

# An Assessment of Gasification as an Alternative Technology for the Disposal of Slaughterhouse Waste

Final Report for  
Investment Agriculture Foundation  
of British Columbia  
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Dr. Thomas E. Dickinson  
Associate Vice-President (Research)  
Thompson Rivers University,  
900 McGill Rd., Kamloops, British Columbia

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## Executive Summary:

This project had its genesis in the need to explore alternative technologies for the destruction of solid wastes from slaughterhouses that contain specified risk material (SRM) for Bovine Spongiform Encephalopathy (BSE). Specifically it aimed at answering two related questions. First, can existing gasification technology dispose of the solid tissue waste from slaughterhouses in an environmentally safe manner? Second, what conditions would make gasification disposal an economically viable alternative technology?

In order to obtain information to address these questions, a test was conducted on August 18, 2005 in Kamloops, BC using a commercially available gasifier designed to recover energy from waste plastic. In this test, various mixtures (20%, 40% and 60%) of slaughterhouse waste and wood pellets were burned. Stack emissions and temperature profiles were continuously monitored during the test and chemical analyses of the fuelstocks and residual ash were carried.

The test demonstrated that gasification can dispose of slaughterhouse waste in a manner that exposes emission gases to temperatures high enough to meet European standards for SRM disposal. Moreover, it demonstrated that the air emissions could meet BC standards for all gases regulated for municipal waste disposal. However, the gasifier unit tested did not dispose of a large volume of waste during the test and experienced an operational failure in part due to excessive fuel feed rates. The ash residue in the unit tested would not have met standards for the destruction of SRM.

Six recommendations were made with regard to the design features that should be addressed in the pursuit of gasification technology as a solution to SRM disposal. The greatest issues involved fuel management and delivery, for which solutions may already be available from other applications of gasification. Other recommendations involve further research and development for the tuning of sensors and automation to deal specifically with slaughterhouse waste as a fuel source.

The question of the economic feasibility of gasifier technology for disposing of slaughterhouse waste was approached from the viewpoint of the conditions identified elsewhere for the commercialization of small scale gasifiers. Chemical analyses demonstrate that SRM have abundant energy that should be economically recoverable. Most of the problems facing the commercial application of gasifier technology can be readily solved if a reliable source of fuel can be guaranteed and an agreement can be negotiated for the purchase of excess energy.

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### Background

The discovery of BSE in Canada and subsequently in the United States has led to measures aimed at reducing the risk of dispersal of the disease. Expert committees tasked with investigating the Canadian and United States agri-food systems adopted a number of internationally agreed upon strategies and recommendations for controlling BSE. The recommendations were largely directed at Specified Risk Materials (SRM), the ruminant parts most likely to contain the infectious agents of the disease—the prions. Among the recommendations was complete removal of SRM from the animal feed chain, including all livestock feeds and pet food. In July 2003, the CFIA proposed that ruminant SRM be removed from all animal feed, while still allowing non-SRM ruminant material to be fed to non-ruminant species. This proposal is expected to be written into law in the very near future.

Since the BSE incident, SRM is being removed from all licensed slaughter plants at a cost to the operator. While it does not comprise a high proportion of the ruminant carcass, segregating it from the rest of the ruminant waste is difficult and costly, and plants are mixing it with other wastes with the result that all ruminant waste is being considered SRM. As a further enhancement of SRM removal from feed, CFIA has suggested in their publication that “SRM must be used or contained in such a manner that it can never re-enter the human or animal feed chain. Conditions of disposal or alternative use must preclude any release into the environment in such a way that it could contaminate the water or food supply. Destruction may be the only acceptable disposal option unless safe methods of containment or alternative use are evaluated and approved”.

If SRM destruction is the disposal option chosen there is at present only one proven method on a commercial scale, that being incineration. Alberta’s Swan Hills incinerator, for example, accepts the material at \$400/tonne. There are other promising methods but they have only been proven only on a laboratory scale, or not in British Columbia. Containment may be attainable through various methods, including encapsulation and land filling, and rendering to MBM followed by controlled storage. This is the method used in the United Kingdom, and though less costly than incineration, is still relatively expensive. Some alternative methods, such as gasification have been used in Europe and have certain economic advantages, but have not yet been implemented in Canada. Several sources have noted its potential value but also the need for further research.

As noted, gasification of solid waste material that contains SRM material is used in Europe, but the technology is not widely used for this purpose in North America. However, as costs of shipping waste to distant land fills or incinerators (acceptable options for disposal) becomes both less socially acceptable and increasingly cost prohibitive for producers, its attractiveness has grown. Gasification has the potential to both eliminate the waste material in an acceptable fashion and recover energy and useable heat. Nevertheless, a number of issues need to be examined before a gasification system designed to dispose of solid waste material containing can be approved. They are:

- The environmental impact of the emissions and solid residues of the gasification process;
- The ability of gasification to comply with the physical conditions needed to destroy prions;

- The capacity of gasification systems to recover energy in sufficient quantity to offset its costs;
- The education of the public regarding the benefits and risks of gasification as an alternative technology.

Before this technology can be recommended as an adequate disposal method, it is necessary to demonstrate through pilot testing the ability to expose waste material to sufficiently high temperatures to meet standards for BSE prion destruction, the acceptability of the residual waste to meet recognized standards, and the capacity to maintain air emissions within prescribed acceptable limits.

The current project was conceived of because of a fortuitous event: Westwood Energy of Kamloops BC anticipated having a small gasifier available for such pilot in the late summer of 2005. Coincidentally Blue Mountain Packers of Salmon Arm, BC has been considering alternatives to the removal of its waste for disposal in Alberta, and agreed to provide processed solid waste material containing SRM for testing purposes. By working with both parties and by overseeing controlled test burns of the waste material, and by arranging for certified testing of air emissions, Thompson Rivers University was in a position to coordinate scientific review gasification as an alternative disposal methodology. In return for applying for the appropriate permits to conduct the tests the university agreed to provide information on the air emissions to the Ministry of Environment Protection Branch. It was believed that such information would help guide the development of emission standards for BC and would provide essential data for the future scaling up to a commercially viable gasifier / energy recovery project to deal with similar solid waste material.

## **Objectives**

The broad goal of this project has been to test the economic and environmental suitability of gasification as a proposed alternative method to dispose of solid waste material typically produced by slaughterhouses and packing facilities that contains all of the Specified Risk Materials (SRM) from cattle.

Specifically, the project aims were to:

- Determine the performance characteristics of commercially available gasification units (generically) using a blended mixture of pelletized wood and solid waste material typically produced at slaughterhouses.
- Validate the capacity of the technology to meet or exceed accepted (European) standards of heat generation and exposure at levels sufficient to ensure the destruction of BSE prions, when working within the BC air emissions standards.
- Identify the range of situations, conditions, and waste disposal volumes under which gasification is an economically viable instrument to dispose of slaughterhouse solid waste.

