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Propane Tests at Chesapeake Building

by

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List of Abbreviations

CFM	Cubic Feet per Minute
CHP	Cooling, Heating and Power
DAS	Data Acquisition System
EDAC	Engine Driven Air Conditioner
HHV	Higher Heating Value
LHV	Lower Heating Value
MT	Microturbine
RTU	Roof Top Unit
sCFM	Standard Cubic Feet per Minute

1 Abstract

Two CHP systems at the University of Maryland Campus, originally operated on natural gas were converted to propane through the addition of two on-site propane storage tanks and some additional gas piping. Minor modifications were carried out to the prime movers in the two systems – one a set of engine driven air conditioning (EDAC) units and the other a 60kW microturbine. These modifications and the change of fuels had no impact on the energy consumption and performance of the EDAC units, but slightly reduced the efficiency of the microturbine at higher loads. These results show that even in the relatively complex CHP systems the switch from natural gas to propane will not cause major changes in operating characteristics or performance.

2 Objective

The objective of this study is to demonstrate the use of propane in advanced CHP (Cooling, Heating and Power) systems for buildings at the University of Maryland, College Park where test equipment has been installed in the Chesapeake Building on campus. The natural gas fuel that the systems currently operate on was replaced over the testing period with a propane system, with the propane stored on-site.

The program will demonstrate the CHP system's fuel flexibility by converting it from natural gas to propane fuel, and show the difference between the equipment/system performance operating on propane and natural gas.

3 Existing CHP Systems

3.1 Introduction

Many DG technologies are capable of operating on more than one fuel – not only does this provide the consumer with flexibility for a choice between grid electricity and on-site generation but also between fuels for the DG prime mover. Natural gas has an extensive piped distribution system and is the most common fuel chosen for DG technology but there are other options that can be more suitable for customers either not willing to pay for the capital investment in piping infrastructure or wanting to not remain tied to one gas utility.

The Chesapeake building is an administrative office building situated on the University of Maryland, College Park campus. It was built in a relatively remote location – on the edge of a very large university campus. The remote location helps to reinforce and demonstrate the idea of distributed on-site power generation. The building has four floors totaling 52,700 ft² of floor space and two air conditioning zones each consisting of two floors.

There are 2 CHP systems currently installed in the Chesapeake Building in its role as a demonstration and test center for Cooling, Heating and Power equipment. In addition to the physical systems composed of CHP equipment, an extensive data acquisition system, advanced control systems and advanced sensor network have also been added. These

systems have been used to demonstrate and test the application of CHP in a real working building. The results of these characterizations have been discussed in several technical papers while the system ran on natural gas.

3.2 CHP System 1

CHP system 1 integrates with the existing Roof Top Unit 1 (RTU1). Figure 1 shows the components of the CHP system 1 along with the associated energy flows. The system consists of 2 natural gas engine driven air conditioning (EDAC) units to provide cooling, which is delivered to RTU1 using a direct expansion refrigerant coil inserted into the mixed air chamber before the existing RTU coil. Heat is recovered both from the engine jacket water circulating throughout the engines in a liquid-to-liquid heat exchanger and also from the exhaust gases from both engines using air-to-water heat exchangers located between the engines. The heat streams from both engines are used to raise the temperature of a 50:50 water/glycol fluid in a pumped heat recovery loop. The heated fluid is delivered to the regeneration side of the liquid desiccant system to raise the temperature of the liquid working fluid – an aqueous lithium chloride solution.

