Anaerobic Digestion at Morrisville State College: Internal Combustion Engine Teardown and Evaluation

A Case Study By
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Based on Engine Analysis by
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The anaerobic digester project at Morrisville State College (MSC) involves a heated, hard-top plug-flow system that is intended to treat organic waste generated on the college's dairy complex (system sized to treat manure from around 400 milking cows) as well as turn out biogas (about 60% methane) which is in turn used to generate heat and power from a 50-kW MAN internal combustion engine (ICE). This case study is intended to document the condition of the ICE after it was in operation for 27,858 hours (unit was first utilized on 28 February 2007 and was taken out of service on December 7, 2010). The generator driven by the ICE produced 1,109,600 kW-hr of electricity before it was replaced by a new unit. During its operation, the engine ran an average of 23.2 hours a day. On average, oil changes (which included 41) were done every 680 hours. After teardown and evaluation, the engine will be reconditioned and set aside as a stand-by unit.

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1. Anaerobic Digestion Overview

Digester Type:	Plug-flow
Digester Designer:	David Palmer, Cow Power
Influent:	Raw manure
Stall Bedding Material:	Sawdust
Number of Cows (design):	400 milking cows
Tank:	Two sides, each with two chambers
Tank Dimensions (width, length, height):	37'x90'x12'
Cover Material:	Hard-top
Design Temperature:	98°F
Estimated Total Loading Rate:	10,000 gallons/day
Treatment Volume:	249,000 gallons
Estimated Hydraulic Retention Time:	25 days
Solid-liquid Separator:	None
Biogas Utilization:	MAN internal combustion engine
Carbon Credits Sold/Accumulated:	No
Monitoring of Results:	Ongoing