The project directly addresses the second strategic goal of the Investment Agriculture Foundation's livestock waste tissue initiative. Specifically, it aims at proving an affordable disposal method for livestock waste that does not create a hazard to human, animal or environmental health that will allow for compliance by producers with existing legislation and expected CFIA regulations by August 2006.

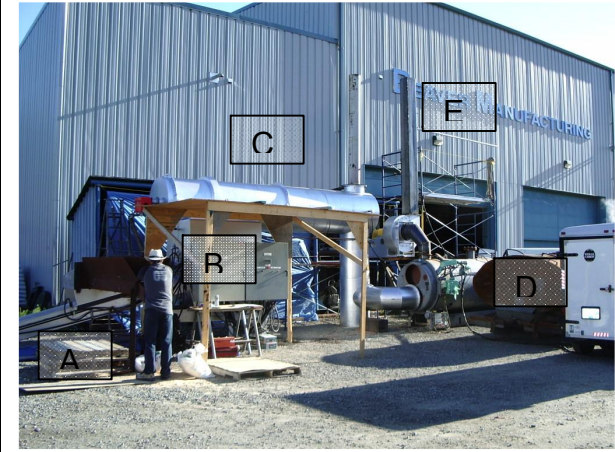



## Methodology

As noted, this test was made possible by the availability of a commercial gasification unit that had been designed for the destruction and recovery of energy from plastics. The unit was designed and built by Westwood Energy of Kamloops BC in collaboration with Beaver Manufacturing, also of Kamloops, BC. A composite photograph of the unit is shown in Figure 1 and its physical dimensions outlined in Appendix I.

The principle of gasification is straightforward, although a number of process variations exist, geared to the fuelstock being consumed. In its simplest form, a gasifier will consist of two separate reaction chambers. In the first chamber, a bed of fuel is exposed to ignition temperatures in the absence of oxygen. The products of this first combustion will be volatile gases and a char of uncombusted material. In the second chamber a subsequent combustion takes place with abundant of oxygen. A more complete description of the process accompanies the schematic drawing of the unit used in the test, illustrated in Appendix I.

# Westwood Gasifer

The particular gasifier used in the test is shown in Figure 1.

	<p>Figure 1. Gasification Unit used for the test burn. Letters refer to separate functional components of the system.</p> <ul style="list-style-type: none"><li>A. Fuel feed</li><li>B. Primary chamber</li><li>C. Secondary Chamber</li><li>D. Heat recovery boiler</li><li>E. Emissions test stack</li></ul>
	<p>A. Ram feed with wood pellets &amp; slaughter-house waste fuel prior to mixing.</p>
	<p>B. Primary combustion chamber with control panel.</p>
	<p>C. Secondary combustion chamber.</p>

## Test Burn Protocol:

A permit was obtained from the Protection Branch of the BC Ministry of the Environment for a 10 hour period to test the performance of the gasifier unit at the Beaver Manufacturing site near Kamloops (Appendix II). The test was attended by two staff from the Kamloops office of the Ministry of Environment Protection Branch. The gasifier unit was modified specifically for this test by the fabrication of a second stack to allow continuous air emission testing. (A. Lanfranco Associates of Richmond BC were contracted to carry out the emissions testing.) For the purposes of the test, the main stack was bypassed and the exhaust from the secondary combustion chamber was passed through a heat recovery boiler.

The fuelstock, consisted of mixtures of wood pellets (commercial horse bedding) and refrigerated solid waste that was boxed separately as 4 inch sized bone, fat & nervous tissue, and digestive tract organs. The pellets and waste were combined manually in different ratios. (The animal tissues were used in the approximate mass ratios 50% bone fragments; 30% digestive tract organs; and 20% fat and nervous tissue.) The first test period burned a mixture of 20% waste and 80% pellets (by weight); the second period burned 40% waste & 60% pellets; and the third period burned 60% waste & 40% pellets. The fuel was pulse fed using a ram feed system (Figure 1b).

On August 17, 2005 the equipment used to sample the stack emissions was installed and the fuel and air feed systems for the gasifier were tested. At approximately 06:00 on August 18<sup>th</sup>, 2005 the gasifier was started with a natural gas fuel source and a feed of 100% pellets was begun. In order to start the process, the fuel in the primary was first completely combusted. By increasing the fuel feed rate, a fuel rich/oxygen starved situation was created and gasification began. Approximately 1 hour was allowed for the temperature profile in the primary and secondary to stabilize. Beginning at 09:30, the temperature was manually recorded at five-minute intervals from thermocouples located in six different locations: the fuel bed, midway and at the exit of the primary chamber, and at the start, middle, and end of the secondary chamber.

Monitoring of the stack emissions began at 0:930 and was organized into three sessions that paralleled the combustion of the three different fuelstocks. Approximately 1 hour of burning 20% waste: 80% pellets, 3 hours of burning 40% waste, 60% pellets, and 1.5 hour burning 60% waste: 40% pellets. Emissions testing equipment was recalibrated at the end of each session.

## **Emissions Testing**

A. Lanfranco & Associates carried out a suite of emissions tests, the details of which can be found in Appendix II. In addition to constantly measuring stack temperatures, continuous monitoring was carried out of the CO<sub>2</sub>, O<sub>2</sub>, CO, NO<sub>x</sub> and SO<sub>2</sub> concentrations (either in % concentration or as ppm). Particulate sizes and concentrations were determined over three separate sampling periods.

Lanfranco & Associates were directed to take a parallel bulk sample of the emission air so that an independent analysis of the gas composition could be performed in TRU labs. This was done, but the integrity sample was not protected in shipping to TRU so that only an analysis of particulate matter could be carried out.

## **Fuelstock Analysis**

The moisture content of the fuel sources was calculated by drying replicate samples of the wood pellets, bone fragments, fat & nervous tissue, and body organs in a drying oven (62°C)

and vacuum desiccators. Mass changes over a five-day period (120 hrs) were used to calculate the % moisture content. Triplicate samples were dried until an asymptote was reached in a weight-loss curve.

The second analysis consisted of a quantitative analysis of the energy content of the components of the fuel. Samples of the component fuels as well as 20, 40, and 60% blends were blended to a fine texture and burned in a bomb calorimeter. Due to the fine texture of the ground wood pellets, samples were wrapped in cellophane prior to burning and the energy content of samples was corrected for the energy in the wrapping material.