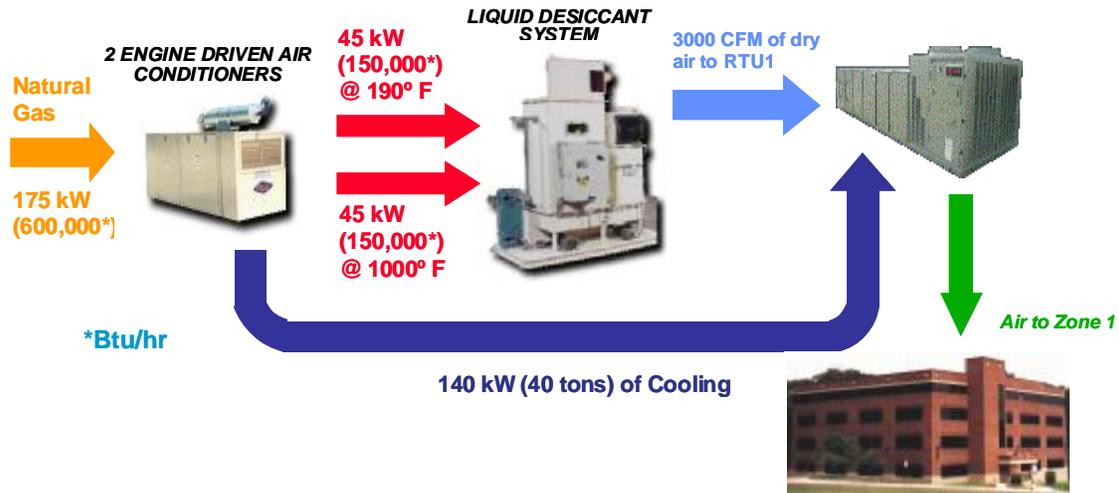


Figure 1: Microturbine Based CHP System 2

3.3 CHP System 2

CHP System 2 integrates with the existing Roof Top Unit 2 (RTU2). Figure 2 shows the components of the CHP system 2 along with their energy flows. The installed microturbine is a Capstone Model C60 high-pressure natural gas unit. The microturbine is installed in a grid-connected mode parallel to the building's 480 volt 60 Hz grid service. The unit has an external fuel gas compressor that compresses the natural gas from 5.5 inches water column up to 90 psig, which is then regulated down in a traditional gas regulator to 75 psig for the microturbine operating on natural gas. The absorption chiller is a Broad 20-ton single-effect lithium bromide water absorption chiller that is designed to use the exhaust gas of the microturbine directly as its heat input source. The absorption chiller is used to provide chilled water that is delivered directly to the existing RTU2 using a chilled water coil inserted in the air stream directly before the original expansion coil. The exhaust of the absorption chiller is used to regenerate the solid

desiccant system. The long duct to the desiccant unit on the roof is a significant source of heat loss in the system to the environment (indicated on Figure 2 as a 20kW loss). This loss is a result of reaching the weight restriction of the roof and having to split CHP system 2 between the ground floor and the roof.