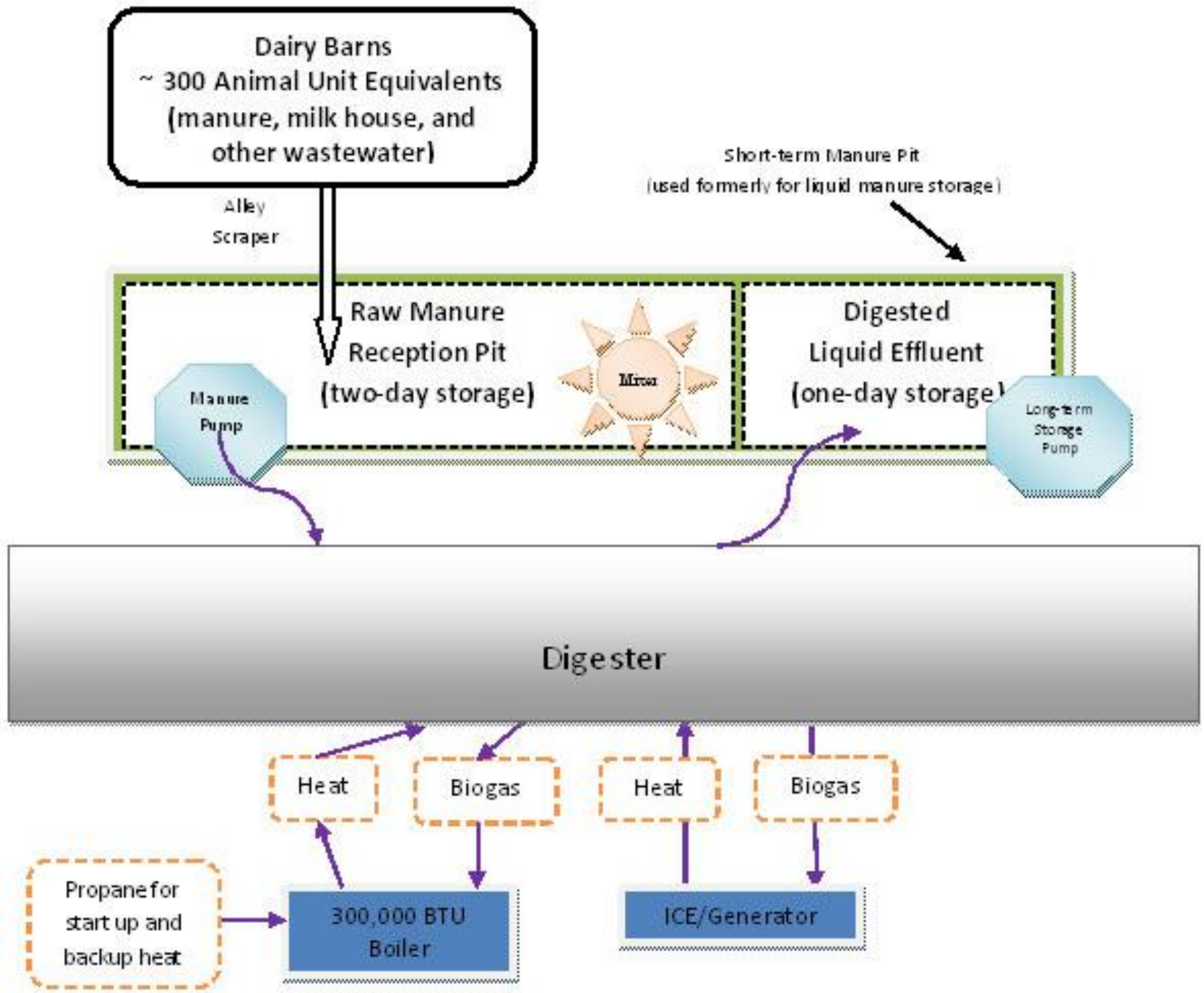
2. Justification for the Digester

The anaerobic digester at Morrisville State College (MSC) is intended to treat dairy manure (generated at the free-stall dairy complex) and other organic waste produced on campus and to use the generated biogas to run a combined heat and power (CHP) generation system. Other objectives included the collection of data on the various components of the system; the analysis of the collected data and the reporting of results; the utilization of the project for demonstration purposes; and the use of the facility within pertinent educational programs offered by MSC.

3. Digester System Description

The plug-flow, hard-top digester at MSC is a rectangular, in-ground concrete tank consisting of two sides (north and south) separated by a concrete wall. Each of the two sides of the digester include another wall that separates the digester tank from a smaller grit chamber where the primary heat exchangers are located for heating the influent waste stream. The bigger chamber on each side of the digester includes a smaller heat exchanger (a heat maintenance loop) to maintain the temperature at an optimum mesophilic condition of about 98^{0}F. The hard-top of the digester is constructed of flat pre-cast concrete planks covered with concrete, insulation, and earth. The digester is covered on the inside with a coating of coal tar epoxy, a layer of polyurethane, and a coating of poly-urea (applied to the ceiling of the digester as well as the inside walls of both chambers to a level of about a couple of feet below the liquid line in the tank) in order to provide a biogas-tight tank. It is insulated on the outside with a layer of polyurethane (to maintain temperature) and a coating of poly-urea (to protect the insulation from UV light damage during construction). The design allows for a maximum of 15" of water column pressure to be developed within each of the two sides of the digester. This precludes the need to compress the biogas before feeding to the internal combustion engine.

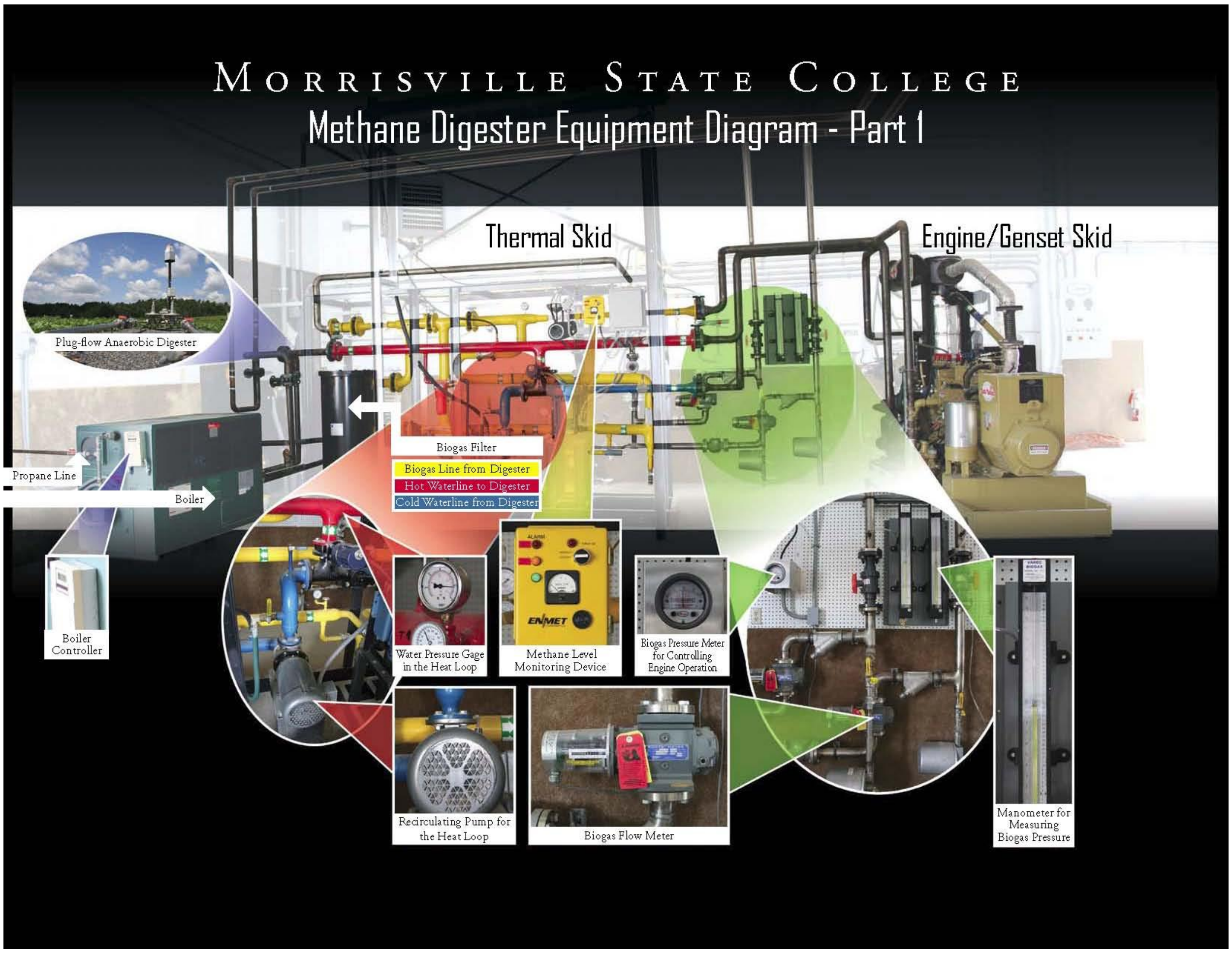
The manure from the dairy complex is mixed before being pumped to the influent manifold of the digester where the flow is distributed equally to the two parallel digesters. As manure is displaced in the two sides of the digester, it flows to the effluent chamber where it gets conveyed to the effluent compartment of the manure reception pit before being pumped to the long-term storage or loaded onto a tanker for spreading on agricultural fields.



