ACRE Final Report

Syngas Monitoring System

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1. PROJECT OVERVIEW

San Juan Bioenergy, LLC (hereafter "SJB") has installed a biomass gasifier designed to burn 10 tons per day, or 4 million BTU per hour, of agricultural waste products (sunflower hulls and dockage) to create renewable energy at its oil seed pressing plant in Dove Creek, Colorado. The biomass gasifier produces a gas (syngas) that is piped to a boiler (80 HP, 1000 lbs of steam/hr) to provide steam for SJB's oil crush process and fuel for a 150 kW syngas powered generator. Syngas monitoring is needed to optimize gasifier performance (Zainal et al., 2002)[1], evaluate feedstock (García-Bacaicoa et al., 2008)[2], and ensure safe and proper operation. The purpose of this project was to develop the capability to sample and analyze the syngas produced by the gasifier. The syngas was tested for particulates and tar to determine its cleanliness and thus suitability for use in powering a 150-500 kW internal combustion generator. The syngas was also tested for permanent gas composition to evaluate gasifier performance (e.g., efficiency, emissions, and economics).

As part of this project, syngas data was analyzed and interpreted with the help of academic institutions and leaders in the industry (e.g., Colorado School of Mines, Argonne National Laboratory, and BTG World). Results of the analysis and interpretations have been provided and will continue to provide additional feedback for the design of an expanded system that would increase the biomass gasifier capacity from 10 tons per day to 100 tons per day. The expanded project (100 tons per day) is expected to offset 8,800 tons of carbon emissions per year (CarbonFund.org) and will save $750,000/yr in natural gas and power cost. The intent is to use agricultural waste and wood waste from area sawmills to provide renewable energy for the SJB facility, other industry, distribution on the local grid, and potentially to produce a liquid fuel.

With appropriately scaled gasification and conversion technology biomass can be converted to usable energy at its location, removing the onerous transportation costs of a very non-dense energy source. Using on-line syngas data, consultant support, and financial support from the ACRE program, SJB has designed, developed and installed a "demonstration" on-line syngas monitoring system. In addition and in this Final Report, information is provided that includes recommendations, analysis and findings about building and operating a comprehensive gas monitoring system. It is the hope of SJB that the presentation of these findings will help advance the energy production industry and benefit other similar projects by providing replicable information.

2. KEY FINDINGS, ANALYSIS AND RECOMMENDATIONS

a. Safety

i. Safety Findings

SJB found that having a personal CO monitor (See Figure 1) was crucial for personnel safety during operation of the gasifier. This was especially true at the beginning of the project during which leaking conditions were detected and remedied. Based on many months of operation, the operator has observed that the gasifier is well designed for safe operation with respect to

explosion and fire hazard; nonetheless precautions for the gasifier's high temperature operation are being addressed in SJB's safety plan.

ii. Safety Analysis

During gasifier startup for a syngas sample collection experiment, a hand held T-40 Rattler CO monitor alarmed, giving a reading of approximately 500-600 ppm. Upon alarm the area was evacuated and the Gasifier Operator (Lennis Arthur), discovered that the gasifier pressure was too high causing a syngas leak through some of the gas pipe plumbing located in the boiler room. The Operator reduced the gasifier pressure and the CO level returned to normal. In another instance, a strong smokey tar or char odor was present in the crate that houses the biomass gasifier. The hand held CO monitor revealed a high level of CO (approx.750 ppm) in the crate. For personnel safety, such high levels should not be sustained for more than ½ hour, according to consultation with Daniel Applegate, Safety Officer at Argonne National Laboratory, Chemical Technology Division. The Gasifier Vendor (Crorey Engineering) was notified of the problem and thereby corrected it by installing higher temperature seals. With this modification, the odor subsided and CO levels in the crate returned to normal. SJB continues to monitor CO levels during gasifier operation for personnel safety.