## **Ash Analysis**

At the end of the test period, the unit was allowed to return to equilibrium temperature on its own. The secondary temperatures dropped to ambient temperatures over a 48 hour period metal and fire brick liner slowly cooled. The air intake to the primary chamber remained closed and the temperatures in the ash bed remained elevated (several hundred °C for 96 hours. Eventually, the ash bed samples were obtained and stored in air-tight containers under refrigeration. The remaining ash was land filled.

Atomic absorption spectra were generated for two visibly different components of the ash at the slowpoke nuclear reactor in Edmonton Alberta. The first sample resembled a fine grained char with a uniform grey appearance. The second was colored like the first, but contained larger chunks of apparently bony fragments up to 1 cm in length that was of a lighter color. A separate analysis of the nitrogen and phosphate content of the samples was independently carried out at TRU. ( Appendix II)

## **Results**

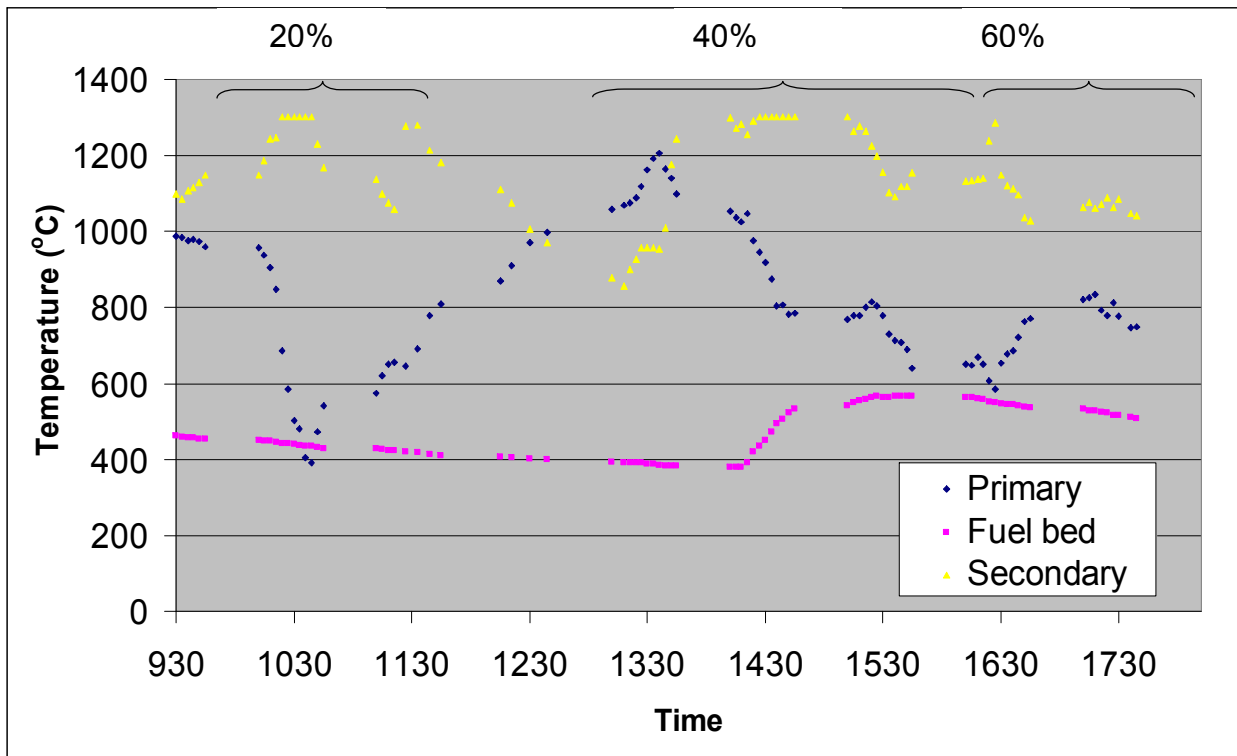
### **Gasifier Performance**

When the entire eight-hour test period is considered, the gasifier unit performed reasonably well. However, the test was not without incident. After approximately 4 hours of operation and 30 minutes into the first emissions testing period, the unit experienced an internal reversal of air flow. This produced an escapement of smoke from the fuel feed orifice and the ash removal drawer. The problem was corrected with little delay by increasing the air flow into the primary combustion chamber, but produced noticeable changes in the temperature profiles and emissions characteristics.

Shortly after the air flow problem was corrected, the heat recovery system experienced a burst pipe. This failure required that the fuel feed be stopped and the emission gases be re-directed out the main stack which new fittings were adapted. A two hour hiatus in the test resulted while the system was brought back up to operational speed following the repairs.

## Temperatures Profiles of the Gasifier

The temperature profiles for the fuel bed, the primary chamber and the secondary chamber (Figure 2) illustrates several aspects of how the gasifier operated during the eight hour test. After reaching operating equilibrium early in the day, the temperature in the fuel bed remained relatively constant, slowly dropping for the first five hours of the test and rising to a higher temperature during the last third of the day. The temperature in the fuel bed seemed less affected by the temperatures in the gases in the chambers and more dependent on the composition of the fuel, reaching a higher temperature when higher proportions of waste material were being consumed.



**Figure 2. Temperature profiles in different chambers over the eight-hour test period.**

The temperatures recorded over the time course of the test illustrate how the system operated while functioning properly, as well as how it recovered from a system failure. During the initial portion of the test during which the 20% waste mixture was consumed, the drafting of the primary chamber was lost and air was drawn in from the secondary. (The most probable cause was a too rapid rate of fuel introduction.) To remedy the problem more oxygen was introduced to the primary chamber and temperatures rose. (At this point the system began functioning less as a gasifier.) This correction was followed by a restoration of the gasification process with a slower fuel feed rate (and a slow decline in the temperature in the primary chamber). During this restoration period the temperatures in the secondary chamber briefly dropped below 850°C.

## Air Emissions

The stack emissions were monitored continuously during three periods of the test burn corresponding to the three fuel mixtures that were being consumed. For clarity, the emissions monitored during each of the periods are reported separately.