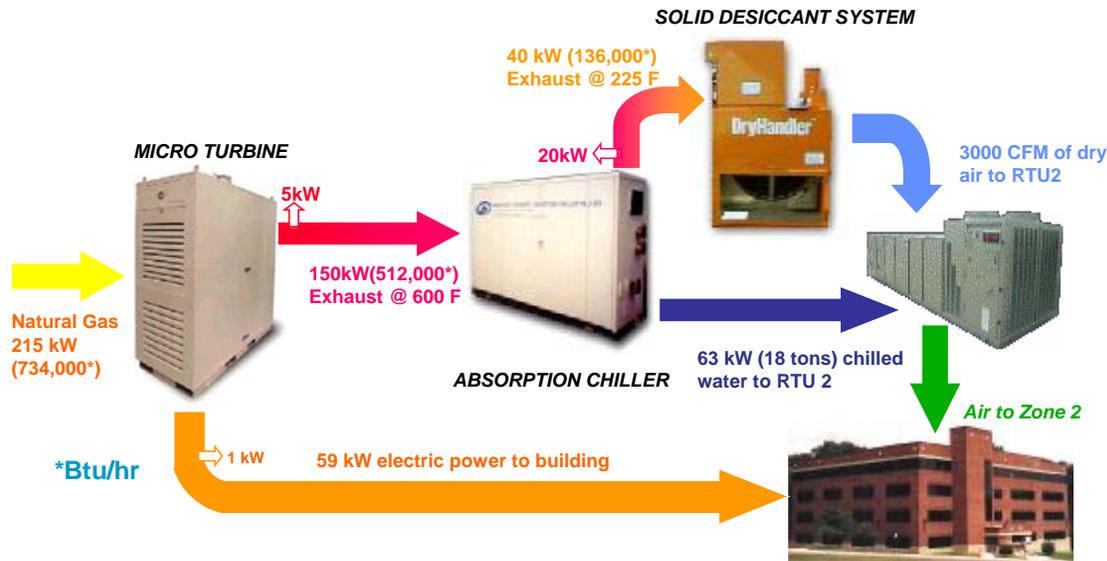


Figure 2: Microturbine Based CHP System 1

4 CHP Systems on Propane

4.1 Properties of Propane

Propane is a liquefied petroleum gas and aromatic hydrocarbon that can be utilized as a gaseous fuel at relatively high ambient temperatures since it will vaporize at atmospheric pressure around -44°F . Propane is a heavy, colorless, flammable gas. Its chemical formula is C_3H_8 . For use as a fuel, propane is liquefied under pressure and sold in tanks, making it a very portable fuel source. The main advantage for using propane as fuel is that it has low pollution characteristics compared to other heavier fraction fuels and its higher energy density in comparison with other clean burning alternative fuels. The Lower Heating Value (LHV) of propane is about 46.4 MJ/kg, very similar to that of natural gas, which is 43 MJ/kg^[1]. The much higher density of propane as compared to natural gas results in much higher energy density per unit volume at the low pressures typical of gas delivery systems. At the Chesapeake Building delivery pressure, which is only a few inches of water column above one atmosphere, the energy density per unit volume is 2500 Btu/scf* for gaseous propane compared to natural gas which has 950 Btu/scf. Liquefied propane (at 60°F) contains a little more than 92,000 Btu per gallon. While natural gas is difficult to store at a commercial or domestic site, propane's higher energy density makes storage less complicated.

* A standard cubic foot (scf) is the USA expression of gas volume at standard conditions and it is very often defined as being measured at 59 °F and 1 atmosphere of pressure.

Compared with natural gas, the saturated temperature is much higher, for example: at 14.7 psia, natural gas will evaporate/condense at - 258.7°F, while the saturated temperature of propane is - 43.6°F. When the propane pressure reaches 90 psig, which normally occurs at the place between microturbine and its fuel gas compressor, the saturated temperature can be 58°F, as in Figure 3. A Capstone C60 currently has no warranty to run on propane, as condensation of propane in the delivery lines is one of the potential problems, this should be avoided by ensuring that a combination of high pressure and low temperature does not occur concurrently.

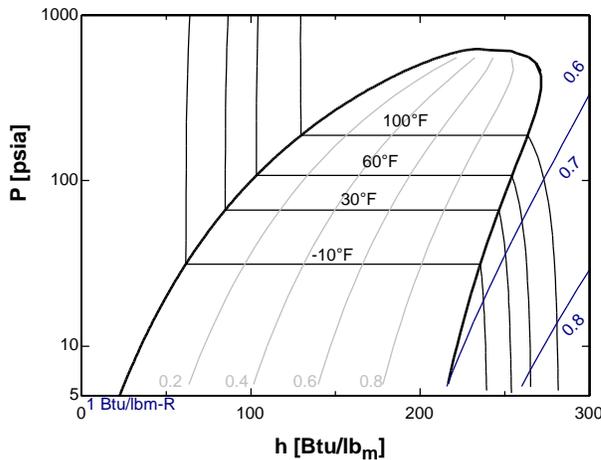


Figure 3. The P-h diagram of propane



Figure 4. Two 1000-gallon propane tanks

4.2 Installation for Propane Operation

4.2.1 Propane tanks and piping

The contractor, Suburban Propane Inc. installed two 1000-gallon propane tanks in the back of the Chesapeake Building (Figure 4). According to the NFPA requirements, the distance between the two filling valves on the center of each tank should be at least 36 inches, and a temporary construction fence around the tanks and propane piping was built. The contractor also connected pipes from the propane tanks through the original dry gas meter to the building's existing natural gas lines. Heat trace and insulation were applied on all external propane pipes to maintain the fuel temperature entering the microturbine between 80-120° F. See Figure 5.

4.2.2 Accessories

The emergency generator was maintained on the natural gas configuration (Figure 6), while the domestic hot water heater tank in the Chesapeake building has been exchanged to a propane model, since the natural gas cylinder in the building could not be converted to propane according to the manufacturer (Figure 7).

4.3 Modifications for Propane Operation

4.3.1 CHP System 1 Modifications

At the inlet of EDAC engine, the fuel is regulated down again to the operational pressure required inside the engine. It needed to be adjusted from its natural gas setting because the required gas pressure for the engines running under propane is much lower than that for natural gas due to the higher energy density. The same regulator could be used for propane by simply inverting it so that instead of the spring pushing the counterweight down with gravity, the spring pushes the counterweight upwards, making the supply gas pressure from the regulator much lower. See Figure 9.



Figure 5. Heat trace and insulation applied on propane pipes



Figure 6. Piping, gas meter and emergency generator (left front green one)



Figure 7. New domestic hot water heater tank burning on propane

4.3.2 CHP System 2 Modifications

Aside from the physical piping changes required to connect the propane to the fuel lines in place of the natural gas, modifications were required in order to protect the microturbine from any condensation of liquid fuel that may occur as a result of high pressures and low temperatures in the propane lines.

At the high gas velocity in the turbine section of the microturbine, the presence of liquids in a gaseous fuel, either from the fuel or from the fuel gas compressor lubricating oil, may result in microturbine (engine) hardware damage. It is important to maintain the gaseous fuel at 18°F above the dew point temperature throughout the fuel system ^[2]. So steps must be taken to avoid this occurrence.