Knightyme Enterprises, a safety-consulting firm, is creating a general plant safety program for SJB. The biomass gasifier has been identified as an important component of the safety plan, due to its production of high CO gas and its required operation at high temperature.

iii. Safety Recommendations

For the Crorey downdraft gasifier, SJB highly recommends personal CO monitoring (a hand held T-40 Rattler CO monitor) as a first priority for safe operation of the gasifier. SJB also recommends addressing general safety aspects related to the gasifier's high temperature operation and potential for fire. The gasifier operator has identified the gasifier design and operation as intrinsically safe; however, of most concern to the operator is boiler operation using the gasifier's syngas. SJB is in the process of incorporating safety and standard operating procedures to ensure boiler safety when using syngas or natural gas and any precautions or procedures that are required while igniting the boiler, switching from syngas to natural gas (and vice versa), and proper boiler shutdown and startup operations.

b. Syngas Testing

i. Testing Syngas for Particulates and Tar

a. Findings

A total of four particulate and tar analysis experiments were carried out (see Table 1). Two experiments were performed in Fall 2009. Due to operational issues with the gasifier and high tar values, additional experiments were postponed until gasifier operational issues (see Section 3b Project Analysis for further details) were resolved. Two more experiments were performed in Spring 2010. Tar results were found to be lower by approximately two orders of magnitude. This change is thought to be due to

several equipment modifications, including (1) adjustments made to the gasifier's char bed, (2) the length of time that the gasifier was running, (3) the temperature of the char bed at the time of analysis, and (4) the length of time that the slide gate was opened during operation. Particulate results were similar over the four experiments with an increase observed on the last experiment.

Results Summary – Table 1

Experiment #	Particulates (g/m_n^3)	Tar (g/m_n^3)
1	NA	2
2	0.02	14
3	0.07	0.1
4	0.3	0.3
Typical*	0.1 - 1	0.5 - 2
IC Engine**	NA	0.01 - 0.1

*Typical contaminant levels for a wood fueled fixed bed downdraft gasifier.
** Acceptable range for an internal combustion engine.

b. Analysis and Interpretation

The results show that particulate and tar (Experiments #3 & #4) levels of our syngas are on the low-end for a typical fixed bed downdraft gasifier (.5 to 2 g/m_n^3). One of the primary reasons for testing syngas for tar is to determine its suitability for use in an internal combustion (IC) engine. An acceptable range of tar in an IC engine is 10-100 mg/m_n^3. Although the results are higher than this (.1 to 14 g/m_n^3), we are encouraged, as the latest results (0.1 to 0.3 g/m_n^3) were significantly lower and are within one order of magnitude of the acceptable range. Only a minimal amount of syngas cleanup may be required to achieve the acceptable limits.

c. Recommendations

SJB will continue to monitor particulates and tar to ensure that levels remain low. The gasifier continues to be modified for improved performance so SJB will continue to test syngas for changes after system modifications. SJB will also investigate the need for further reduction in tar levels for improved gasifier performance and syngas use in an IC engine generator.

ii. Testing Syngas for Permanent Gas Composition

a. Findings

1-Liter SUMMA canisters were used to collect grab samples of syngas for permanent gas (hydrogen, nitrogen, methane, carbon monoxide, carbon dioxide, and oxygen and argon) analysis. Columbia Analytical Services' (CAS) Air Testing Laboratory, in Simi Valley, California analyzes the canisters for fixed gases.

Results Summary – Table 2

Experiment #	CO_2 %	CO %	H_2 %	CH_4 %	N_2 %
1*	2.03	1.71	1.75	0.312	74.5
2	12.7	12.7	14.2	2.13	55.6
3	11.9	7.41	11.7	1.76	60.9
4	12.7	7.60	7.18	1.29	67.1
Typical**	12.9	18.0	14.2	1.9	53.0

* The first experiment resulted in erroneous results due to an air leak during sampling. The sampling procedure was modified for following experiments.
**Typical levels for a wood fueled fixed bed downdraft gasifier.

b. Analysis and Interpretation

In Experiment #1, the 1-Liter SUMMA canister was placed after the particulate and tar analysis apparatus. It was originally thought that sampling after tar and particulate analysis would minimize canister contamination; however, this experiment produced erroneous results due to an air leak during sampling. According to Crorey Engineering, the data indicated that the gas was not combustible, while SJB observed that the gas did indeed combust and was being used to heat SJB's boiler water at the plant. In Experiment #2, the SUMMA canister was instead placed prior to particulate and tar removal. The CAS Laboratory was contacted to determine if sampling before tar and particulate removal would cause a problem with the gas canister analysis. It was determined that the contaminant levels should be low enough in order to not interfere with the gas analysis. Therefore, in subsequent experiments a pre-cleanup sampling approach was taken.