## **Oxygen & Carbon Dioxide Levels**

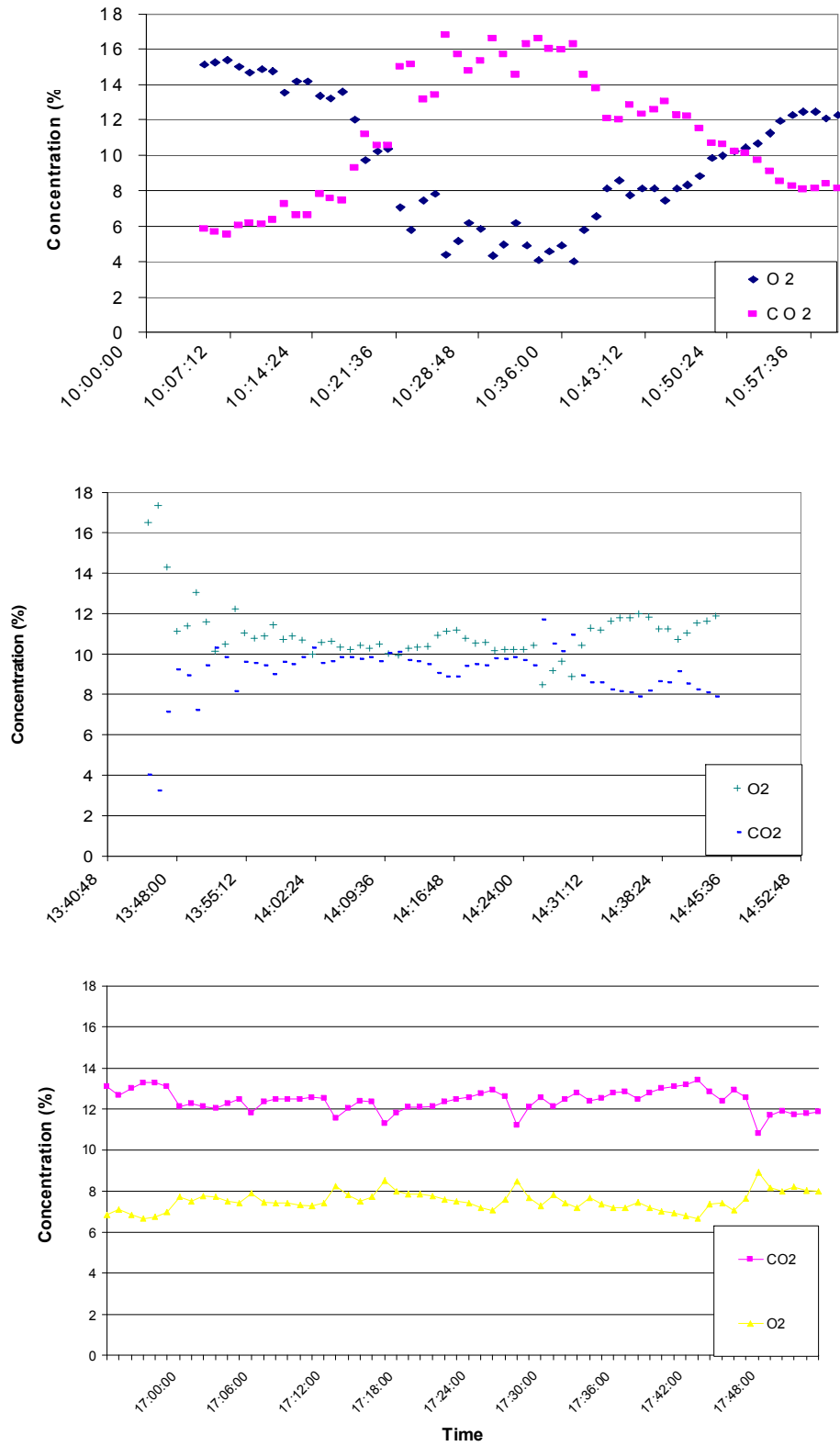
The O<sub>2</sub> and CO<sub>2</sub> profiles (Figure 3) illustrate changes in the performance characteristics of the unit during the three burn periods. During the first monitoring period the changes in the air flow to the primary chamber showed up in the percentage of oxygen monitored in the emissions. As the primary chamber was gradually starved of air, O<sub>2</sub> levels in the stack emissions fell. Corresponding increases came about as CO (the principle fuel gas from the primary chamber) was converted to CO<sub>2</sub> in the secondary with abundant O<sub>2</sub> available. As mentioned during the description of temperature changes in the unit, the increased O<sub>2</sub> concentration in the second half of the first test period came about as a result of flooding the primary with air to compensate for a venting failure.

During the second period of monitoring, air flow into the primary chamber was again progressively restricted in order to promote gasification. This resulted in a decline in the O<sub>2</sub> content of the emission gases. As expected there was a compensatory increase in the CO<sub>2</sub> content of the stack gases. Under the operating conditions established during the second period, these gases in the stack emissions fell into a more-or-less stable balance at about twice the O<sub>2</sub> concentrations present at system failure in the first period. Undoubtedly during this portion of the test the primary chamber was less starved of O<sub>2</sub> than in the first and presumably less gasification was occurring.

The system had clearly stabilized by the time the third emissions monitoring period had begun. The balance of CO<sub>2</sub> and O<sub>2</sub> in the stack emissions remained at these stable levels throughout the test period. Levels of O<sub>2</sub> were intermediate between those recorded in the first and second monitoring periods as was the CO<sub>2</sub> level. Because the percentages of waste in the fuel were increased between each monitoring period, it is unlikely the observed differences were a result of the fuelstock. A more consistent explanation is that the emission changes were the result of manual readjustments to air flow aimed at maintaining temperature.

## **Particulate Matter**

At no time did the emissions exceed the permitted 10% opacity. Quantitative measurement of the stack emissions confirmed very low loadings of emissions with particulates (<0.05 Kg/hr) and very low discharge rates (avg. 43.2 mg/Sm<sup>3</sup> @11% O<sub>2</sub>). This low rate of production was confirmed by the analysis of a parallel emission sample analysed in TRU's labs. Overall, 96% of the particulates were smaller than 10µ in size and 85% were smaller than 2.5µ. These levels are all well within those acceptable for incinerators disposing of municipal waste in BC.



**Figure 3. The comparative profiles for O<sub>2</sub> and CO<sub>2</sub> during the monitoring periods.**

## Other Emission Gases

The concentrations of three main groups of gases were monitored over the three test periods: oxides of Nitrogen (NO<sub>x</sub>); oxides of Sulphur (SO<sub>x</sub>); and Carbon Monoxide (CO). Figure 4 illustrates the changes in emission levels in each of the three monitoring periods.

CO levels were generally very low (see also Table 1 below). CO was detected in emissions mainly during short intervals in the first monitoring period and was associated with the failure and recovery of the airflow in the primary combustion chamber. Since CO is the main gas generated during the gasification process, its appearance in stack emissions during air flow disruption would be expected. As noted however, the peaks were transient and not typical of the unit when it was operating normally. The relatively higher levels of CO correlated with higher percentages of wood pellets in the fuelstock, but this could have been entirely coincidental.