Firstly, the coalescing filter, which filters out liquid fuel, water and particulate matter was moved from the inlet of the fuel gas compressor to the outlet of the compressor, just upstream of the microturbine where the highest pressure exists in the system and condensed fluid is most likely to occur, Figure 10.

Secondly, the setting of the gas regulator after the fuel gas compressor was changed from 75psig to 70psig on Capstone's advice. Figure 8 shows the gas line pressure of CHP system 2 at different locations.

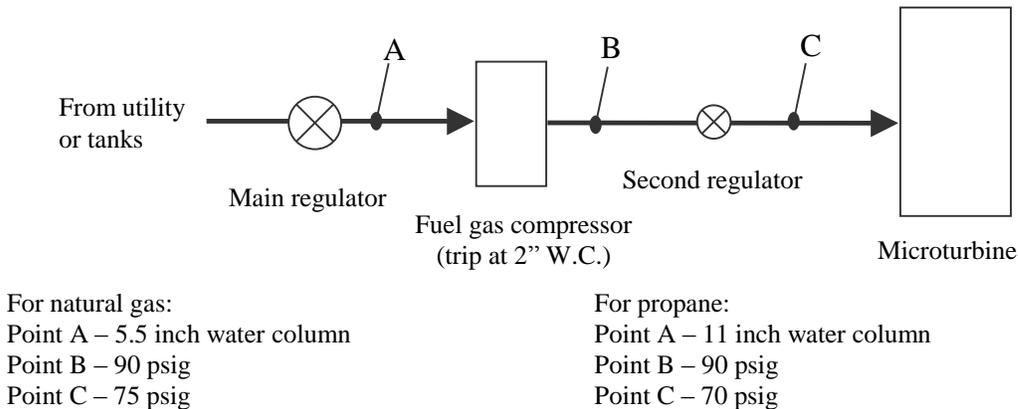


Figure 8. CHP System 2 gas line pressure

In addition, provisions must be made for purging the fuel system upon shutdown, and/or prior to startup. The shutdown procedure was modified on the C60 so that instead of using the software to shut down the machine the fuel tap was turned off manually upstream of the microturbine so that the microturbine flamed out rather than going through its normal cool down procedure ^[3].

Finally, the fuel index in Capstone control software was changed according to the instruction of Capstone – but the adjustment was simply a matter of changing two index values in the control software. The two values changed reset the initial value for the fuel controller – the values after startup are set by PID control loops to maintain engine speed

and power output. No hardware changes were required to be made to the microturbine at all.



Figure 9. EDAC regulator



Figure 10. MT coalescing filter

4.4 Operation on Propane

In each system, only one component was directly effected by the fuel change, since heat was provided to downstream equipment as a result of combustion within only the prime mover in each system. So the propane tests focus on the operation and performance of prime movers.

4.4.1 CHP System 1

In CHP System 1, the equipment directly effected by the fuel change to propane are the EDAC units. After adjusting the regulator, the whole system can operate on propane with no visible change in operation as a result of the fuel change. Both EDAC units can operate at 2 stages in all conditions in which the EDAC units would normally operate. The EDAC units have been operated on propane for totally 60 hours; the only restriction is the cold weather, since in cold weather there are no cooling requirements the units are not tested in cooler outdoor air conditions.

4.4.2 CHP System 2

In CHP 2, the microturbine is the prime mover and the only device to consume propane. After the modifications listed in Section 4.3.2 had been completed the microturbine was able to operate on propane as well as natural gas at low power levels. At higher power levels (40kW and above at normal conditions) the gas regulator began to restrict the flow of fuel to the microturbine. Since the fuel gas compressor has a low line pressure inlet sensor (the trip setting is 2 inches water column) as required by code the flow restriction would eventually trip it out of operation and the microturbine would shut down as well.

Figure 11 shows the size of natural gas regulator and propane regulator which regulate the gas pressure from utility or propane tanks, the downstream pressure after the regulator is normally set at 5.5 inches water column for natural gas and 11 inch water column for propane application. The microturbine could not run at 60kW full load on propane due to the low line pressure fault. The improper size or pressure setting of propane regulator and propane condensation due to cold weather and inadequate heating may be the causes of the fault.

A range of power levels were tested over the course of the installation and the results are displayed in subsequent chapters. The C60 microturbine has been operated on propane for totally 40 hours.