Complete engine and gas handling skids that meet the specifications of the design were procured from Martin Machinery (GenTec) and factory-installed (the systems were put together with compatible equipment and controls thereby reducing on-farm hassles).

4. Biogas Utilization

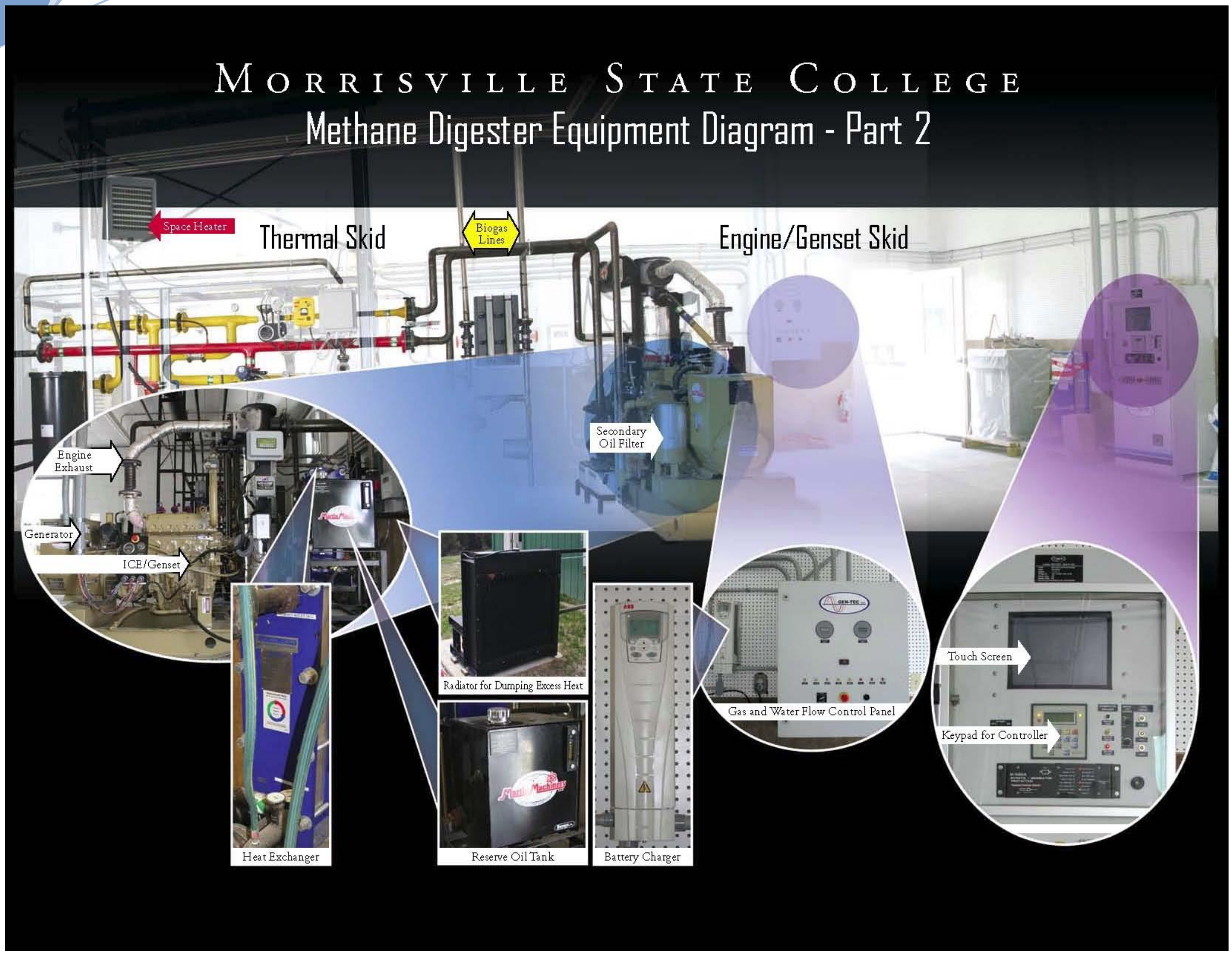
Biogas is collected from the two sides of the digester and fed to an internal combustion engine (ICE) located in the equipment (or CHP) building. The engine (MAN) is attached to a 50-kW generator. Hot water from the engine is used to maintain the digester temperature and for heating a nearby system that is being used to conduct applied research on growing algae for biodiesel production. A radiator located outside the equipment building is used to release the excess heat. A 300,000-Btu/hr output boiler system is also installed within the CHP to be used to heat the digester during the startup phase as well as when the ICE is down. The boiler was acquired from Performance Engineering Group of Livonia, MI, as a research donation. Stainless steel biogas lines connect the gas chambers within the two sides of the digester to the CHP building. A flare system is also installed to burn excess biogas or the generated biogas when the ICE is down (the flare mount and gas line supports are located on the top of the digester's concrete tank).