The syngas results from Experiment #2 appear to be comparable to a typical downdraft gasifier. However, expert consultant, Harrie Knoef of BTG World, indicated that CO content is low (12.7% versus 18.0% - typical) and CH_4 content is high. Higher levels of CO are desirable and may be increased through adjustment of the gasifier's operating conditions (i.e., temperature and air flow). Additional investigation of tar measurements will be required, as Knoef indicated that high methane content indicates production of tars even though SJB's last two tar collection experiments resulted in lower than typical tar results for a downdraft gasifier. In addition, the operator is still observing evidence of tar buildup on gas valves and various other places in the system.

Experiments #3 & 4 with elevated nitrogen levels, show possible evidence of either an air leak during sampling or the gasifier running in a mode that favors combustion over gasification, per consultation with Knoef. Experiment #3 was initially intended for a replicate study. SJB requested two 1-Liter SUMMA canisters from CAS Laboratories and planned to collect two samples, one immediately after the other. CAS Labs shipped clean and under-vacuum canisters; however, one canister showed evidence of a leak and could therefore not be used for sampling. This canister was returned to CAS and a replacement canister was

received by SJB for use in a separate (non-replicate) experiment (#4). Results from Experiment #4 show even higher levels of nitrogen and lower levels of hydrogen. So far, Experiment #2 shows the most reasonable results. It is unclear at this point whether Experiment #3 & 4 results are due to degraded gasifier operation or air leaks during sampling.

c. Recommendations

Knoef recommends an alternate method for sampling syngas for gas composition analysis: "the best way to sample gas is a glass container filled with water. If syngas is replacing all of the water, there cannot be an air leak". SJB will investigate this alternate method for future gas composition sampling.

Knoef noticed a low CO content of the syngas and high methane (CH_4) content. It is desirable to have a higher CO content as this relates to the amount of energy available in the syngas. Once the gasifier is operating more reliably, SJB will continue to analyze the syngas for CO content to determine whether low CO levels are a persistent problem. Knoef also pointed out that the gas composition results indicate high methane content, which is an indicator of tar production. This is also an undesirable result, thus SJB will continue to measure and monitor methane content of the syngas. Methane can be less labor intensive to determine and so for the future SJB would like to investigate correlation of tar measurement results with methane results.

iii. Short Chain Hydrocarbon Analysis

a. Findings, Analysis, and Recommendations

For Experiment #1 a short hydrocarbons (C2-C6) analysis was requested, but due to the previously mentioned sampling error in the section above, these results were not valid. Therefore, for Experiment #2, SJB requested fixed gas results to first determine if the new sampling approach produced reasonable results which would indicate the ability to proceed with C2-C6 analysis. In the meantime, Knoef was consulted who suggested that C2-C6 results were not particularly useful at this stage and those efforts and funds would be better used to focus on the permanent gas and tar results; therefore further requests for C2-C6 analyses have been suspended.

iv. Water in Syngas

a. Findings

SJB is currently not equipped to directly test water in syngas; yet, the operator has observed signs of what appears to be excessive amounts of water in the syngas. The operator regularly drains water that collects in two gas valves that are located just prior to the boiler (See Figure 9).

b. Analysis

It is suspected that as the gasifier temperature rises an increasing amount of water makes its way into the syngas until an unstable flame is observed in the boiler. A system is in place to prevent water from entering the syngas stream but some amount of water is still making it past this system.

c. Recommendations

In order to test the hypothesis that excessive water in the syngas develops as the gasifier temperature rises, one or more of the following options was recommended: (1) An SRI Instrument's gas chromatograph (capable of water detection) may be rented for a period of about one month (or purchased) to determine if the unstable flame condition coincides with higher water levels in the syngas; or (2) Explore the use of an alternate or additional water removal system; or (3) Explore ways to minimize overheating of the gasifier's char bed to see if this reduces the accumulation of water in the gas valves. The latter option may be the best first approach as overheating of the char bed is also the cause of other operational difficulties that must be resolved. We plan to also investigate how water content of the feedstock (sunflower hull pellets) may affect water levels in the syngas.

v. Feedstock

a. Findings, Analysis, and Recommendations

Crucial to this gasification project, was adequate pelletization of SJB's feedstock (sunflower hulls). This proved to be more challenging than anticipated. Based on SJB's experience and delays encountered with feedstock pelletizing issues, SJB recommends that detailed consideration be given to proper feedstock preparation. SJB's experience in pelletization can be a valuable resource to other similar ventures in the State. In SJB's ACRE July 30, 2009 Interim Report pelletizer problems that were encountered were described in detail and how SJB ultimately produced an acceptable pellet for gasification.