Figure 11. Natural gas regulator and propane regulator

5 Data Process

5.1 Constants and Formulas

The constants/properties used in the data processing were:

- LHV: 2500 Btu/scf (46.4 MJ/kg^[1]) for gaseous propane; 950 Btu/scf (43.0 MJ/kg^[1]) for gaseous natural gas.
- Pressure at the gas meter: the line pressure is 0.4 psig for propane; 0.2psig for natural gas according to Washington Gas.

The MT efficiency is defined as:

$$\text{Efficiency} = (\text{MT output power} - \text{parasitic power}) / \text{fuel consumption (LHV)}$$

5.2 EDAC Data

Figure 12 shows the gas input to one EDAC unit in two similar days. The amount of fuel energy required operating under either natural gas or propane is almost identical at 2700rpm – stage 2, and slightly higher for propane at 1600rpm – stage 1. It is difficult to say whether this result has much significance when considering the impact of fuel changes. It may be that the higher propane energy input results from a combination of several factors – maybe imperfect settings for the gas regulator, a carburetor in the engine designed for natural gas, the impact of the part load characteristics of the engine on its fuel consumption, and weather fluctuation within one day. The excellent agreement at high rpm shows that there can be little difference between the two fuels at full load.

Figure 13 shows the fuel standard flow rate to one EDAC unit. The volumetric flow rate of propane converted to standard condition is lower than that of natural gas at both stage 1 and stage 2.

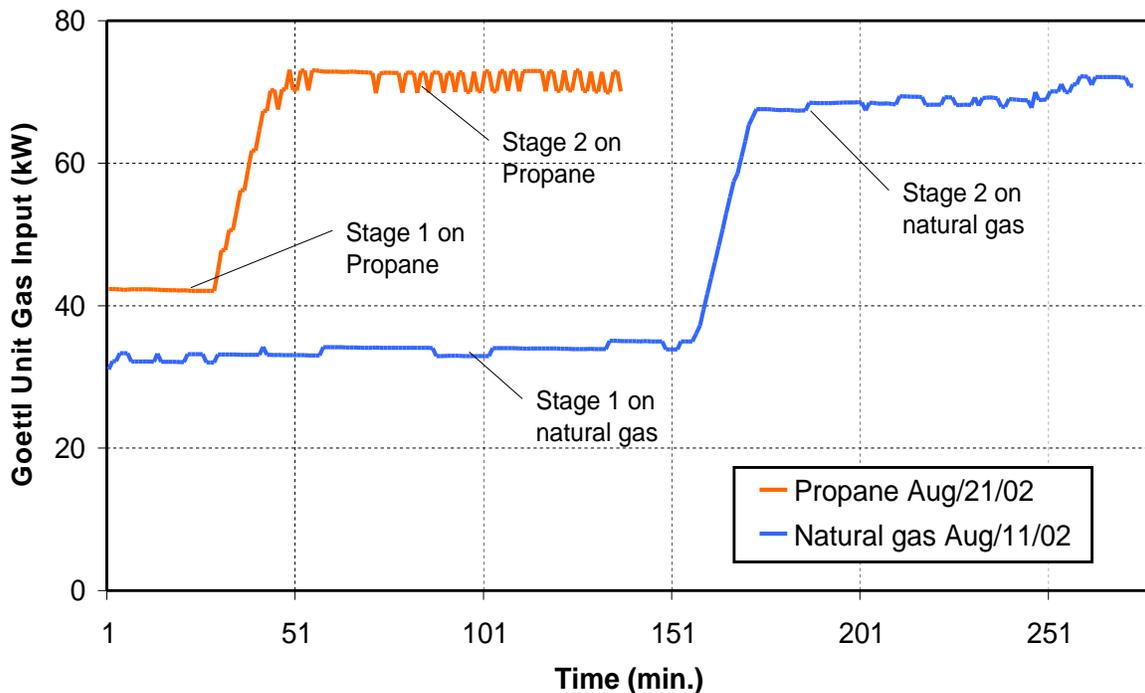


Figure 12. Example data: the gas input in two similar days – one operating on propane and the other on natural gas