The ICE utilized biogas at an average rate of 23,518 ft^3/day (about 82.9 ft^3/lactating cow equivalent/day). The biogas consists of methane (about 60%), carbon dioxide (about 40%), a small amount of sulfide compounds (around 1,500 ppm), and other trace gases. On average, the generator electrical output was 40.2 kW which corresponds to an annual electricity production of 340,868 kW.hr/year.

5. Internal Combustion Engine (ICE) Operation

The ICE which is part of the combined heat and power (CHP) generation system was installed in the equipment building was in operation from 28 February 2007 to 7 December 2011 (except for six months



when the system was down from 17 December 2008 to 12 June 2009). Over the forty months of engine operation, a daily average of 23,518 ft^3 of the generated biogas from the digester was used for electric power generation. During the period, the ICE/generator set ran an average of 23.2 hours/day and an average electrical output of 934 kW.hr/day was measured. Details of system operation are available online as explained in the last section of this document.

Other than for a short period (around March 17, 2007) when the system was shutting down several times a day (and the six months when the system was down for repairs), the ICE ran mostly non-stop except for 41 oil changes that took place on average every 680 hours. The system was in operation for 27,858 hours. The engine is being reconditioned and will be set aside as a stand-by unit. A new ICE was installed by a technician from Martin Machinery. Swapping the engines took two days and the new unit was started on Friday - December 10, 2010.

Existing economic information on the system are available in a separate case study and include the initial capital costs and the potential savings in electric energy costs due to the installation of the system.

6. ICE Evaluation Results

As stated earlier, the ICE was taken out of service on 7 December 2010 to be evaluated and then reconditioned for use as a backup engine. The ICE was brought to the Automotive Department's laboratories for disassembly and evaluation. The following were a list of questions that needed to be addressed as part of the evaluation of the ICE after operating on biogas for 27,858 hours:

- Has the engine exhibited normal wear over its operation cycle?
- Has the use of methane as a fuel contributed to excessive internal engine wear?
- What recommendations on additional maintenance can be drawn from this evaluation?
- Will this engine require above normal reconditioning procedures to utilize it as a back-up unit?

6.1. *Visual inspection*

Visual inspection found the external engine case to be sound and free from oil and coolant leaks with no signs of overheating. The engine did not have low oil pressure and was running normally at the time of removal. No compression test was conducted prior to removal but the engine was running normally with no complaints of loss of power or misfiring.

6.2. *Inspection of external manifold, intake, and exhaust*

All manifolds gasket surfaces and bolt torque seemed normal for an engine of this type and no signs of leakage or corrosion of gasket material were found. The exhaust manifold looked normal with no signs of overheating or discoloration. Normal exhausts carbon build-up was observed in the exhaust ports and runners. Intake gasket was free of corrosion and seemed intact. However, excessive amounts of black greasy carbon deposits were observed in the main intake runner and were found on the walls of each intake runner up to the intake port of each cylinder. This could be due to the type of fuel being used. Deposits on intake runners are normal in internal combustion engines but this was above the normal levels indicating a potential problem that could result in engine mechanical damage such as sticking valves resulting in compression loss. Excessive carbon can also result in engine piston deposits that could increase compression and reduce efficacy. Engine damage can result from large amounts of carbon ingested during the normal engine cycle resulting in internal combustion engine damage.

