovery



https://www.crd.bc.ca/docs/default-source/wastewater-planning-2014/2018-05-15-infosheet-wastewater-treatment-process.pdf?sfvrsn=e0a1fca_2

ANALYTICAL TECHNICS

AR heat-dried Biosolids (granulite) and its combustion product (ash) were analyzed thoroughly for composition verification, heating value, inorganic/organic toxicants, pathogen and emerging substances of concern (ESOCs) as per the Table 1 below:

Table 1: Analytical Methodologies employed in this study

Analyses	Methodology	CALA*	Granulite	Combustion Ash
Moisture	ASTM D3173	N/A	Yes	Yes
Proximate	ASTM D7582 (D3173,D3174,D3175)	N/A	Yes	Yes
Ultimate	ASTM D4239A/D5373	N/A	Yes	Yes
Heating Value	ASTM D5865	N/A	Yes	No
Metals	US EPA 200.2/6020A	Yes	Yes	Yes
PAHs (Polycyclic Aromatic Hydrocarbons)	US EPA 3540C, 3630C, 625, 8270	Yes	Yes	Yes
PCDDs/PCDFs (Dioxins/Furans)	US EPA 1613	Yes	Yes	Yes
PCBs (Polychlorinated Biphenyls)	US EPA 1668	Yes	Yes	Yes
Acidic Neutral Drugs	US EPA 1694	No¶	Yes	No
OC (Organochlorine) **Pesticides**	US EPA 1699	Yes	Yes	Yes
PBDEs (Polybrominated diphenyl ethers)	US EPA 1614	Yes	Yes	Yes
Pathogens	TMECC 07.01/MFLP-75	Yes	Yes	No
Halide emissions	Method 26	Yes	Yes	N/A
Metal emissions	Method 29	Yes	Yes	N/A
LandFill suitability/Leachate Tests	TCLP/Method 1311	Yes	N/A	Yes

Note:
Yes = analyzed; No = not analyzed;
*CALA - Canadian Association for Laboratory Accreditation;
¶ Research Methodology based on EPA 1694;

Proximate, Ultimate and Calorific Analyses

The as-received (AR) heat dried biosolids (granulite) was analyzed for gross and elemental composition by proximate and ultimate analyses respectively as detailed in Table 2. The AR granulite was composed of 11.5 wt.% (wb) moisture and 33.65 wt.% (db) mineral ash. The volatile matter and fixed carbon contents of AR granulite were determined to be 56.3 wt% (db) and 10.05 wt% (db) respectively. The heating/calorific value of biosolids was found to be 15.1 MJ/kg, which is comparable to most low grade coals found in the region. Based on the elemental composition analyses, AR granulite was found to contain N and S in high proportions, which are not desirable for combustion applications since they lead to the formation of NOx and SOx emissions respectively.

Table 2: Granulite Composition Verification and Energy Content

	Moisture Wt.% (wb)	Proximate Composition Wt.% (db)			Ultimate Composition Wt.% (db)					Calorific Value MJ/kg (db)
	M.C.	ASH	V.M.	F.C.*	C	H	N	S	O*	
AR Granulite - Heat Dried Biosolids	11.5	33.65	56.30	10.05	34.27	4.48	5.11	1.51	20.98	15.1
Combustion Ash	0	97.15	2.85	-	0.80	1.00	0.12	0.43	0.5	N/A

Note:

- wb = wet mass basis; db = dry mass basis;
- M.C. = Moisture Content; V.M. = Volatile matter; F.C. = Fixed Carbon; N/A = not applicable;
- *Fixed Carbon content was determined by difference according to the formula below:
  Fixed Carbon (% Dry Basis) = 100 – [Volatile matter (% Dry Basis) + Ash(% Dry Basis)]
- *The oxygen content was determined by difference according to the formula below:
  Oxygen (% db) = 100 – {Carbon(% db) + Hydrogen(% db) + Nitrogen(% db) + Sulphur(% db) + Ash(% db)}

Ash Fusion Temperature Biosolids

Ash fusion temperatures give an indication of the softening and melting behavior of fuel ash and are valuable guides to the high-temperature behavior of the fuel's inorganic mineral matter. Fusion temperatures typically are measured at four defined points under both reducing and oxidizing conditions as follows. The biosolids combustion ash complied with class II medium combustibility ash, as shown in the Table 3 below.

Table 3: Ash Fusion Temperature (AFT) of Granulite Combustion Ash

Ash Fusion Temperature °C				
Environment	**Initial (IT)**	**Softening (IT)**	**Hemispherical (HT)**	**Fluid (FT)**
Reducing	983	1099	1129	1217
Oxidizing	1002	1110	1140	1252

Note:

- Initial deformation temperature (IT): the point of cone begins to round
- Softening temperature (ST): the base of the cone is equal to its height
- Hemispherical temperature (HT): the base of the cone is twice its height
- Fluid temperature (FT): the cone has spread to a fused mass no more than 1.6 mm in height
- Fluid Temperature: Class I Refractory Ash AFT > 1426 deg C; Class II Medium Fusibility Ash AFT > 1204 deg C;

PATHOGEN TESTS

The AR biosolids (Synagro Heat Dried biosolids) were cultured for human pathogen detection using the TMECC and MFLP methodologies. TMECC is widely employed in compost quality analysis, while a modified MFLP-75 isolation method of the Compendium of Analytical Methods was used for the detection of Salmonella in manure. As indicated in Table 4, the biosolids sample (Granulite) was found to be free of E. coli, Fecal Coliform and Salmonella.

Table 4: Pathogenicity Tests

PARAMETER	RESULT	UNIT	DETECTION LIMIT	Class A Bio-Solids Guideline	METHOD REFERENCE
E. coli	<3	MPN/g dry	3	< 3	TMECC 07.01
Salmonella spp.	NEGATIVE	P-A/25.0 g (ml)	1 CFU		MFLP-75 *
Fecal Coliform	<3	MPN/g dry	3	< 1000	TMECC 07.01

The Synagro supplied heat-dried biosolids were processed to meet Class A biosolids quality guideline, which is a higher degree than class B biosolids, thus having a much lower pathogen concentration in the finished product and much less restrictive handling and land application requirements.