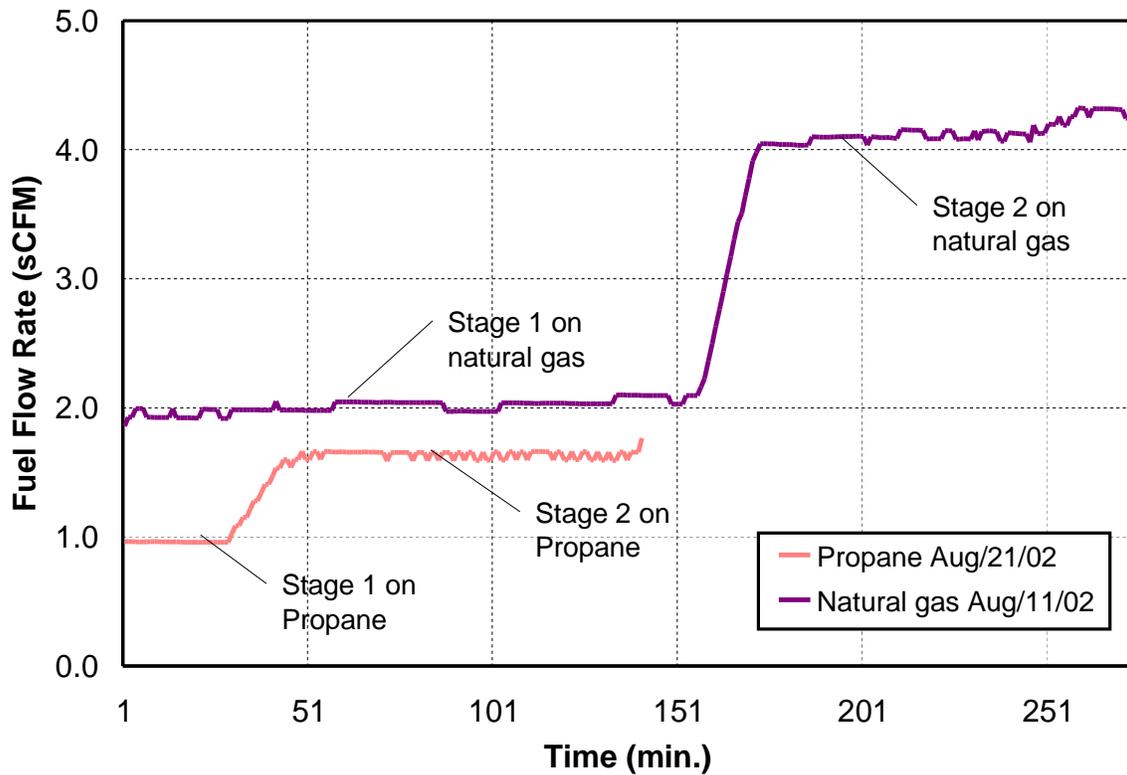


Figure 13. Example data: the fuel standard flow rate in two similar days – one operating on propane and the other on natural gas

5.3 Microturbine Data

Figure 14 shows a comparison with error bars between the efficiency of the microturbine operating on propane and natural gas. At part loads below 20kW, they have almost no difference, but with the loads increased, the efficiency of propane is lower than that of natural gas. However the difference is slightly outside the measurement error of the experiment, the changeover of fuels has made little difference to the performance of the microturbine as a power generator. The lower efficiency of propane at higher loads may cause by:

- Improper size or pressure setting of propane regulator;
- Propane condensation due to cold weather and inadequate heating;
- C60 microturbine is not designed for the operation on propane.

The uncertainty of microturbine thermal efficiency due to the error of sensors is $\pm 3.16\%$ [4]. Considering the error introduced by sensors, in Figure 14 the error bars show the magnitude of sensor error.

Figure 15 shows the microturbine fuel flow rate that has been converted to standard CFM at different power output. The propane has lower volumetric flow rate than natural gas; in addition, the data also shows a perfect linear adjustment of fuel flow rate. Figure 16 gives the linear fuel input at different power output.