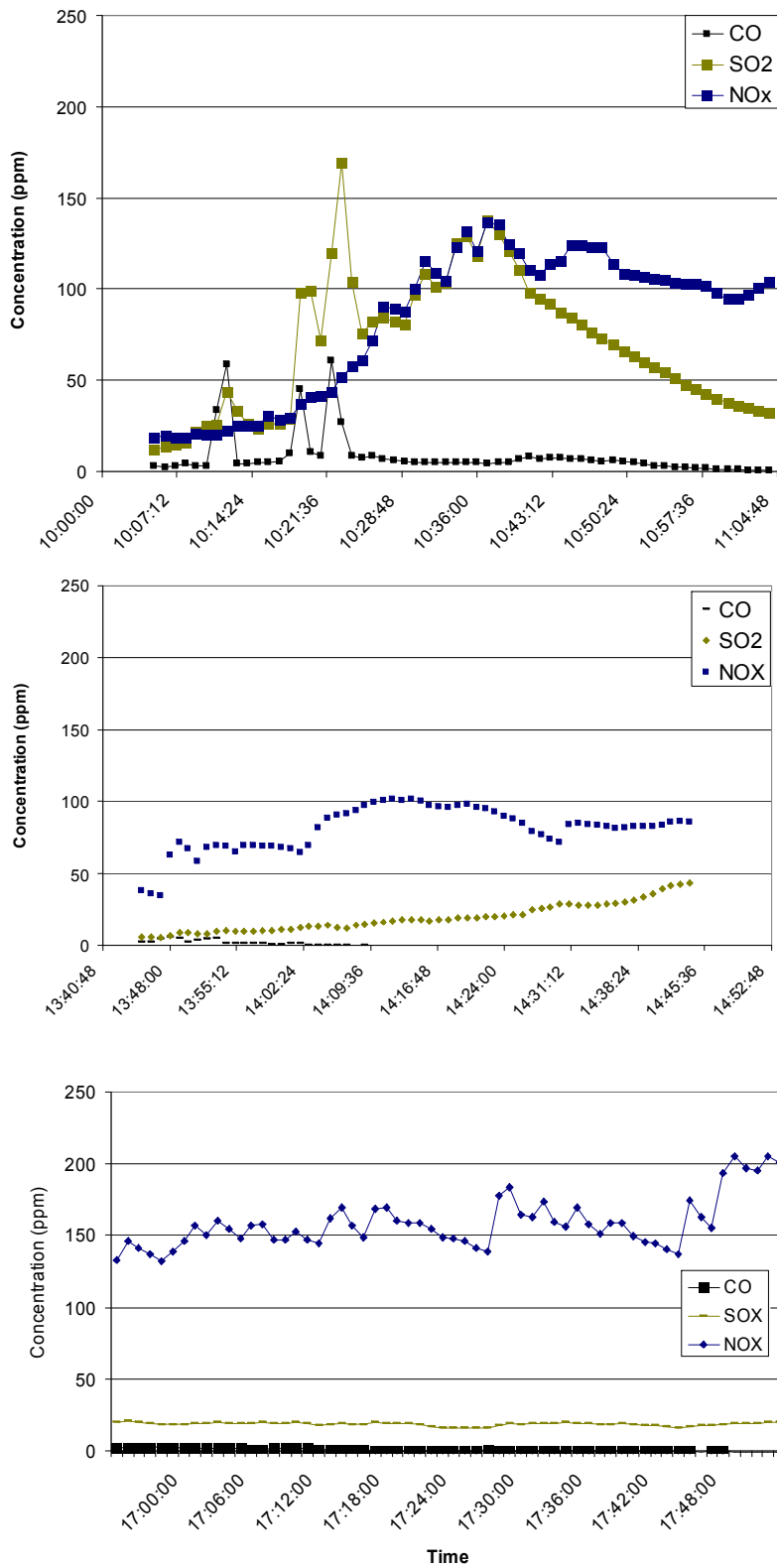
SO<sub>x</sub> emissions were generally very low as well, particularly during the third monitoring period, when the operation of the unit appeared to stabilize. A small increase in SO<sub>x</sub> during the second monitoring period paralleled a slow drop in the operating temperatures of the primary combustion chamber. It is conceivable that the source of the SO<sub>x</sub> could have been the auxiliary natural gas burners in this chamber that may have activated at the lower temperatures. This interpretation is consistent with the observed large spikes in SO<sub>x</sub> that accompanied the rapid drop in primary temperatures in the first monitoring period.

NO<sub>x</sub> emissions showed the greatest variability over the three monitoring periods. Concentrations first increased as the operating temperature of the secondary combustion chamber reached temperatures in excess of 1200 °C and tended to remain at this level (or higher) during the remainder of the test period. When exposed to high temperatures, the air introduced to stabilize combustion processes would naturally produce NO<sub>x</sub>.

Two other quantities were measured to ensure compliance with the air emissions restrictions of the permit from the BC Ministry of the Environment: Chloride gas content (measured as HCl) and Total Hydrocarbons (THC measured as propane equivalents). Table 1 shows the levels of these substances as well as the concentration of CO gas recorded during the three monitoring periods.

**Table 1. Concentrations of rare gases in stack emissions over the course of the test.**

Parameter	Period 1 (10:05- 11:04)	Period 2 (13:35- 14:25)	Period 3 (16:56-17:56)	Average
HCl (mg/Sm <sup>3</sup> )	--	4	16 & 22	14
CO (mg/Sm <sup>3</sup> )	9	<1	1 & 1	3
THC (mg/Sm <sup>3</sup> )	1	1	<1 & <1	<1



**Figure 4. Comparative changes in the concentrations of SOx, NOx, and CO in emissions.**

## Fuel Consumption Rates

The unit that was tested was designed to dispose of plastics. As such, the system was poorly suited to feed the pellet: waste fuel mixture. The system contrived on site (a modified ram feed), the day before the test, did not allow accurate measurements of fuel consumption. However, it is possible to roughly estimate the fuel consumption rates during the testing period (Table 2). Because of mechanical difficulties that introduced delays during the testing periods, these estimated consumption rates must be interpreted cautiously.

**Table 2. The fuel consumption rates during the three monitoring periods of the test.**

Monitoring Period Time Interval	Pellet: Waste Mixture	Mass of Pellets (kg)	Mass of Waste (kg)	Total Mass (kg)	Waste Consumption Rate kg/hr
10:00-11:10 (~1.2 hr)	80:20	308.44	77.11	385.55	65.9
13:25-16:30 (~3.1 hr)	60:40	278.96	185.97	464.93	60.38
16:30-18:00 (~1.5 hr)	40:60	36.29	54.43	90.72	36.2

Over the course of the test, fuel consumption rates were purposefully changed. The reason was that the high fuel feed rates in the initial part of the test was assumed to result in the system failure

## Fuel Characteristics

Because there was no published literature on the nature of slaughterhouse waste as a fuel source, an extensive chemical analysis was performed with two objectives. The first was to estimate the moisture content of the components used in the fuel stock. The second was to estimate the potential energy yield of the fuel. (There was insufficient time or equipment available on site to monitor the amount of heat dumped from the emission gases. Laboratory analyses while more precise can only estimate what is potentially recoverable as heat energy.)