INORGANIC CONTAMINANTS

Biosolids typically contain a lot of phosphorus, compared to other renewable resources. This phosphorus could be potentially recovered from incineration of biosolids in mono-combustion regime and the resulting ash used as a nutrient source for sustainable food production. As one of the major ash-forming constituent in biosolids, phosphorus plays an important role in altering the ash melting behavior of the resultant combustion ash. Additionally, biosolids combustion ash is known to contain other important macro- and micro-nutrients, such as B, Mg, Al, Si, P, S, K, Ca, Mn, Fe in high abundance, which are beneficial for plant growth. Additionally, the combustion ash meets all the criteria stipulated in the CFIA T-4-093 guideline for the maximum allowed concentration of heavy metals in fertilizers and soil supplements (CFIA T-4-093 Standards for Metals in Fertilizers and Supplements - Plants - Canadian Food Inspection Agency).

Table 5: Metal Content in Heat-Dried Biosolids (Granulite) and its Combustion Ash

Analyte, Total		**Biosolids (ppm)**		**Combustion Ash (ppm)**		**Regulation Land Application (ppm)**				
Parameter	CAS	RDL	Result	RDL	Result	CFIA T-4-93	CAN/ BNQ	BC OMRR Class A Biosolids	US EPA	
Aluminum	7429-90-5	80	21900	16	7720					
Antimony	7440-36-0	0.01	1.19	0.02	4.16					
Arsenic	7440-38-2	0.01	6.61	0.02	18.4	75	41	75	41	
Barium	7440-39-3	0.06	128	0.12	190					
Beryllium	7440-41-7	0.08	0.122	0.008	0.415					
Bismuth	7440-69-9	0.01	25.8	0.02	33.1					
Boron	7440-42-8	0.7	50.2	1.4	214					
Cadmium	7440-43-9	0.01	0.887	0.001	0.639	20	15	20	39	
Calcium	7440-43-9	20	19600	2	3040					
Chlorine	7782-50-5	390	< 390	39	392					
Chromium	7440-47-3	0.3	29.8	30	670	1060	1000	N/A	1200	
Cobalt	7440-48-4	0.02	1.67	2	521	150	150	150		
Copper	7440-50-8	2	392	200	1390	757	1500	N/A	1500	
Iron	7439-89-6	9	6070	18	15400					
Lead	7439-92-1	0.2	15	0.4	33.0	500	300	500	300	
Lithium	7439-93-2	0.01	1.41	0.001	7.32					
Magnesium	7439-95-4	0.4	3880	0.04	484					
Manganese	7439-96-5	0.09	131	0.18	633					
Mercury	7439-97-6	0.01	0.358	0.001	0.535	5	4	5	17	
Molybdenum	7439-98-7	0.03	9.15	3	126	20	20	20	18	
Nickel	7440-02-0	0.07	16.2	0.14	1110	180	180	180	420	
Phosphorus	7723-14-0	200	24000	2000	78800					
Potassium	7440-09-7	8	2100	16	4510					
Selenium	7782-49-2	0.2	4.02	0.02	9.50	14	25	14	36	
Silicon	7440-21-3	40	20200	4	42000					
Silver	7440-22-4	0.006	2.19	0.0006	1.33					
Sodium	7440-23-5	2	1050	0.2	1280					
Strontium	7440-24-6	0.03	146	0.06	249					
Sulfur	7704-34-9	760	10900	76	2370					
Thallium	7440-28-0	0.03	0.066	0.003	0.191					
Thorium	7440-29-1	0.02	1.7	0.002	0.319					
Tin	7440-31-5	0.03	27.2	0.06	37.2					
Titanium	7440-32-6	4	1660	40	3990					
Uranium	7440-61-1	0.003	3.36	0.006	13.2					
Vanadium	7440-62-2	0.2	8.83	0.4	47.6					
Zinc	7440-66-6	0.7	413	1.4	877	1868	1850	1850	2800	
Tellurium	13494-80-9	R	0.0105							
Tungsten	7440-33-7	R	0.2841							

- RDL – Reported Detection Limits; R = research methodology/non-accredited methodology (non-routine testing);
- CFIA - T-4-93 Safety Guidelines for Fertilizers and Supplements;
- BNQ National Standard of Canada (Soil Amendments – Alkaline or Dried municipal biosolids) maximum trace element conc.
- BC, Min. of Env., Organic Matter Recycling Regulation (OMRR) for land application of Class A biosolids (2002);
- US EPA 1993, Federal regulation for application of biosolids;
- Combustion ash not suitable for land application due to high concentration of Co, Cu, Mo, Ni;

ORGANIC CONTAMINANTS

The AR heat-dried biosolids were thoroughly characterized for various organic contaminants including routine PAHs, PCDDs/PCDFs, PCBs, and ESOCs (emerging substance of concern) such as OBDE (fire extinguishers), OC pesticides, pharmaceuticals, drugs and personal care products.

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are a group of more than 100 different chemicals that are formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances. PAHs generally occur as complex mixtures, not as single compounds. They can have a faint, pleasant odor. They are found throughout the environment in the air, water, and soil. They can occur in the air, either attached to dust particles or as solids in soil or sediment.

Although the health effects of individual PAHs are not exactly alike, the following 17 PAHs are considered as a group in this profile:

- acenaphthene
- acenaphthylene
- anthracene
- benz[a]anthracene
- benzo[a]pyrene
- benzo[e]pyrene
- benzo[b]fluoranthene
- benzo[g,h,i]perylene
- benzo[j]fluoranthene
- benzo[k]fluoranthene
- chrysene
- dibenz[a,h]anthracene
- fluoranthene
- fluorene
- indeno[1,2,3-c,d]pyrene
- phenanthrene
- pyrene

These 17 PAHs were chosen to be included in this profile because:

(1) more information is available on these than on the others;

(2) they are suspected to be more harmful than some of the others, and they exhibit harmful effects that are representative of the PAHs;

(3) there is a greater chance that you will be exposed to these PAHs than to the others; and

(4) of all the PAHs analyzed, these were the PAHs identified at the highest concentrations at hazardous waste sites; and

(5) some of them are listed in EPA's Priority Chemical list including

1. Acenaphthene,
2. Acenaphtylene,
3. Anthracene,
4. Benzo(g,h,i)perylene,
5. Fluorene,
6. Phenanthrene,
7. Pyrene,

Benzo[a]pyrene is the most studied polycyclic aromatic hydrocarbon, is considered the most toxic, and is listed as a Group 2a carcinogen by the IARC. The EPA Toxicity Equivalency Factors (EPA-TEF) for the select PAHs available in literature are presented in Table 6. As noted, Benzo[a]pyrene has a TEF = 1, and has been employed as a human health risk indicator for PAH exposure and as a marker for overall PAH exposure. The total Benzo(a)pyrene toxicity equivalent was estimated based on the detected probable carcinogenic PAHs in the given biochar sample as per the EPA-TEF methodology (US EPA 1993). The polycyclic aromatic hydrocarbons in the biosolids were determined by HRGC/MS technique as reported in Table 7. Based on the PAHs analyses, the total PAHs detected in the biosolids was found to be 27.44 ppm with an associated B(a)P TEF of 3.08. Upon combustion, the cumulative PAH content decreased drastically to 1.04 ppm with an associated B(a)P TEF of 0.07.