View of the black greasy carbon deposits observed in the main intake runner.

Another image of the heavy intake deposits.

6.3. Inspection of water pump

The water pump assembly was removed from the front of the engine. The gasket surface was found normal with only light corrosion and no leaks. The internal engine coolant passage was found to have rust and corrosion, an indication of lack of corrosion protectors in the coolant. Water was found to be the main coolant and was not mixed with any other product. This could over time, result in internal engine component damage resulting in coolant loss and overheating. Radiator passages could also plug resulting in engine overheat.

View of the coolant passage of the water pump showing rust and corrosion.

6.4. Upper engine evaluation and assessment

The valve cover was removed and found to be torqued correctly with no sign of gasket failure. The inside of the valve cover was clean with no oil deposits, carbon, or buildup of any kind. Overall, all internal engine components were found to be incredibly clean for an engine with this many hours of operation (27,858 hours). On the other hand, heavy white carbon deposits were observed on all combustion chamber surfaces and valve faces. Normal seat and valve face wear was also found. The valve to guide clearance was normal and within specifications not needing special machine processes or replacement of parts for continued service. The valves could be cleaned and re-surfaced and then put back into service. White carbon deposits may be due to the fuel type (biogas) and the continued operation at low engine coolant temperatures. This could result in higher than normal compression ratios resulting in poor engine performance and potential mechanical failure.

Picture showing clean valve cover and internal engine components.

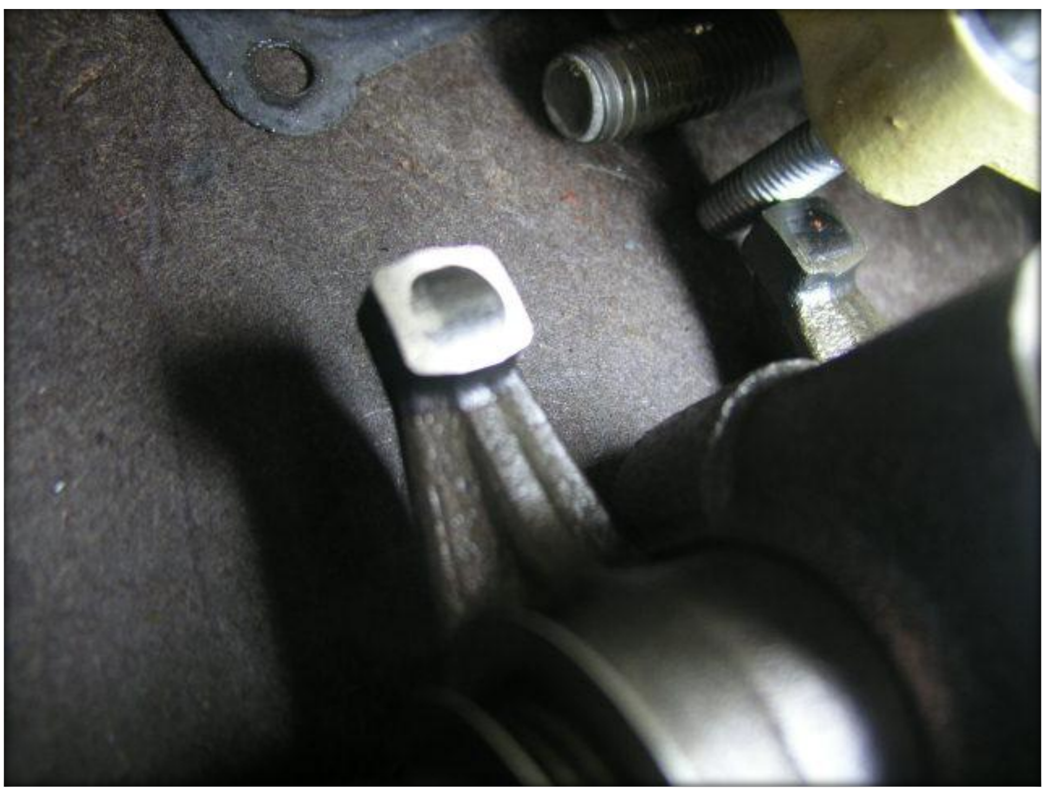
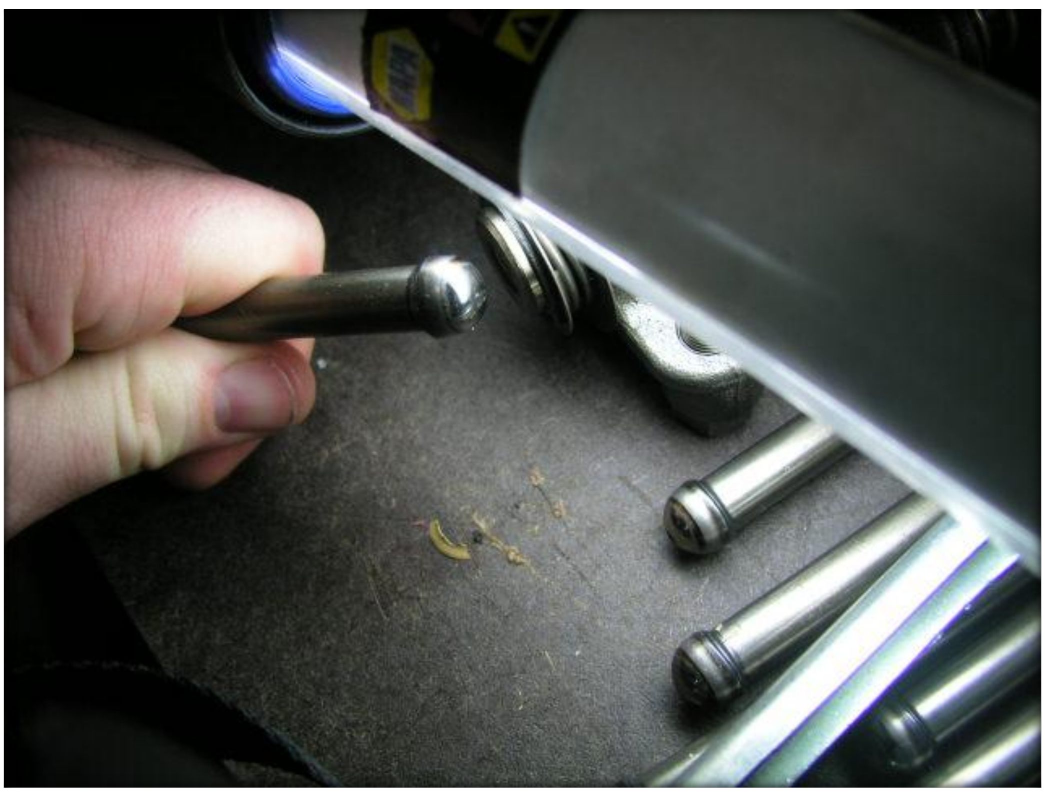