vi. Gasifier Operation

b. Findings and Analysis

Multiple gasifier operational and optimization issues were encountered in this project and are discussed throughout this report. The original goal of this project was to use syngas testing to ensure that syngas quality meets the gasifier vendor's claims and to monitor for continued proper operation.

c. Recommendations

SJB highly recommends having a syngas testing plan in place for gasification projects. Syngas testing has proven useful for identifying and resolving gasifier operational issues, and ensuring continued proper operation. Syngas testing has also been useful for evaluating syngas purity for use in an IC engine generator and identifying additional syngas cleanup needs. This project has allowed SJB to better understand and troubleshoot the gasification process and has provided insight into how gas quality relates to gasifier operation. This ACRE grant has afforded SJB the

opportunity to learn about and choose appropriate syngas testing procedures: this knowledge may too be used as a resource for similar ventures in the State.

3. PROJECT DESIGN, ANALYSIS AND RECOMMENDATIONS

a. Project Design

San Juan Bioenergy has designed, constructed and employed a sampling system to test for tar and particulates in syngas produced by a 10 ton per day biomass gasifier. The particulate and tar sampling and analysis system was designed and constructed based on the online technical report, "Sampling and analysis of tar and particles in biomass producer gases"[3]. See the Exhibits section (Figure #2) at the end of this report for a schematic of the sampling system.

In the original proposal, SJB planned to purchase a gas chromatograph for determining gas composition of the syngas. Unexpected operational difficulties with the gasifier created a need to dedicate additional staff time to solving several of the gasifier's operational issues. To account for the unexpected delays and added expense, SJB decided to postpone the purchase of a gas chromatograph and instead send samples off-site for testing. Therefore, gas composition has been determined by collecting 1-Liter grab samples of syngas and sending them to Columbia Analytical Services' (CAS) Air Testing Laboratory in Simi Valley, California where they are analyzed for fixed gases (hydrogen, carbon monoxide, carbon dioxide, methane, nitrogen, oxygen, and argon).

b. Analysis

Following is a description of the major operational difficulties we encountered. Initially, gas testing was delayed because we experienced problems with inadequate pelletization of sunflower hull pellets. This problem was eventually resolved by replacing two smaller pelletizers with a single, larger, more reliable unit.

Throughout Summer 2009, SJB began experiencing issues with gas pump operation: two pumps, one larger (Dresser–Roots) and one smaller (Tuthill), draw gas from the gasifier before it is fully burned in the combustion chamber. The smaller pump worked as designed, which allowed the production of a smaller quantity of gas, but was insufficient to operate the boiler at full power for an extended period of time. In August/September 2009 syngas testing for particulates and tar began and it was discovered that higher than typical levels of tar were present. However, the gasifier vendor claimed very low levels of tar would be produced from the product. SJB experienced operational difficulties with the gasifier whereby it was not able to run for extended periods of time (i.e., more than 3-4 hours). SJB suspected that high tar levels might be related to the gasifier not able to run for long durations to reach its normal steady state of operation. Further particulate and tar measurements were therefore halted until the gasifier was able to run for extended periods of time. Through Fall and Winter of 2009/2010, the gasifier vendor replaced the larger pump with three different designs from a single pump vendor. The pump still did not operate as designed. The same vendor that supplied the small pump, which is working as designed, will now supply the larger pump. The larger pump will be replaced and tested within the next several weeks (May/June 2010). It is expected that this larger pump will allow the syngas to supply the boiler at full load.

SJB also experienced overheating issues in the char bed of the gasifier. Some partially effective adjustments to the char bed were made that allowed somewhat longer run times before the gasifier would overheat and shut down. At this point, additional particulate and tar measurements were completed. These measurements resulted in greatly reduced levels of tar, below what is typical of most downdraft gasifiers and consistent with the vendor's claim of a low tar gasifier system.