Table 6: Toxicity Equivalency Factors of common PAHs with probable carcinogenicity (IARC Class 2a) to human (US EPA 1993)*

Compound	Toxicity Equivalency Factor (TEF)
Dibenz[a,h]anthracene	1
Benzo[a]pyrene	1
Benz[a]anthracene	0.1
Benzo[b]fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Indeno[1,2,3-c,d]pyrene	0.1
Anthracene	0.01
Benzo[g,h,i]perylene	0.01
Chrysene	0.01
Acenaphthene	0.001
Acenaphthylene	0.001
Fluoranthene	0.001
Fluorene	0.001
Phenanthrene	0.001
Pyrene	0.001

World Health Organisation Toxic Equivalence Factors for PAHs as per NEPM Schedule B1, Table 1A.

PAH	Toxic Equivalence Factor (TEF)
Benz(a)anthracene	0.1
Benzo(a)pyrene	1
Benzo(b+j)fluoranthene	0.1
Benzo(k)fluoranthene	0.1
Benzo(g,h,i)perylene	0.01
Chrysene	0.01
Dibenz(a,h)anthracene	1
Indeno(1,2,3,cd)pyrene	0.1

*EPA. 1993a. Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons. Environmental Criteria and Assessment Office. Cincinnati, OH. Final Draft. ECAO-CIN-842. March 1993.

Table 7: Occurrence and Concentration of Polycyclic Aromatic Hydrocarbons (PAHs) in Biosolids and Combustion Ash

Poly Aromatic Hydrocarbons (PAHs)	**EPA TEF[∫]**	**Granulite Bio-solid**	**Combustion Ash**
Parameter		**Result (µg/g) or ppm**	**Result (µg/g) or ppm**
1-Methylnaphthalene		0.236	0.007
2-Methylnaphthalene		0.237	0.007
3-Methylcholanthrene		< 0.005	< 0.002
7,12-Dimethylbenz(a)anthracene		< 0.005	< 0.002
Acenaphthene	0.001	0.442	0.014
Acenaphthylene	0.001	0.063	0.040
Acridine		< 0.005	< 0.002
Anthracene	0.01	0.315	< 0.002
Benzo(a)anthracene	0.1	1.56	0.040
Benzo(a)pyrene	**1**	1.78	0.038
Benzo(b,j,k)fluoranthene	0.1	4.75	0.072
Benzo(c)phenanthrene		< 0.005	< 0.002
Benzo(e)pyrene		2.34	0.043
Benzo(ghi)perylene	0.01	1.75	0.068
Chrysene	0.01	2.08	0.034
Dibenzo(a,h)pyrene		< 0.005	0.005
Dibenzo(a,l)pyrene		< 0.005	0.029
Dibenzo(ah)anthracene	**1**	0.434	0.017
Fluoranthene	0.001	3.79	0.113
Fluorene	0.001	0.482	0.019
Indeno(1,2,3-cd)pyrene	0.1	1.87	0.033
Naphthalene		0.221	0.191
Perylene		0.494	0.023
Phenanthrene	0.001	1.48	0.063
Pyrene	0.001	2.84	0.149
Retene		0.273	0.030
ΣPAHs, Total (µg/g)		**27.44**	**1.04**
B(a)P TEF (µg/g)		**3.08**	**0.07**

PolyChlorinated Dibenzo Dioxins/DiFurans (PCDDs/PCDFs) & Polychlorinated Biphenyls (PCBs):

Heat-dried biosolids and solids combustion ash were analyzed for polychlorinated dibenzo dioxins/furans (PCDDs/PCDFs) as per Table 8. Polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) are formed when organic matter is burned in the presence of chlorine, and are therefore found in fly ash from incinerators and produced naturally in forest fires. PCDDs and PCDFs are highly persistent in the environment, and are considered ubiquitous environmental contaminants. They can be found at very low levels in all living organisms and are able to bioaccumulate in food chains due to their lipophilic characteristics.

Depending on the degree of chlorination (1 - 8 chlorine atoms) and the substitution pattern, one can distinguish between 75 PCDDs and 135 PCDFs, called "congeners". The toxicity of dioxin congeners varies considerably. Of the 210 congeners, only 17 are of toxicological concern, and the analysis for "Total Dioxins" conducted by the CFIA is based on the combined concentration of these 17 dioxin and furan congeners. Exposure levels or residues are expressed in toxic equivalents (TEQ) of the most toxic congener, 2,3,7,8-tetrachloro-dibenzo-p-dioxin (2,3,7,8-TCDD), which allows for comparison of analytical results.

The International Agency for Research on Cancer (IARC) has classified 2,3,7,8-TCDD as a Group 1 carcinogen, which indicates that it is carcinogenic to humans. Effects seen in experimental animals include endometriosis, developmental effects at the behavioural level, reproductive effects, and toxicity to the immune system. The biochemical and toxicological effects following dioxin exposure are dependent on the tissue level, not the dose, and are therefore the same regardless of whether the intake is a large dose over a short period or a small dose over a long period.

Polychlorinated Biphenyls (PCBs) are also considered to be persistent pollutants. PCBs differ from PCDDs and PCDFs in that they were intentionally manufactured while dioxins and furans are produced unintentionally as unwanted by-products. PCBs consist of 209 different congeners. Some of the 209 congeners, because of their chemical structure and biological activity, are considered to be "dioxin-like". Twelve to 14 of the most toxic dioxin-like PCBs are expressed in toxic equivalents (TEQ).

In the current study, seven dioxin congeners, 10 furan congeners and 12 dioxin-like PCBs are considered TEQ estimation following standard World Health Organization (WHO) -

International Program on Chemical Safety. Based on the analytical results of PCDDs and PCDFs (Table 8) and PCBs (Table 9), both granulite biosolids and its combustion ash passed the regulatory guidance (for land application).