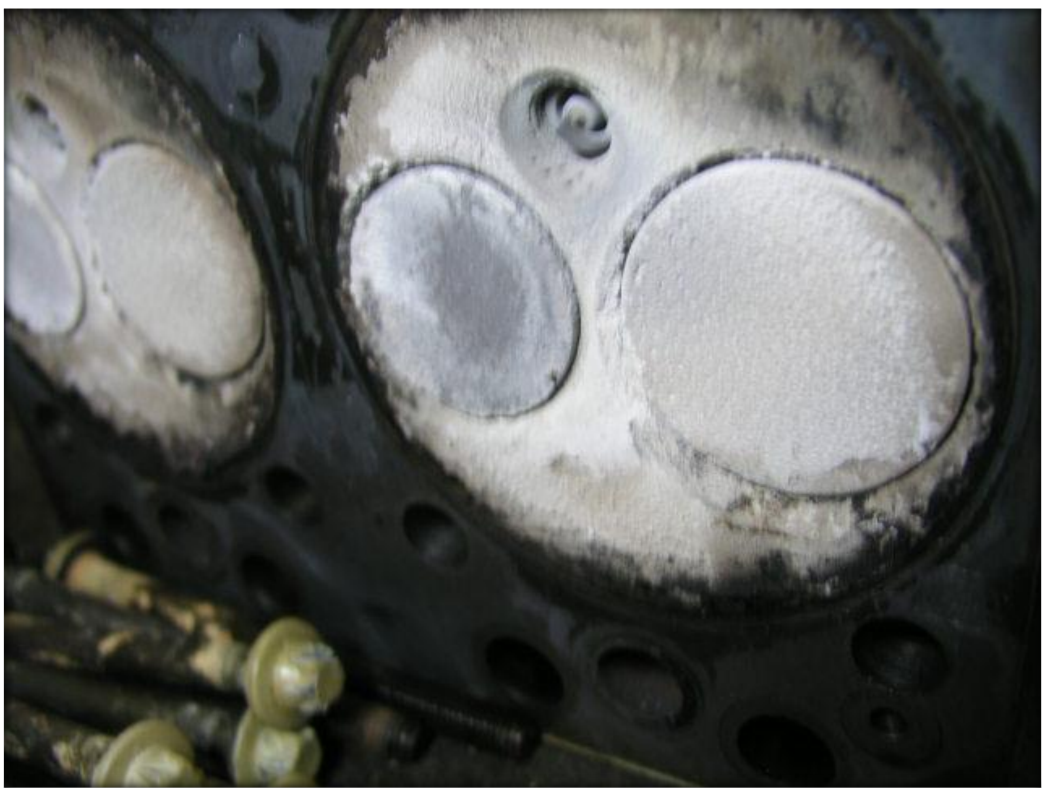
Image showing very light wear on rocker arm pivot.