Today, some overheating issues are still present and may require further adjustments to the char bed. The gasifier operator suspects that overheating may also be resulting in the presence of excess amounts of water in the syngas, as noted in the key findings section of this report. Water has been observed to accumulate in various gas valves. Other evidence of overheating problems was found by observing the boiler flame. After the gasifier has been running for a few hours and the temperature in the char bed begins to rise, the boiler flame degrades and flickers.

c. Recommendations

Based on experience to date, SJB recommends that the following actions be taken before additional syngas testing resumes: (1) install a larger pump and motor to allow the gasifier to power the boiler at its full capacity; (2) determine and resolve the cause of overheating in the char bed, (3) determine and resolve the cause of what appears to be excess water in the syngas, and (4) attempt to further lower tar levels to acceptable limits for an internal combustion engine. Once these issues have been resolved, SJB will begin re-testing the gas for particulates, tar and fixed gas composition. When the water content of the syngas visually (See Figure 9) reaches a reasonable level testing the gas for water content will begin.

SJB has identified a gas chromatograph made by SRI Instruments that is capable of determining the water content of syngas as well as gas composition. This unit would be available for rental use. Furthermore, when the gasifier is working more optimally SJB hopes to upgrade the syngas analysis system for greater ease of use. This upgrade will also improve accuracy and precision and will enable additional testing needed to ensure that the produced syngas is of the quality needed for use in an internal combustion engine generator.

4. NEXT STEPS/ACTIONS TO BE TAKEN AS A RESULT OF THE PROJECT

a. Continued Testing

Continue to test for gas composition and particulates and tar in order to track further changes and improvements to the gasifier and its operation. To date, SJB has not collected as much data as originally planned due to continuing operational difficulties with the gasifier. Once the gasifier is operating properly on a more consistent basis, SJB plans to continue syngas testing to demonstrate consistent gasifier operation. SJB will also work to refine the precision and accuracy of gas sampling and analysis procedures.

b. Water Capture and Removal

Currently, there is evidence of excessive amounts of water in the syngas. The gasifier vendor and SJB's gasifier operator will continue to work together to determine the cause of water accumulation

in various gas valves. This problem may be resolved by re-designing the system that currently removes water from the syngas. Alternately, it is thought that high char bed temperatures might be contributing to excess water making it past the gasifier's water trap. Once this problem appears to be resolved SJB plans to rent (or possibly purchase) a gas chromatograph (GC) that is designed to determine water content as well as gas composition. Currently, it is premature to move forward with the rental or purchase of a gas chromatograph until several of these operational issues have been resolved. Once a gas chromatograph is in place, it will require gas cleanup mechanisms to remove particulates and tar from the gas stream prior to entering the gas chromatograph. As options to consider, for tar removal, SJB may has looked into employing packed glass wool coupled with a drop in syngas temperature and may employ Swagelok stainless steel in-line particulate filters for particulate removal.

c. Increased Accuracy and Precision of Results

Based on analysis results and experience gained with the current syngas analysis system it is foreseen that improvements to the system will continue to be made to facilitate sample collection and improve on the accuracy and precision of test results. With the experience gained SJB will be better able to address the most pressing needs and find efficient solutions to sampling challenges. Once consistently acceptable results have been achieved for particulates, tar, and gas composition SJB plans to test the syngas for other measures of gas quality as may be required for various other electric power generators. These tests may include testing for short chain hydrocarbons, H_2S concentration, NH_3 concentration, and others.[4]

d. Operational Issues

Most importantly SJB management and SJB's gasifier operator will continue to work with the gasifier vendor to resolve several persistent operational and optimization issues.

5. NOTABLE SUCCESSES AND/OR ACCOMPLISHMENTS

a. Pelletizer

An unexpected challenge with regard to pelletizing the fuel (sunflower hulls, an agricultural waste product) resulted in additional staff time and expense not previously anticipated during the scoping and proposal process. In the July 30, 2009 Interim Report SJB described in detail the pelletizer problems that were encountered and how SJB ultimately produced an acceptable pellet for gasification. Although not an original goal of this project, this was a milestone for the project and can be invaluable systems information to be used by similar ventures in the State. It was vital that this step be resolved before SJB could begin operating the gasifier and thereafter begin syngas sampling or analysis

b. Biomass Gasifier

The 10 ton per day biomass gasifier was installed and is currently operational. The gasifier has produced a combustible syngas that has fueled SJB's boiler used for heat and steam needed for its oil seed pressing plant. Crorey Mechanical Engineering designed and implemented a system that

allows the boiler to operate using either natural gas or syngas from the gasifier. David Petrick, consultant to the project and Research Faculty at Colorado School of Mines, found it encouraging to learn that SJB was producing a combustible syngas with the installed biomass gasifier.