Table 8: Occurrence and Concentration of of Dioxins and Furans in Heat Dried Biosolids and Combustion Ash

	Granulite – Biosolids ppt – pg/g	# of pks	Biosolids Combustion Ash	# of pks
Furans				
2378-TCDF	5.3		0.3	
Total TCDFs*	38.1	15	0.4	2
12378-PeCDF	1.8		0.2	
23478-PeCDF	1.5		NDR (0.1)	
Total PeCDFs*	25.0	10	0.2	1
123478-HxCDF	4.8		NDR (0.1)	
123678-HxCDF	1.8		ND (0.1)	
234678-HxCDF	1.6		NDR (0.1)	
123789-HxCDF	NDR (0.3)		ND (0.1)	
Total HxCDFs*	23.6	6	0.3	1
1234678-HpCDF	21.2		0.5	
1234789-HpCDF	NDR (1.0)		ND (0.1)	
Total HpCDFs*	32.4	2	0.5	1
OCDF	31.1	1	NDR (0.6)	
Dioxins				
2378-TCDD	ND (0.1)		NDR (0.1)	
Total TCDDs*	48.6	7	2.0	1
12378-PeCDD	ND (0.1)		0.1	
Total PeCDDs*	11.0	3	1.4	3
123478-HxCDD	0.7		NDR (1.4)	
123678-HxCDD	2.7		NDR (1.4)	
123789-HxCDD	2.2		ND (0.1)	
Total HxCDDs*	20.8	7	ND (1.4)	
1234678-HpCDD	47.5		0.9	
Total HpCDDs*	96.2	2	0.9	1
OCDD	412	1	7.4	1
I TEQ**	**3.88 ppt**		**0.111 ppt**	

Table 9: Occurrence and Concentration of Poly Chlorinated Biphenyls in Heat Dried Biosolids and Combustion Ash

PCB CONGENER		Granulite – Biosolids (ppt – pg/g)	# of pks	Biosolids Combustion Ash	# of pks
GROUP TOTALS					
Mono-chloro-PCBs		364	3	22.6	2
Di-chloro-PCBs		1520	6	1560	5
Tri-chloro-PCBs		3600	12	124	7
Tetra-chloro-PCBs		11300	19	217	13
Penta-chloro-PCBs		15902	21	219	16
Hexa-chloro-PCBs		10712	20	136	13
Hepta-chloro-PCBs		4990	15	33.6	3
Octa-chloro-PCBs		1465	8	19.3	7
Nona-chloro-PCBs		381	2	4.2	1
Deca-chloro-PCBs		86.0	1	1.8	1
TOTAL PCBs*	*ppt*	50320		2337	
	ppb	50.3		2.34	
	ppm	0.0503		0.00234	
WHO TEQs**					
(ND = 0)		0.47		0.00	
(ND= 1/2*DL)		0.68		0.07	
(ND=DL)		0.88		0.14	

* Calculated as the sum of the 82 indvidual named PCBs and other detected un-named PCBs. The summations do not include ND and NDR values.

** The reported TEQ is a calculated parameter.

ESOCS (EMERGING SUBSTANCE OF CONCERN)

Emerging substance of concern (ESOCs) include OC pesticides, PBDE (fire extinguishers), pharmaceuticals, drugs and personal care products. As noted from Table 10, most of the organochlorine pesticides detected in the granulite biosolids were found to be completely destroyed during combustion with the exception of g-BHC (gamma benzene hexachloride) whose concentration increased proportionately to ash enrichment.

TABLE 10: Concentration of Organo Chlorine Pesticides in Biosolids and Combustion Ash

ORGANOCHLORINE PESTICIDE	Granulite - Biosolids (ng/g ≅ ppb)	Combustion Ash (ng/g ≅ ppb)
a-BHC	ND (0.01)	NDR (0.01)
HCB	0.40	0.02
b-BHC	ND (0.01)	ND (0.01)
g-BHC	1.01	3.47
Heptachlor	NDR (0.06)	ND (0.01)
HeptachlorEpoxide	4.60	0.06
Oxychlordane	0.63	ND (0.01)
g-chlordane	32.8	0.40
op'-DDE	0.19	ND (0.01)
a-chlordane	31.1	0.39
t-nonachlor	27.4	0.32
pp'-DDE	8.24	0.11
op'-DDD	25.3	NDR (0.19)
pp'-DDD	6.51	ND (0.02)
op'-DDT	ND (0.08)	ND (0.03)
c-nonachlor	7.02	0.10
pp'-DDT	ND (0.10)	ND (0.03)
Mirex	0.23	ND (0.01)

Polybrominated diphenyl ethers (PBDEs) are compounds used as flame retardants in a wide variety of applications. The main commercial classes of the PBDEs sometimes referred to generically as brominated flame retardants (BFRs). Only the decabromo diphenyl ether (DPE) product is allowed for use in Canada. The environmental and health concerns with PBDEs centre on their persistence, potential toxicity and ability to bioaccumulate.

PBDEs were detection in the AR biosolids, as detailed in Table 11. The cumulative sum of PBDEs detected in biosolids was found to be 1.17 ppm, which after combustion was reduced to 0.015 ppm ie., 99% reduction was noted.

Table 11: Polybrominated Diphenyl Ether (PBDE) data (ppt - pg/g)

Polybrominated Diphenyl Ether	Granulite - Biosolids	Biosolids Combustion Ash
BDE #3	ND (57.8)	41.7
BDE #7	286	NDR (4.8)
BDE #15	476	33.9
BDE #17	5130	56.2
BDE #28	4020	53.0
BDE #49	17300	214
BDE #71	1060	20.7
BDE #47	248000	2740
BDE #66	4610	61.6
BDE #77	ND (11.5)	ND (0.1)
BDE #100	53300	718
BDE #119	ND (28.8)	20.6
BDE #99	197000	2330
BDE #85	6770	75.0
BDE #126	ND (31.5)	ND (0.3)
BDE #154	15000	191
BDE #153	18900	235
BDE #138	1650	28.8
BDEs #156	ND (47.9)	ND (1.4)
BDE #184	361	ND (1.4)
BDE #183	2800	41.1
BDE #191	ND (78.6)	ND (3)
BDE #197	2880	44.2
BDE #196	2270	ND (6.5)
BDE #207	15200	195
BDE #206	20100	252
BDE #209	550000	7990
Total (sum of above BDEs)		
ppt (pg/g)	1170000	15342
ppb (ng/g)	1170	15.3
ppm (ug/g)	1.17	0.0153

ND = Not detected (detection limit in parenthesis)

As noted in Table 12, most of the acidic and neutral drugs (Pharmaceuticals) analyzed for, could not be detected in the granulite biosolids within the reported method detection limit and instrument sensitivity, as demonstrated in the Table 12 below.