Table 3 shows the comparative moisture content of the components of the fuelstock used in the test as well as the overall values for the mixtures. Wood pellets were found to contain very little moisture (close to the advertised 7% content) while the fat and nervous tissue contained nearly four times that amount. However, despite relatively large differences in the moisture content of the different components of the solid wastes, the total fuel varied only by a few percentage points from one another. One of the main functions of the wood as a fuel

additive was likely the buffering of the moisture content of the fuel, resulting in more even combustion characteristics.

**Table 3. Analyses of moisture and energy content of materials used in the test.**

	Pellet s	Bone Fragment s	Fat & Nervous Tissue	Body Organs	80:20 Fuel Mixture (calc.)	60:40 Fuel Mixture (calc.)	40:60 Fuel Mixture (calc.)
Moisture Content (%)	6.90	7.27	28.00	19.55	8.4	9.9	10.0
Energy Content (kJ/g)	19.4	25.2	29.2	32.8	21.17	23.90	24.70

Table 3 also shows the results of the laboratory analyses of the energy content of the different components of the fuelstock. The most energy -rich animal tissues contain close to 70% more energy than do wood pellets. However when pellets were combined with mixtures of the waste tissues, the energy content of the mixes differed by only 12%. Combining animal tissue with pellets buffered the variation in the energetic content of the fuelstock.

With knowledge of the mass specific energy of the components of the fuel and the rate at which fuel was consumed in the different test periods, it is possible to calculate the rates of energy release and the power generated during the test. From these quantities, it is then also possible to calculate the portion of that energy that would have been used to vaporize the water contained in the fuel itself and the energy used to raise the temperature of the ambient air from 25°C to the temperature in the secondary chamber at 1200°C. The final energy balances for the three tests are shown in Table 4.

Because of the greater rate at which fuel was fed to the primary combustion chamber in the first test period, there was a higher potential amount of power generated, despite using a fuel of relatively lower energetic value. When the energy required to vaporize the water in the fuel and the energy used to raise the temperature of the air in the system is taken into account, there is energy that remains unaccounted for. This unaccounted energy balance likely reflects incompletely combusted fuel. Anecdotally, it was observed that a char remained in the fuel bed after the end of the test and temperatures in excess of 700°C persisted for several days after the delivery of new fuel ceased. Similar results were obtained for the other tests and differences likely reflect vagaries in the actual rates of fuel delivery more than differences in the completeness of fuel consumption.

**Table 4: Actual and potential rates of energy release for the three test periods.**

Period (Fuelstock)	Energy Consumption (GJ/hr)	Potential Power Generated (kW <sub>th</sub> )	Total Energy Potentially Released (kJ)	Energy to Vaporize H <sub>2</sub> O & Heat Exhaust Gas (kJ)	Unaccounted Energy Balance (kJ)
1.17 hr 10:00-11:10 (20% waste)	6.97	1.94 x 10 <sup>3</sup>	8.16 x 10 <sup>6</sup>	6.04 x 10 <sup>6</sup>	2.12 x 10 <sup>6</sup> (26%)
3.08 hr 13:25-16:30 (40% waste)	3.46	9.61 x 10 <sup>2</sup>	10.65 x 10 <sup>6</sup>	7.89 x 10 <sup>6</sup>	2.67x 10 <sup>6</sup> (25.1%)
1.5 hr 16:30-18:00 (60% waste)	1.49	4.13 x 10 <sup>2</sup>	2.24 x 10 <sup>6</sup>	1.58 x 10 <sup>6</sup>	6.65 x 10 <sup>5</sup> (29.7%)

### Ash Analysis

Atomic absorption analysis yielded expected results. The residual ash had relatively high proportions of elemental calcium and phosphate (the inorganic constituents of bone) and of sodium, and potassium (inorganic constituents of muscle). In addition, however, there were significant levels of aluminium (likely a contaminant from the paint used on the exterior of the unit). The very low concentrations in elements (Table 1) was a consequence of high levels of organic matter and nitrogen. Higher levels of levels of carbon and nitrogen could indicate the residual presence of protein or inorganic nitrogen salts and charcoal.

A purified sample of the solid bone fragments analysed at TRU showed that the nitrate content of the residue was 7.92% ± 0.97%. and the phosphate 3.59% ± 0.45%.

**Table 1.** INAA Results for two qualitatively different ash samples.

ID	KD char	1 sigma	KD grey	1 sigma
Al (wt %)	0.030	0.002	11.2	0.3
Na (wt %)	0.014	0.003	2.36	0.1
K (wt %)	0.21	0.01	4.19	0.33
Fe (µg/g)	268	59	37700	900
Mn (µg/g)	227	8	1580	80
V (µg/g)	ND		146	10
As (µg/g)	0.49	0.04	1.35	0.26
Sb (µg/g)	0.12	0.02	0.42	0.06
La (µg/g)	0.11	0.02	21.2	0.7
Cr (µg/g)	ND		181	9
Sc (µg/g)	0.05	0.01	17.2	1.3
U (µg/g)	ND		2.06	0.19
Th (µg/g)	ND		7.98	0.3
Ti (µg/g)	ND		5500	600

## Discussion

The goals of this study were to answer two related questions:

- Can commercially available small gasification units dispose of a blended mixture of pelletized wood and animal waste tissue in an environmentally safe manner?; and
- What is the range of situations, conditions, and waste disposal volumes under which gasification is an economically viable instrument to dispose of slaughterhouse solid waste?

Overall, this study produced some valuable insights into both of these questions.

### Can gasifiers safely dispose of solid waste?

When it operated properly, the unit tested reached high operating temperatures, generated an even supply of readily recoverable heat, and produced stack emissions that were well within what are acceptable provincial standards for municipal waste disposal. For these reasons, it is recommended that gasification technology be taken seriously as an effective waste disposal technology for BC operators.

Despite this conclusion, the unit used for this test would not be categorized as acceptable by the some regulatory agencies. (For example some agencies take a strict definition of the gasification process as one that requires an absolute deficiency of oxygen (and air flow) into the primary chamber.) Thus, although performing well, the design of unit tested might not be approved for waste disposal under some federal guidelines. With this knowledge, as well as what was learned through the functional failures and inadequacies experienced in the field test, some critical recommendations can be made regarding the next stages of testing this technology.

#### Recommendation 1:

When operating smoothly the gasification unit tested produced temperatures in the second combustion chamber that were in excess of those required to destroy BSE prions in exhaust gases. However, with this unit, the temperatures in the fuel bed never reached those needed to destroy agent.