c. Extended Operation of Biomass Gasifier

SJB's 10 ton per day biomass gasifier is the largest gasifier built and installed by Crorey Engineering. The Crorey gasifier is a proprietary design that claims a very clean (low tar) syngas. The syngas must be clean (free of tar) for the planned operation of a 150kW IC engine generator. Crorey Engineering has been making progress towards solving the issues with regard to extended gasifier operation. SJB considers it a milestone that the gasifier is operational with SJB's own pellets and is able to power the boiler. However, the gasifier now typically runs for only approximately 3 to 4 hours before a shutdown occurs. The goal is to be able to run for at least 8 hours and preferably as much as days at a time. SJB is currently working on solutions to the causes of the gasifier's operational problems.

d. Syngas Testing

A sampling apparatus and analysis procedure has been designed, constructed, and employed for particulates, tar, and gas composition. After pump installation, the gasifier vendor will work with SJB to remedy other identified operational issues. SJB is ready to continue syngas sampling and analysis when additional progress has been made on improving gasifier operation. Syngas testing that has been completed to date, has allowed SJB to gain experience and improve upon gas sampling and analysis. Although the particulate and tar analysis experiments are labor intensive each experiment goes smoother. SJB has initiated discussions with various consultants regarding preliminary results. Knoef, of BTG World, has offered the most useful input thus far. The results from gas composition Experiment #2 appear to be the most reliable thus far.

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2. García-Bacaicoa, P., Mastral, J.F., Ceamanos J., Berrueco, C., Serrano, S., 2008. Gasification of biomass/high density polyethylene mixtures in a downdraft gasifier. Bioresource Technology, 99: 5485-5491.

3. Sampling and analysis or tar and particles in biomass producer gases – Technical Report, prepared under CEN BT/TF 143 "Organic contaminants ("tar") in biomass producer gases", July 2005, www.tarweb.net.

4. Martin Machinery, 39425 Excelsior Dr., Latham, MO 65050, www.martinmachinery.com: specifications for electrical generators.

FIGURES

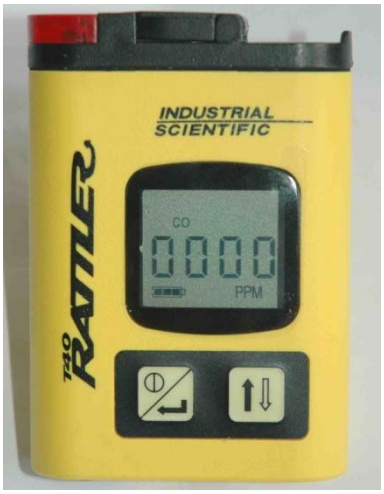


Figure 1. Carbon monoxide personal safety monitor.

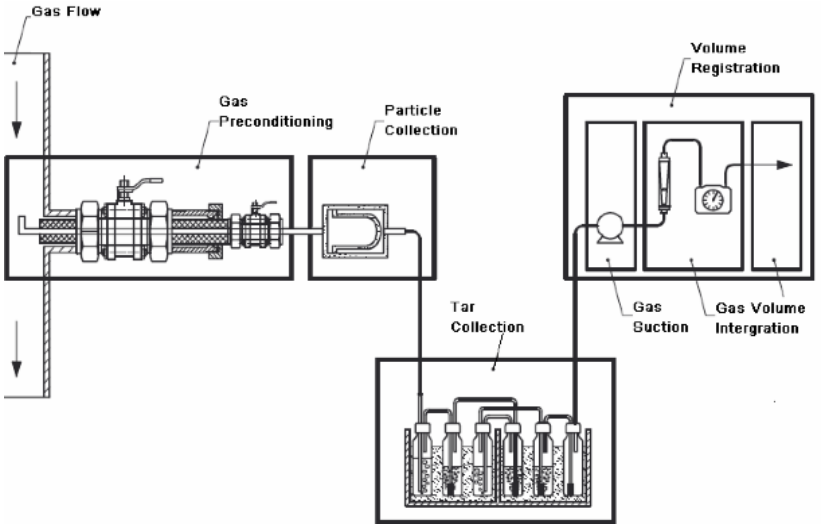


Figure 2. Schematic of particulate and tar collection system.

Figure 3. Impingers used for tar collection.