Table 12: Pharmaceuticals, drugs and personal care products

		Granulite Biosolids	
Parameter	**CAS**	**RDL**	**Result (ppm or ug/g)**
3,4,4-Trichlorocarbanilide	101-20-2	0.05	< 0.05
Acetylsalicylic acid	50-78-2	0.02	< 0.02
Bezafibrate	41859-67-0	0.2	< 0.2
Caffeine	58-08-2	0.04	< 0.04
Carbamazepine	298-46-4	0.02	< 0.02
Clofibric acid	882-09-7	0.02	< 0.02
Diclofenac	15307-86-5	0.02	< 0.02
Fenoprofen	29679-58-1	0.01	< 0.01
Gemfibrozil		0.01	< 0.01
Ibuprofen	15687-27-1	0.01	< 0.01
Indomethacin	53-86-1	0.1	< 0.1
Ketoprofen	22071-15-4	0.02	< 0.02
Meclofenamic acid	644-62-2	0.02	< 0.02
Methyl Triclosan	4640-01-1	0.02	< 0.02
N,N-diethyl-m-toluamide	134-62-3	0.01	< 0.01
Naproxen	22204-53-1	0.01	< 0.01
Salicylic acid	69-72-7	0.05	< 0.05
Tolfenamic acid	13710-19-5	0.01	< 0.01
Triclosan	3380-34-5	0.05	< 0.05
Acetaminophen	103-90-2	0.1	< 0.1
Benzoylecgonine	519-09-5	0.02	< 0.02
Chloramphenicol	56-75-7	0.02	< 0.02
Ciprofloxacin		0.04	< 0.04
Clindamycin	18323-44-9	0.02	< 0.02
Cocaine	50-36-2	0.02	< 0.02
Codeine	76-57-.3	0.1	< 0.1
Cotinine	486-56-6	0.02	< 0.02
Enrofloxacin	93106-60-6	0.04	< 0.04
Erythromycin	114-07-8	0.02	< 0.02
Fluoxetine	54910-89-3	0.02	< 0.02
Lincomycin	154-21-2	0.1	< 0.1
Methamphetamine	537-46-2	0.04	< 0.04
Norfloxacin	70458-96-7	0.04	< 0.04

Norfluoxetine	83891-03-6	0.04	< 0.04
Ofloxacin	84219-36-1	0.04	< 0.04
Oxolinic Acid	14698-29-4	0.02	< 0.02
Pentoxifylline	6493-05-6	1	< 1
Pipemidic Acid	51940-44-4	1	< 1
Sulfabenzamide	121-71-9	0.1	< 0.1
Sulfadimethoxine	122-11-2	0.1	< 0.1
Sulfadoxine	2447-57-6	0.1	< 0.1
Sulfamerazine	127-79-7	0.1	< 0.1
Sulfamethazine		0.1	< 0.1
Sulfamethoxazole	723-46-6	0.1	< 0.1
Sulfapyridine	144-83-2	0.1	0.00250
Sulfaquinoxaline	59-40-5	0.1	< 0.1
Sulfathiazole	72-14-0	0.1	< 0.1
Trimethoprim	738-70-5	0.04	< 0.04

RDL: Reported Detection Limits;

COMBUSTION EXPERIMENTS

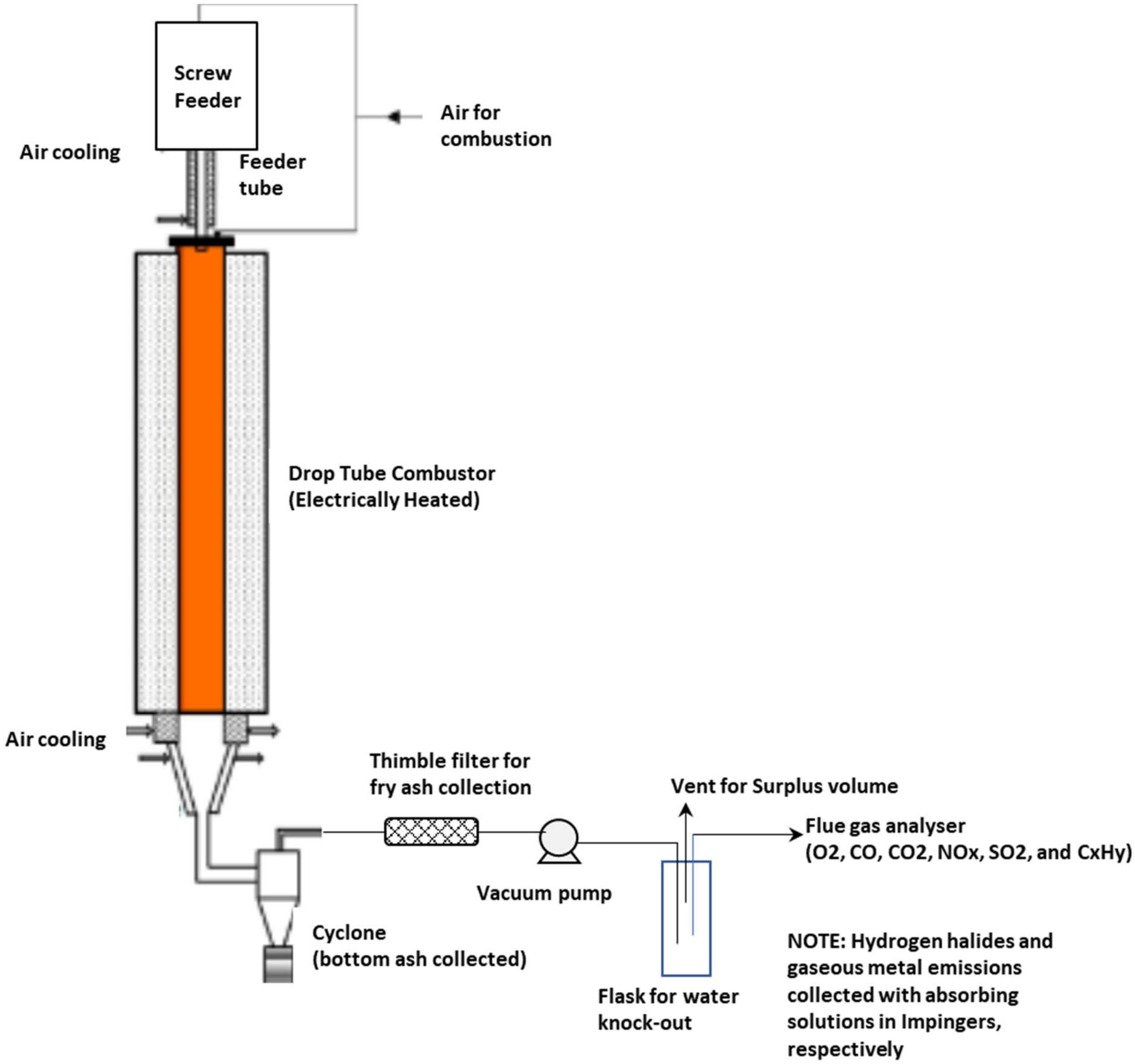
The biosolids combustion experiments were conducted in an atmospheric entrained-flow reactor using a drop tube furnace (DTF) that consisted of a feeding system, a high temperature furnace and a sampling system, as shown in Fig. 2. The reactor furnace consisted of an electrically heated vertical core constructed from a Mullite tube (63.5 mm i.d., 1546 mm height), which is electrically heated with molybdenum disilicide (Moly-D 33) heating elements. Three PID temperature controllers (Omron E5CK), located at the middle, bottom and top of the DTF, control temperature along the length of the tube. These temperature controllers are run using Lab View interface on the associated computer. The DTF is calibrated periodically using a quarter inch calibrated K-type thermocouple. The maximum working temperature achievable in the DTF was 1500 °C. A screw feeder (Schenck AccuRate volumetric feeder) with pulsating walls and a flight-free auger with a stirring rod and poly nozzle was used to feed the solid pulverized feedstock into the reaction tube through a custom-designed jacketed feeder probe. The feeding probe connects the volumetric feeder to the reactor. The feeding probe is jacketed for cold water circulation due to its proximity to the hot zone and also to eliminate any likelihood of material (biosolids) degradation prior to its entry into the DFT. The feeding system was volumetrically calibrated prior to each experiment. A primary flow of air was used to entrain the particles into the reaction tube.