*If gasification (or more accurately partial gasification) units such as the one tested in this study are to be used, either the residual ash has to be re-incinerated, buried, or otherwise properly disposed of. Alternatively, a fuel bed mixer could be added to the system that might ensure that all of the residual char has been exposed to the criterion temperatures for prion destruction.*

#### Recommendation 2:

Although referred to as a gasifier (and when functioning properly the fuel reacted properly in a fuel starved environment), the openness of the system as evidenced during the reversal of air flow during a system failure carried the potential to disperse infected material.

*Because of the potential for dispersing infectious agents, the fuel feed and ash removal compartments should be housed sealed units to prevent escapement were the systems to fail.*

### **Recommendation 3:**

During the testing, a combination of overly aggressive fuel feed rates and overly abrupt declines in both oxygen availability and temperature in the primary chamber contributed to a system failure that could have had led to the dispersal of infected material.

*In order to prevent the appearance of conditions that precipitated the system failure, oxygen and temperature sensors linked to an automated air feed should be engineered into such systems. Even so, a trained operator would need to be available during the hours of operation to deal with the inevitable system failures that will occur.*

### **Recommendation 4:**

The amount of tissue destroyed during the testing period was remarkably small. In part this was due to the small scale of the system tested and the extended shut down period during the test. Even so, several aspects of the system's operation (e.g. stable temperature profiles and gas emission patterns) suggest that it was operating at or above full capacity for most of the day. Recognizing that the unit tested was not designed for the fuelstock that was consumed; under the testing conditions here a maximum of only 1500 kg would have been consumed in 24 hr of continuous operation. (Moderate sized slaughterhouses regularly produce close to 5 times this volume on peak days.)

Gasification excels at efficiently capturing energy from biomass; however, the main goal of this exercise was not the recovery of energy per se, but the destruction of waste. Moreover, it appears as if there would be more than enough energy in the kind of waste that needs to be destroyed that some efficiency could be forfeited and plenty could still be recovered in various ways.

*In the process of scaling up the equipment to handle the anticipated commercial volumes of waste material running the system with a modestly greater availability of oxygen could increase waste consumption, decrease ash build-up, and maintain clean air emissions.*

### **Recommendation 5:**

The mix of wood and animal waste that comprised the fuelstock for this test, although adding to the cost of disposal, appeared to work well: the wood pellets likely evened fluctuations in the moisture and energy content of the fuel, which undoubtedly led to better combustion. Nevertheless, the physical characteristics of the fuel source and the feed system could have been greatly improved.

*Fuel handling has to be a priority in the design and engineering of gasification units to accommodate the volumes of waste tissue that need to be destroyed. The design of the fuel handling system should include mechanisms to produce smaller sizes of bony material to*

*facilitate more complete gasification/combustion. The design should also provide a method to contain the stockpile of animal waste fuel to limit the potential for environmental contamination by flying insects.*

### **Recommendation 6:**

Stack emissions were relatively clean and within the acceptable standards, especially for potentially corrosive gases such as SO<sub>x</sub> and NO<sub>x</sub>. Although officials with the BC Ministry of Environment Air Protection Branch considered them to be acceptable, they expressed concern with regard to the cumulative effects of operating a scaled-up gasification unit continuously within an airshed.

*If a centralized model for disposal using gasification is chosen, engineering may be required to add “scrubbers” to the stack to reduce the environmental impact of continuous low concentration emissions.*

### **Under what conditions would gasifiers be economically feasible?**

While it can be argued that gasification is a technically feasible solution to the disposal of animal waste, an equally relevant issue is whether it is economically feasible and at what scale does the feasibility change. Any economic argument must compare the relative benefits associated with employing a technology with its economic costs. A thoughtful treatment of this issue, as well as a case study, has been written by H.E.M. Stassen and H.A.M. Knoef. 1995) A copy of this article is included as Appendix III. (What follows in this discussion reiterates some of the main points in their article.)

Some of the information needed to carry out an economic assessment as it pertains to slaughterhouse solid waste is available from the chemical analyses of the fuelstock and the calculation of its energy potential content. Even without the detailed analyses however, it was clear that during the test situation the gasification of less than 1000 kg of waste led to the recovery of abundant hot water over an eight hour period. (Indeed, the ability to disperse the excess heat became a challenge during the test!)

Chemical analyses show that the energy content of the fuelstock (whether pure animal waste or pellets and waste mixed) approaches that of charcoal (25,000 kJ/kg)—a fuel that has been shown to be economically viable for commercial gasifiers. Finally, the cleanliness of the gas emissions suggests that opportunities would exist for cogeneration of steam and/or hot water and air turbine-based electrical generation. Given this information, it would be worthwhile developing a predictive model to estimate the total cogeneration capacity of such a unit. Such a model would presume an infinitely accessible supply of a fuel. Such an exercise is beyond the scope of this project.

The capital costs of the equipment necessary to achieve profitable power generation are not insubstantial. Several commercial suppliers have suggested that the cost will scale with the volume of waste that needs to be destroyed, and that the relationship will be roughly linear. (One commercial supplier of gasifier technology not associated with this project suggested a base price of approximately \$200,000 and a cost of \$100,000 increase for every additional 2500 kg of waste processed daily.) As with all technology however, the actual price can easily double, depending on the number and types of sensors and automation involved.

The operational costs of gasifiers can also be appreciable. Although the operational energy costs may be small, the need for qualified and motivated operators is paramount. A complicating factor is that recently it is proving difficult to train and keep highly qualified operators in most trades positions in BC.

Stassen and Knoef have identified the following conditions that must be met for the successful commercialization of small scale gasification technology:

- The technology to be employed should be mature and proven in demonstration and prototype models. Accurate and objective information on the technology, the gasification system and its capabilities, its limitations, and how it compares with competing systems should be available to potential customers.  
(This study can be taken as evidence that such exists for slaughterhouse waste.)
- A local capacity for manufacturing the gasifier system must exist. (This exists in the interior of BC through Westwood Energy and other existing companies.)
- Manufacturers must provide an adequate after-sales service, guarantees and training of operators. Furthermore, labour, with the skills and motivation required for operation of gasifiers, should be available. (The School of trades and technology at Thompson Rivers University is willing to help with training needs.)
- Loan finance should be available for purchasers of approved systems. (The Waste Tissue Initiative may provide resources with regard to this condition.)
- Regulations covering the safety, quality of gas produced, permitted level of noxious emissions and discharges, and other aspects of gasifier operation should be in force. (This study has given provincial authorities a greater level of confidence that gasifiers can safely dispose of the waste containing SRM.)
- Any legal obstacles to the sale of surplus electricity should be removed. (This condition needs to be negotiated.)