Image showing no excessive wear on any valve train related parts.



Another view of pushrod pivot showing very little wear.

A picture of the cylinder head assembly showing no internal engine oil deposits or sludge build-up.



A view of the carbon deposits observed on valve faces.

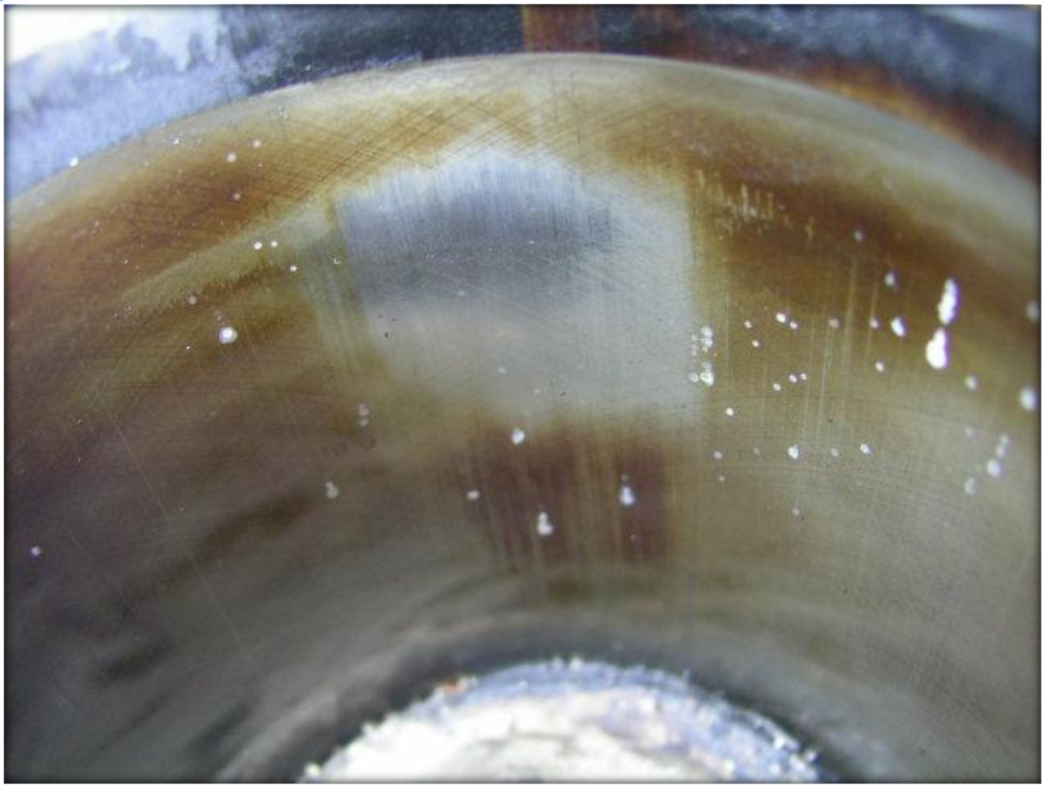
6.5. Lower engine evaluation and assessment

Heavy white deposits were observed on all piston faces, including some having large pieces flaking off that could be a potential for mechanical failure. Deposits could be contributed to fuel usage or lower engine operating temperatures.

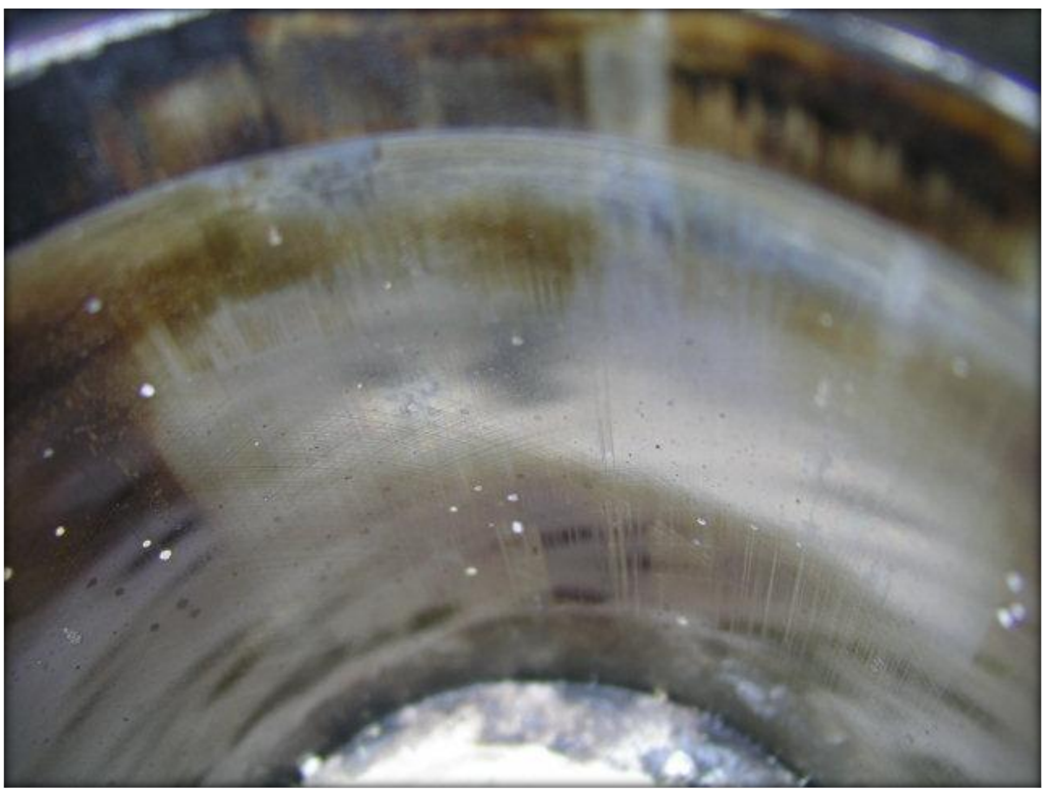
A view of the heavy white deposits observed on the faces of all pistons.