The down-stream equipment employed to measure gaseous, halide, metal emissions and collected particulate matter are shown in Figure 3 below. The hot combustion products from the DFT were passed through an air-cooled cyclone and collection chamber, where larger char/ash particles were separated from flue gas and soot. The flue gas was then passed through a filter (Whatman glass fibre thimbles 603G) to collect particulate emissions, then to a flue gas analyzer. Gaseous emissions such as CO, SOx, NOx, CxHy, and O2 were measured using the Testo 350 XL. For halide and metal emission measurements, impinger trains containing standard solutions of 0.1 N H2SO4 and 0.1 N NaOH were employed downstream of the particulate filter to capture halides emissions (Fluoride, Chloride, Bromide) in flue gas as per method 26. Likewise impinger trains containing standard solutions of 5% HNO3/10%H2O2 and 4% KMnO4/10% H2SO4 were employed to determine metal emissions in flue gas as per method 29. The saturated solutions from impingers were analyzed for halides and metals by IC and ICP/MS respectively. Table 13 summarizes the various test parameters measured and methodology employed in the current combustion tests based on the COP for the manual stack emission test. In the current test regime, combustion of granulite biosolids was carried out at 1000 °C with 52% excess air, based on the theoretic carbon content of the granulite biosolids feedstock.

Table 13: Emission Test Parameters and Methodology

Parameters (Analyses)	Evaluation Methods	Reference
Particulate Matter (PM)	Isokinetic sampling and gravimetrical mass determination	US EPA Method 5
Hydrogen Chloride (HCl)	Stack grab sampling and Ion chromatography (IC)	US EPA Method 26
Carbon Monoxide (CO)	Continuous emission measurements using flue gas analyzer	ASTM Method D6522-00
NO_x	Continuous emission measurements using flue gas analyzer	ASTM Method D6522-00
SO_2	Continuous emission measurements using flue gas analyzer	ASTM Method D6522-00
Gas Velocity	Stack grab sampling and gravimetrical mass determination	US EPA Method 2
Flue Gas Molecular Weight and Density	Stack grab sampling and gravimetrical mass determination	US EPA Method 3
Flue Gas Moisture Content and Others (O_2, CO_2 and N_2 by difference)	Stack grab sampling and gravimetrical mass determination	US EPA Method 4, and ASTM Method D6522-00
Unburnt Gas (CxHy) for Determination of Chemical Heat Loss	Continuous emission measurements using flue gas analyzer	ASTM Method D6522-00
Gas Enthalpy Calculations for Energy Balance	Gas enthalpy calculated based on measured gas compositions and temperature	B415.1 Performance Testing of Solid-Fuel-Burning Heating Appliances, published by the Canadian Standards Association

Figure 2: Schematic of the Drop Tube Furnace employed for Incineration of Biosolids