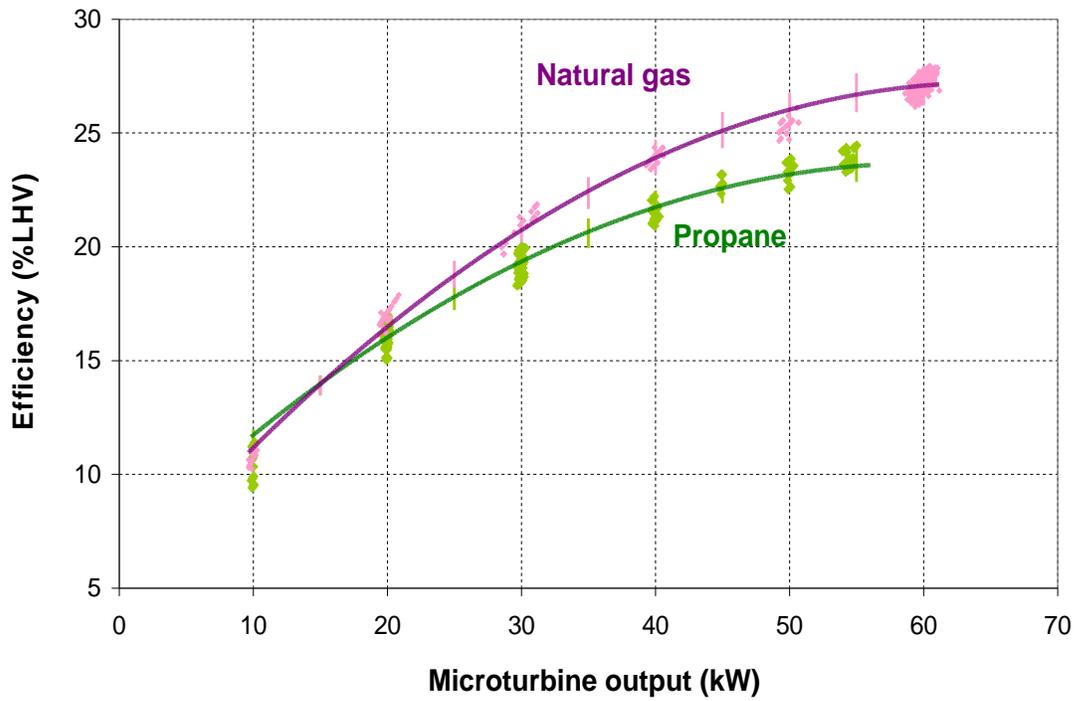


Figure 14. The efficiency comparison between MT operating on propane and natural gas with sensor error bars