### **Recommendation 7:**

The use of gasification technology to economically dispose of slaughterhouse waste will depend most directly on the assurance of a constant supply of fuel (and a fuel management system), a minimization of transportation costs to suppliers of the fuel, reliable labour for the safe operation of the system, an ability to sell excess energy back to a supplier grid.

*All of these conditions for the successful commercialization of a gasifier could be met if:*

- *one (or a small number) centrally located gasifier facility (ies) were constructed near a transportation corridor and in an ecologically acceptable area;*
- *an advance cooperative agreement were struck with slaughterhouse and packing plant operators in a "catchment" area whereby a cost and profit sharing arrangement existed for the sale of excess energy; and*
- *the technology was sized to accommodate the existing cooperative partners as well as room for expansion.*

Other “free enterprise” models for the establishment of a central facility could also work if they fulfilled these conditions.

## **Reference**

Stassen, H.E.M and Knoeff, K.A.M. 1995. Small scale gasification systems. Pp.41-48 in UNDP/World Bank Small Scale gasifier monitoring program-final findings. Energy for Sustainable Development II.(I).

## Analysis of Bone Ash for Phosphate and Nitrate Content Kingsley Donkor (PhD)

### 1. Phosphate content of bone ash

The phosphate content of the bone ash was determined by the technique of Flow Injection Analysis (FIA). In its simplest form, the sample zone is injected into a flowing carrier stream of reagent. As the injected zone moves downstream, the sample solution disperses into the reagent, causing the product to form. A flow-through detector placed downstream records the desired physical parameter such as colorimetric absorbance or fluorescence.

The modern Flow Injection Analysis (FIA) system usually consists of a high quality multichannel peristaltic pump, an injection valve, a coiled reactor, a detector such as a photometric flow cell, and an autosampler. Additional components may include a flow through heater to increase the speed of chemical reactions, columns for sample reduction, debubblers, and filters for particulate removal.

A block diagram of the FIA system is shown in Figure 1.

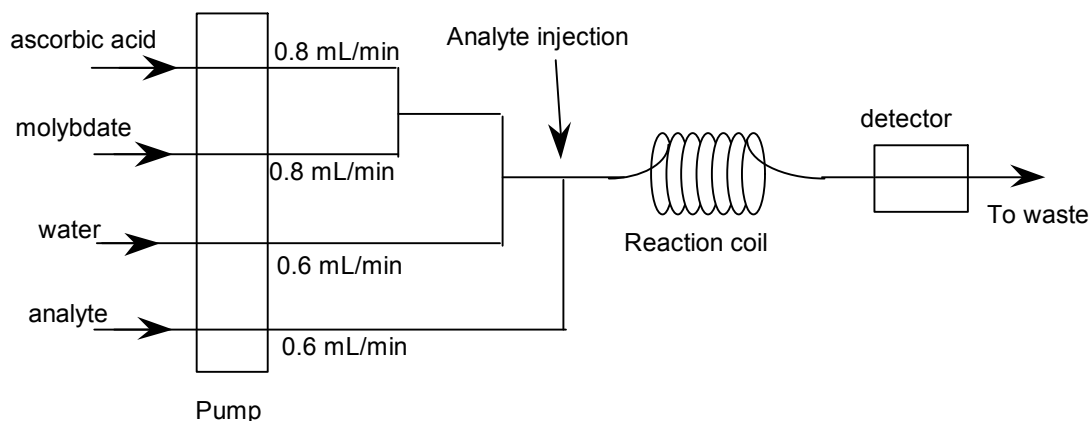
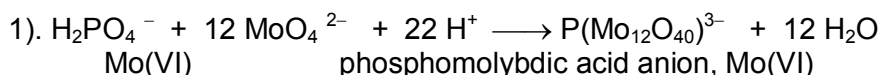


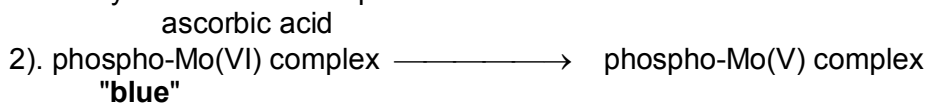
Figure 1. Block schematic of FIA arrangement for this experiment.

The analysis is based upon an old classical "spot-test" colorimetric detection scheme for molybdenum - the "molybdenum blue" test. This test depends upon a two-step process:

The first being the reaction of molybdenum (as molybdate) with phosphorus (as ortho-phosphate) to produce a heteropolyacid, **phosphomolybdic acid**, in which Mo is present as an Mo(VI) oxidation state.



Secondly, the molybdenum in this heteropolyacid can be reduced by a mild reducing agent (here an organic - ascorbic acid) to the Mo(V) oxidation state, yielding an intensely coloured "blue" polymer, the so-called molybdenum blue complex which was monitored at 660 nm.



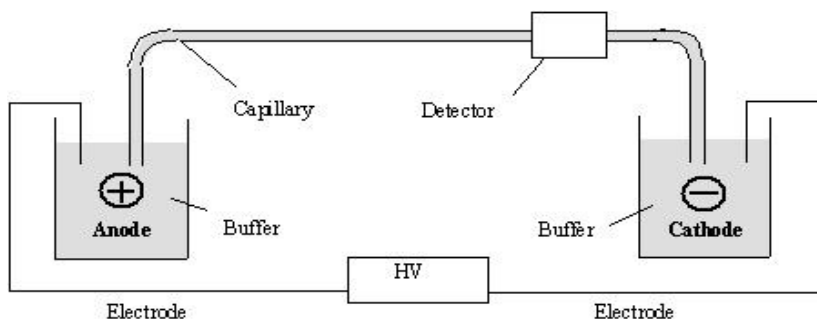
**Result:**

**Using FIA, the phosphate concentration in the bone ash was found to be  $3.59\% \pm 0.45\%$ .**

**2. Nitrate content of bone ash**

The nitrate content of the bone ash was determined by the technique of capillary electrophoresis (CE).

CE is a separation technique in which the analysis take place in narrow-bore capillaries, normally from 25 to 100  $\mu\text{m}$  in internal diameter (ID). A positive (anode) and negative (cathode) electrode are placed in a buffer solution. An electric current is applied to the capillary and this causes the buffer to move towards the cathode. When the sample is injected, it moves through the buffer carrying the ions of interest. The ions are separated based on differing electrophoretic mobilities, which are related to size-to-charge ratios. Once the analyte reaches an ultraviolet detector, it is processed and displayed as an electropherogram. The electropherogram shows peaks, representing different analytes, at different migration times. The area under the peak is proportional to the amount of analyte and the migration time is unique to each compound. A block diagram showing the essential parts of a CE instrument is shown below in Figure 2.



**Result:**

**Using CE, the nitrate concentration in the bone ash was found to be  $7.92\% \pm 0.97\%$ .**