Schematic diagram of the entrained-flow combustor and flue gas analyses

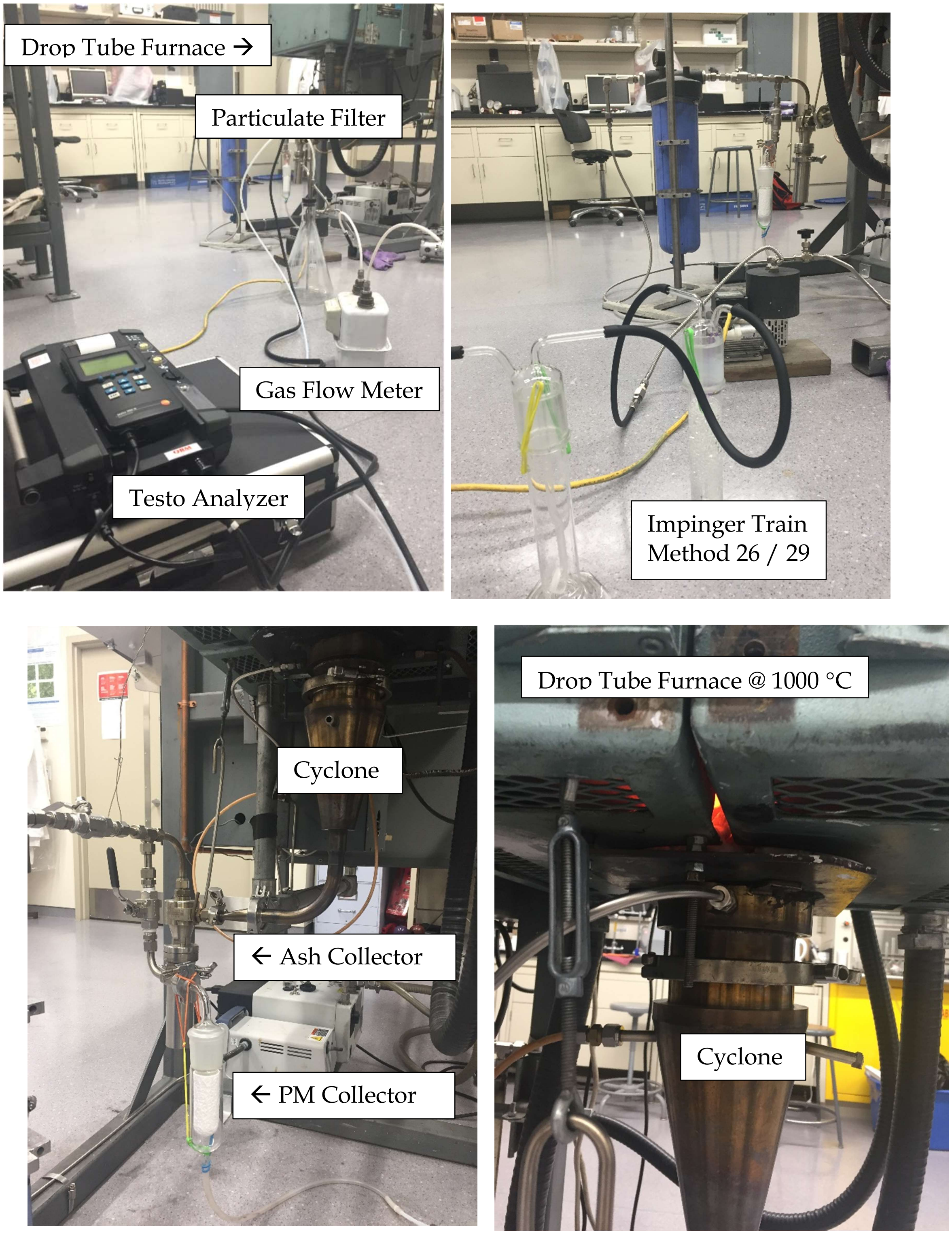


Figure 3: Testo Analyzer employed for measuring gaseous emissions (top left); Impinger Train employed for measuring halide/metal emissions (top right); Air cooled Cyclone used for collected larger ash/char particles (bottom right); Whatmann fibre filter used for particulate matter collection (bottom left).

Accordingly to the BC adopted air quality objectives and standards for Emission Guidelines for MSW incinerators, the stack emissions from a small incinerator shall not exceed any of the following limits:

- Total Particulate Matter (TPM): average 20 mg/Rm^3 (@ 11% O_2)
- Sulphur Dioxide (SO_2): 250 mg/Rm^3 (@ 11% O_2)
- Nitrogen Oxides (NOx): 350 mg/Rm^3 (@ 11% O_2)
- Carbon mono oxide (CO): average 55 mg/Rm^3 (@ 11% O_2)
- Hydrogen chloride (HCl): 75 mg/Rm^3 (@ 11% O_2)
- Cadium (Cd): 100 µg/Rm^3 (@ 11% O_2)
- Lead (Pb): 50 µg/Rm^3 (@ 11% O_2)
- Mercury (Hg): 20 µg/Rm^3 (@ 11% O_2)

Note:

Rm^3 reference cubic metre at 25 °C and 101.3 kilopascals pressure. Concentrations are also to be corrected to 11 percent oxygen and zero percent moisture (dry) for reporting and compliance purposes

The emission profile generated from the mono-incineration of granulite biosolids in a drop tube furnace (DFT) at 1000 deg C with 50% excess oxygen, as shown in Figure 4 and Table 14 respectively. Based on the data generated, it can concluded that the biosolids incineration generated higher than regulated emissions of particulates (TPM), NOx, SOx and Chromium emissions. Co-incineration strategies or fuel mix strategies with N-, S- lean feedstocks should be devised to mitigate the emissions issues.

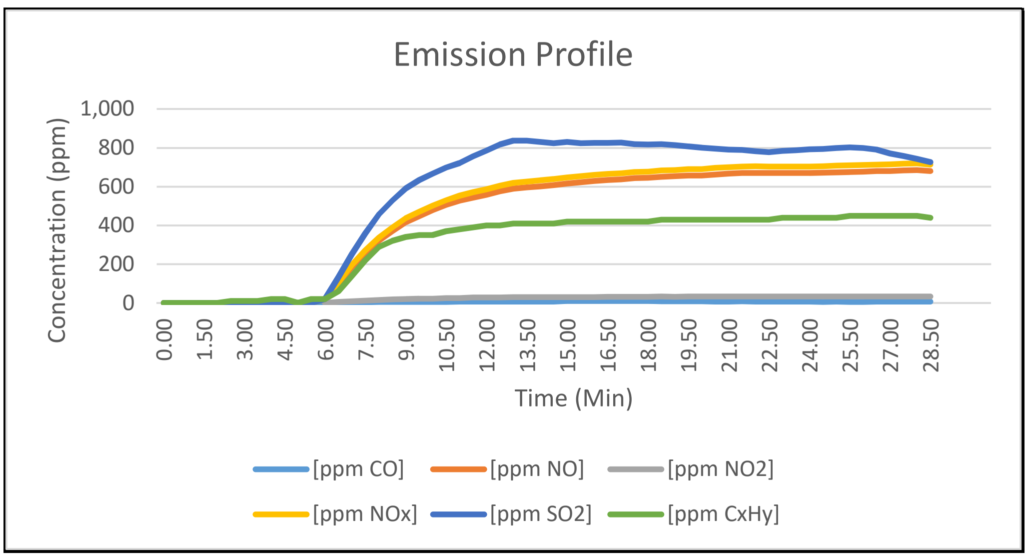


Figure 4: Emission Profile derived from incineration of biosolids in a Drop Tube Furnace (DFT)

Table 14: Emissions data, dry mass basis corrected to standard conditions at 11 % O_2 reference and 25 °C

Emissions	Concentration (mg/Rm3)	BC-MOE (mg/Rm3)	CCME (mg/Rm3)	Compliance
CO	6	55	57	Passed
NOx	478	350	400	Failed
SO_2	994	250	260	Failed
HCl	9.29	70	75	Passed
HF	0.02	3	-	Passed
TPM	25	20	20	Failed
Arsenic (As)	0.0027	0.004	0.001	Passed
Cadmium (Cd)	0.021	0.1	0.1	Passed
Chromium (Cr)	5.04	0.01	0.01	Failed
Lead (Pb)	0.03	0.05	0.05	Passed
Mercury (Hg)	0.0009	0.2	0.2	Passed

TPM = total particulate matter; Rm^3 = Reference cubic meter at standard conditions;

The metal emission results derived from impinger test as per method 29, are shown in Table 15 below.