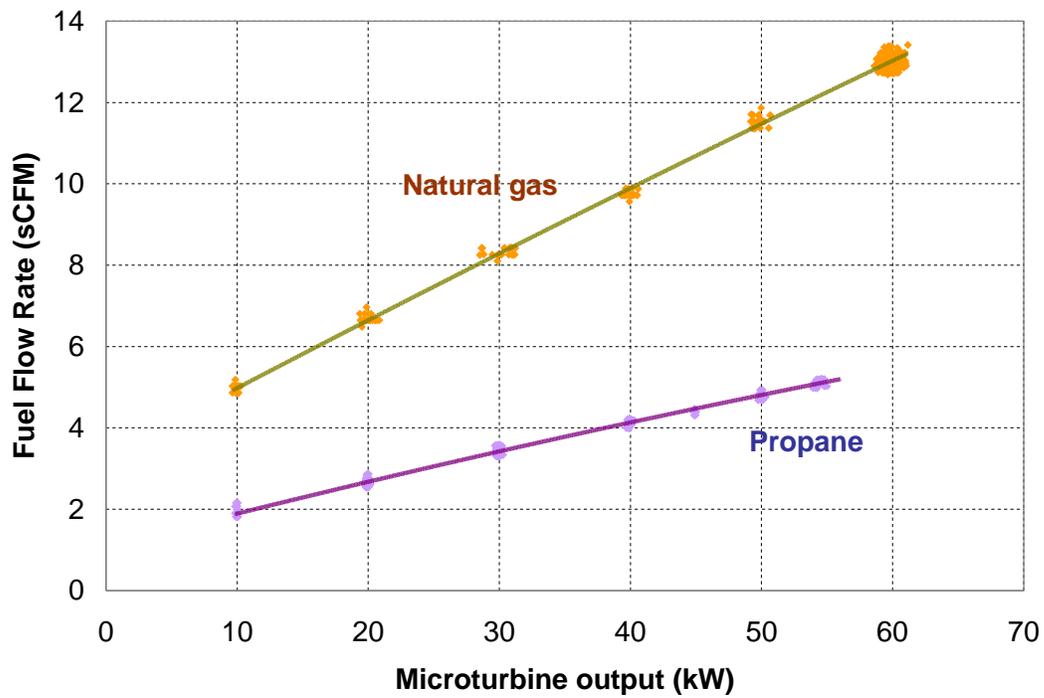


Figure 15. The fuel standard flow rate at different microturbine power output

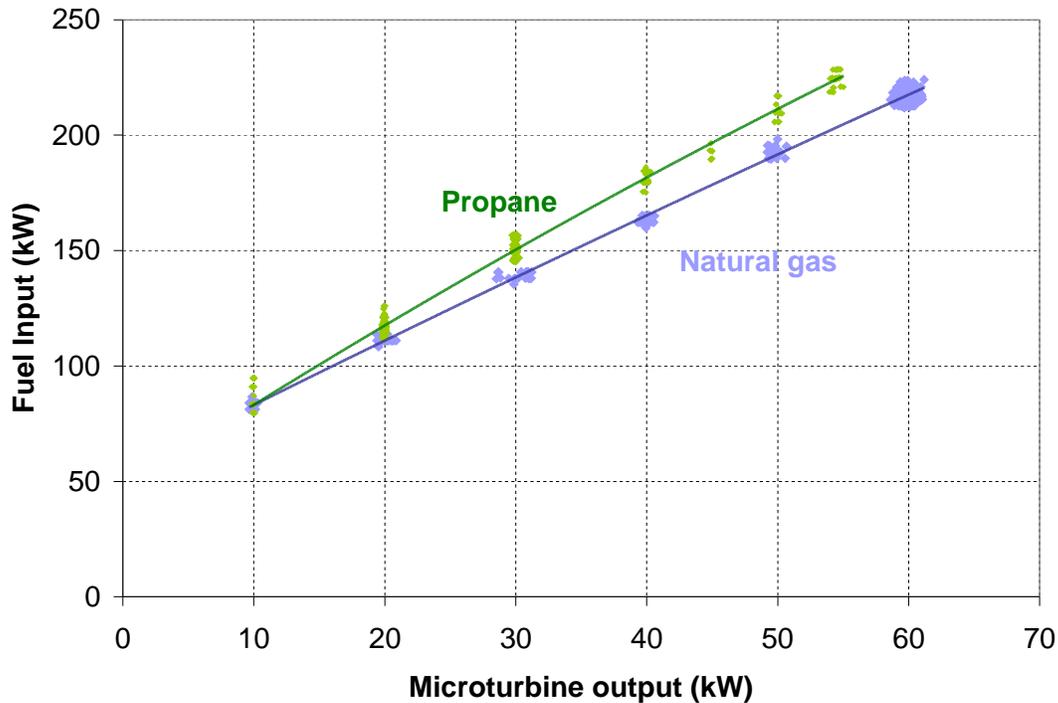


Figure 16. The fuel input at different microturbine power output

5.4 Error Analysis

Figure 14 shows the efficiency comparison with error bars, which are solely due to the sensor error, here it is $\pm 3.16\%$. However, there are several places where additional, unquantified errors could be introduced:

- The properties of natural gas. The heating value of natural gas varies with geographic region and season. Natural gas is a mixture mainly of methane (about 96% by volume), ethane, small amounts of propane, some trace nitrogen and CO_2 . In the region where the Chesapeake Building is located, the LHV of natural gas is 950 ± 20 BTU/scf according to Washington Gas.
- The properties of propane. In commercial use propane is not pure either. The LHV of commercial propane is 2500 ± 50 BTU/scf according to Washington Gas.
- The pressure in the gas meter. We assume the pressure is 0.2 psig for natural gas and 0.4 psig propane according to the set point of the gas company, but there is no pressure gauge installed to obtain the actual dynamic reading.

Several methods were used to minimize data error, such as:

- Calibrating sensors by adjusting the formulas in HP VEE program of Data Acquisition System
- Retaining steady state data and eliminating the transient data from analysis;
- Use moving average to process the gas meter readings;
- Convert data under different weather conditions to data under standard condition.

The data acquisition system records outdoor temperature and humidity, the fuel volume flow rate of primary movers and power output. To calculate the primary energy consumption, 2 different equations are used for propane and natural gas separately to reduce error.

For the calculation of primary energy consumption, the following equation is used:

$$Q_{in} = V_{real} * (\rho_{real} / \rho_{standard}) * LHV$$

In which:

Q_{in} – the primary energy consumed by prime mover (kW)

V_{real} – the volume flow rate of fuel gas at actual condition (m^3/s , converted from the CFM reading)

ρ_{real} – the density at actual condition (kg/m^3)

$\rho_{standard}$ – the density at standard condition (kg/m^3)

LHV – Lower heating value (kJ/m^3 , converted from 950 BTU/scf for natural gas and 2500 BTU/scf for propane. Note: 1 BTU/scf = 37.26 kJ/m^3).

6 Conclusions

The CHP equipment tested at the Chesapeake building was successfully converted to operate on propane with a minimum of redesign and re-engineering of the system. In CHP System 1 only small changes were necessary to the operation of the gas regulators. In CHP system 2 the changes were more involved and centered on a desire to ensure that condensed fuel was not combusted in the microturbine to avoid damage to the engine assembly. Heat trace and coalescing filters were used to this end. In CHP system 2 propane operation was also unfortunately restricted by limitations in the gas regulating capacity of the installed fuel delivery system, making full load data more difficult to achieve, but this reflects the site specific installation, not the properties of the propane fuel itself. Evaluated performance data showed few variations from that obtained operating under natural gas.

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