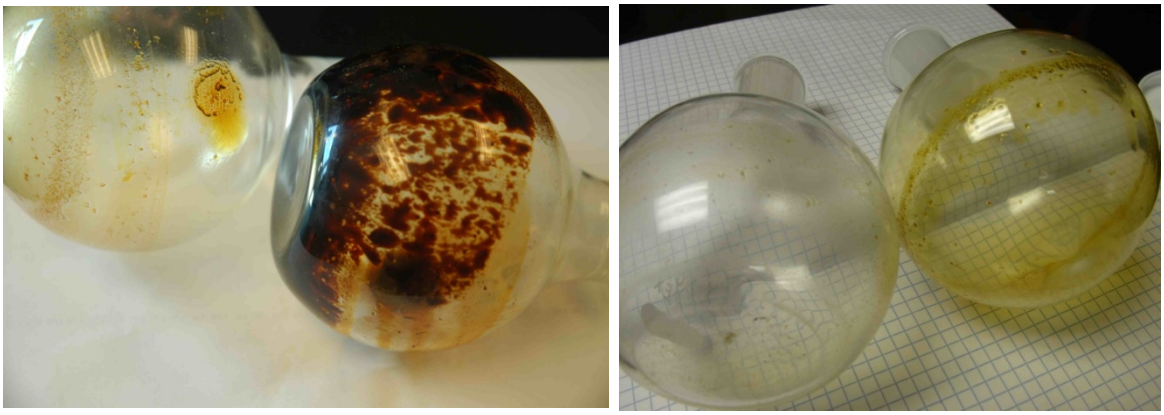
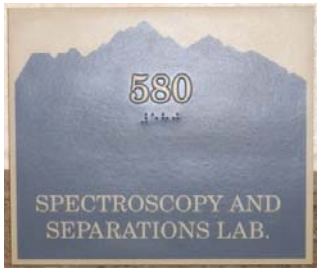


Figure 4. Tar collected from experiments #1 and #2 (left) and experiments #3 and #4 (right).



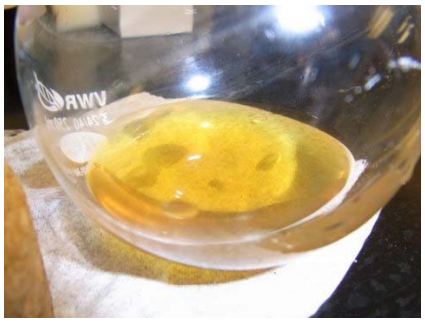


Figure 5. Gravimetric tar analysis performed at Fort Lewis College, Durango, CO.

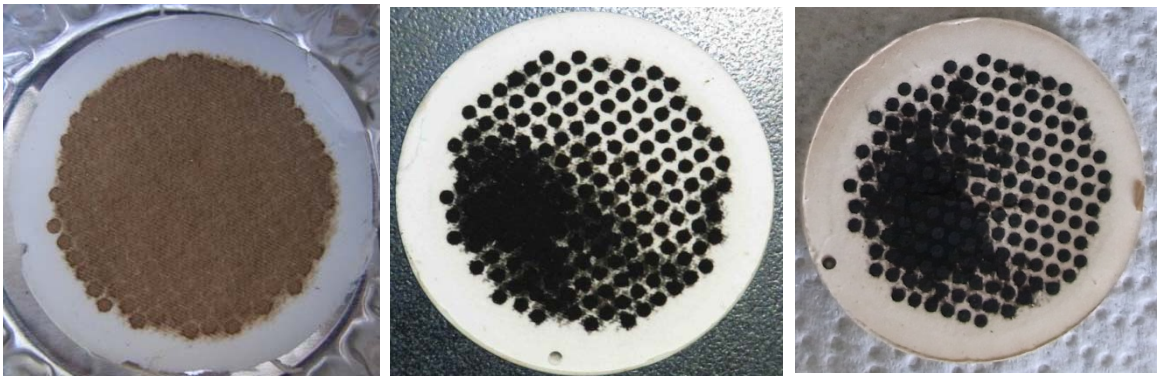


Figure 6. Particulate collection from experiments #2, 3, and 4 (left to right).

Figure 7. Particulate filter holder.

Figure 8. 1-L SUMMA canister for permanent gas composition.

Figure 9. Mr. Arthur (gasifier operator) examining water collected from a gas valve and close up of water (right).