Table 15: Metal emissions dry basis, corrected to standard conditions at 11 % O_2 and 25 °C

Analyte	Result	Unit
Antimony, Total	2.72	µg/Rm3
Arsenic, Total	2.66	µg/Rm3
Barium, Total	3.32	µg/Rm3
Beryllium, Total	0.00	µg/Rm3
Cadmium, Total	20.85	µg/Rm3
Chromium, Total	5.04	mg/Rm3
Cobalt, Total	0.05	mg/Rm3
Copper, Total	1.35	mg/Rm3
Lead, Total	0.03	mg/Rm3
Manganese, Total	795.09	µg/Rm3
Mercury, Total	0.89	µg/Rm3
Nickel, Total	4.05	mg/Rm3
Phosphorus, Total	70.82	µg/Rm3
Selenium, Total	< MDL	µg/Rm3
Silver, Total	1.46	µg/Rm3
Thallium, Total	0.04	µg/Rm3
Zinc, Total	5.51	mg/Rm3

Rm^3 = Reference cubic meter at standard conditions;

TOXICITY CHARACTERISTIC LEACHING PROCEDURE

Based on literature Toxicity Characteristic Leaching Procedure (TCLP), test method 1311 is the most widely used and suitable leaching method for testing ash and slag as it simulated wide range of landfill cell environments. Accordingly leaching media of varying pH ranging from acidic, neutral to basic were employed in the current tests.

Toxicity Characteristic Leaching Procedure, test Method 1311 in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," EPA Publication SW–846 was employed for the leaching tests to determine the mobility of inorganic analytes. The leaching tests were carried out with a batch leaching procedure in four steps, buffer solutions of varying pH (4, 7, 10) were used as the leaching media in order to emulate/simulate all landfill scenarios. The accumulative liquid to solid ratio (L/S) of 20:1 was employed based on bone dry weight of ash. The ash ± water mixtures were agitated in Teflon containers on an orbital shaker for 18 h. After agitation, the leachate was filtered using 45 µ filters to separate the solid ash from the leachates. All leachates were subsequently analysed for their levels of As, Ba, Cd, Cr, Pb, Hg, Se and Ag by ICP/MS and compared with the pertinent regulation as shown in Table 16.

Table 16: TCLP, method 1311 maximum allowable limits for heavy metals in leachate

Heavy Metal	Hazardous Waste Code	EPA Allowable Limits
Arsenic	D004	5.0 ppm (mg/L)
Barium	D005	100.0 ppm (mg/L)
Cadmium	D006	1.0 ppm (mg/L)
Chromium	D007	5.0 ppm (mg/L)
Lead	D008	5.0 ppm (mg/L)
Mercury	D009	0.2 ppm (mg/L)
Selenium	D010	1.0 ppm (mg/L)
Silver	D011	5.0 ppm (mg/L)

The concentration of various analytes leached at varying pH are shown in Table 17. Based on the findings documented in Table 17, the combustion ash meets regulatory guideline stipulated for heavy metal including for As, Ba, Cd, Cr, Pb, Hg, Se and Ag analytes at acidic, neutral and alkaline pH with the exception of Chromium analyte, which failed the TCLP test at acidic leaching conditions (ie., pH = 4). The non-compliance of Chromium analyte under acidic conditions could be attributed to enhanced digestibility of heavy metals under acidic conditions.

TCLP Method 1311:

1. pH = 4 (pH < 5) - Passed (except Chromium analyte)
2. pH = 7 (pH > 5) - Passed
3. pH = 10 (pH > 7) - Passed

Table 17: Toxicity Characteristic Leaching Procedure Test Results

Analyte	EPA Regulatory Level (ug/L or ppb)	MDL (ppb)	TCLP pH = 4 (ppb)	Pass/ Fail	MDL (ppb)	TCLP pH = 7 (ppb)	Pass/ Fail	MDL (ppb)	TCLP pH = 10 (ppb)	Pass/ Fail
As	5000	0.02	47.2	P	0.02	72.7	P	0.1	499	P
Ba	100,000	0.1	248	P	0.1	0.55	P	0.5	1230	P
Cd	1000	0.005	11.4	P	0.005	0.716	P	0.005	12.2	P
Cr	1000	3.0	1980	**F**	0.6	8.9	P	3.0	853	P
Pb	5000	0.05	2.6	P	0.05	< 0.05	P	0.2	387	P
Hg	200	0.15	0.37	P	0.15	0.99	P	0.15	5.23	P
Se	1000	0.4	22	P	0.4	38.4	P	2.0	121	P
Ag	5000	0.006	0.099	P	0.006	0.047	P	0.006	2.57	P

MDL = Method Detection Limit; P = Passed; F = Failed; TCLP – Method 1311;

REGULATORY COMPLIANCE

The various guidelines and their compliances are summarized in the Table 18 below:

Table 18:

Category	Description	Guideline	Compliance	Notes
Synagro Biosolids	Class A	CCME Compost	Satisfied	
	Land Application	CCME/BC OMRR	Satisfied	
Combustion Ash	Land Application	CCME	Satisfied	
	Landfill Suitability	TCLP (pH = 10)	Satisfied	
		TCLP (pH = 7)	Satisfied	
		TCLP (pH = 4)	Satisfied	Except for Cr
Emission	CO	BC-MOE/CCME	Satisfied	
	Halides	BC-MOE/CCME	Satisfied	
	Metal	BC-MOE/CCME	Satisfied	Except for Cr
	NOx	BC-MOE/CCME	Not Satisfied	
	SOx	BC-MOE/CCME	Not Satisfied	
	Particulate Matter	BC-MOE/CCME	Not Satisfied	

- BC, Min. of Env., Organic Matter Recycling Regulation (OMRR) for land application of Class A biosolids (2002);

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LIST OF APPENDICES

- Granulite MSDS
- Gas Analyzer_Certification
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  - Ash_Metals
  - Ash_PAHs
  - Ash_PCDD/PCDF
  - Ash_PCB
  - Ash_OC
  - Ash_BDE
  - Ash_TCLP

Notes:

- ✓ *Granulite – heat dried biosolids sourced from Synagro*
- ✓ *Ash – Ash derived from incineration of granulite biosolids in a DFT (Drop Tube Furnace)*