Glazing oil deposits on cylinder walls showing some oil burning during combustion suggest possible oil ring failure. This type of oil glazing is normal for an engine operating for this many hours (the factory cross hatch machine pattern is still visible indicating very minimum wear on cylinder walls). A large carbon ridge was found above ring travel at the top of the cylinder bore but no cylinder wear ridge was found, indicating that the cylinders require minimal machine work for re-service.

Overall, no excessive cylinder wall wear was observed but some vertical scratches were found on cylinder walls which could be due to hard carbon dragging above the number one compression ring. This is due to large amounts of carbon buildup on piston land surface above the compression rings (light engine machining would be required to repair this condition). The cylinder walls were straight and free of excessive taper and out of round (no cracks or abnormal wear was observed and the condition of all parts are considered serviceable). The cylinder decks and head surfaces were flat and free of warping and cracking. As such, no machine work will be required for re-service.



A typical view of the cylinder walls.



The clean patch shown in picture was wiped clean to see cross hatch.

6.6. Lower engine components

Engine oil pan was free of particulates or excessive oil sludge buildup. Gasket and seals were normal with no signs of excessive wear or leaking. The cleanliness of all internal components indicates a well maintained engine with good oil quality.

Oil pickup was free of restrictions and sludge with no abnormal conditions. Main and rod bearing surfaces were normal with no signs of excessive wear. Bearing material did show signs of normal wear based on the hours of operation. No machining would be necessary to reuse the crankshaft rods or other rotating assembly parts. Piston skirts show normal wear and could be reused if needed but would recommend piston replacement.

7. Summary of Analysis and Recommendations

7.1. Overall condition of ICE

This engine with minimal machine process (such as a valve job and cylinder wall reconditioning) could easily be put back into service. The cleanliness of the internal components is outstanding in regard to the lack of normal oil sludge. The carbon buildup in the combustion chamber is alarming as is the buildup found in the intake runner. This could result in mechanical failure and should be addressed. It is recommended that a particulate filter (or screen) is installed at the intake runner to reduce the likelihood that carbon can enter the intake valve area. It is also recommended that a combustion chamber cleaning process is instated as a maintenance procedure. Monitoring engine coolant temperatures should be considered in order to ensure proper coolant temperatures which will help reduce combustion chamber build up. Engine coolant usage should include corrosion preventer. Overall, the condition of the engine is excellent with no abnormal engine component failures.

7.2. Recommendations

Based on the evaluation of the ICE, it is obvious that the engine exhibited normal wear over its operation cycle. As for using methane as a fuel and its potential contribution to excessive internal engine wear, it was clear that some combustion chamber carbon build-up existed but without any associated mechanical problems. The recommendations on additional maintenance that can be drawn from this evaluation include the usage of combustion chamber cleaning additives and intake particulate trap as well as the addition of corrosion preventer to the engine coolant. Finally, it is clear from the evaluation that the engine will not require above-normal reconditioning procedures to utilize it as a back-up unit (i.e., this should be a normal re-buildable unit).

8. Additional and Contact Information

A website on the methane digester and pertinent renewable energy projects is maintained under Morrisville State College's main page. The website is available under the "Alternative Energy Projects" link accessible from the "Technology" tab which may be accessed from the home page of the college's website at www.morrisville.edu. The main page on "Alternative Energy Projects" can also be accessed directly using the following address: www.morrisville.edu/alternativeenergy/default.aspx. In addition, two slideshows were developed to present overviews of digester construction and operation. Finally, an "adobe Flash" show was developed to conceptually highlight the process of anaerobic digestion. These links may be accessed online at www.morrisville.edu/alternativeenergy/methanedigester.aspx.

For additional questions, please contact any of these individuals:

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