121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014

Paper ID #10968

Integration of Alternative Fuels and Turbine Research in an Undergraduate Classroom

Dr. Nadir Yilmaz P.E., New Mexico Institute of Mining & Technology

Nadir Yilmaz is an Associate Professor of Mechanical Engineering at the New Mexico Institute of Mining and Technology. He received his B.S., M.S., and Ph.D. degrees in Mechanical Engineering from Istanbul Technical University (1999), Bradley University (2001) and New Mexico State University (2005), respectively. His work is in the areas of combustion and CFD. He has been a noted author of about 60 technical papers and reports in these fields. Dr. Yilmaz is an active member of SAE, ASME, ASEE, NSPE, and currently is serving as the editor-in-chief for the SAE International Journal of Fuels and Lubricants, along with being a committee member on the SAE ABET Board. He has received New Mexico ”Young Engineer of the Year” Award (2013), NMT University Distinguished Teaching Award (2013), ASEE Section Outstanding Teaching Award (2013), SAE Faculty Advisor Award (2013) and SAE Ralph R. Teetor Educational Award (2011).

Mr. Kyle Jeffrey Benalil, New Mexico Institute of Mining and Technology

Kyle Benalil is a third year undergraduate student at New Mexico Institute of Mining and Technology that is studying mechanical engineering. He has taught pre-calculus and the First Year Experience seminar for incoming freshmen. He also tutored students in engineering science, physics, math, and mechanical engineering courses. Also throughout his college career, he has become the president of the soccer club, and president of the SAE Collegiate Student Chapter at New Mexico Tech. He has become an active member of different professional societies including SAE, ASME, ASEE and AIAA. Awards presented to him include Standout Techie, the President’s Honor Roll, and New Mexico Tech Scholar.

Mr. Francisco Martín Vigil, New Mexico Institute of Mining & Technology

Francisco Vigil is from Española, NM. He graduated from NMT in December 2013 with a Bachelor of Science in Mechanical Engineering and plans to pursue a graduate education at the University of New Mexico. Throughout his undergraduate degree, Francisco was the President of the NMT Society of Automotive Engineers Student Chapter. During his time as president, the chapter grew to become one of the largest chapters in the world. He also volunteered at the NM State Science and Engineering Fair and NM State Science Olympiad. Francisco was awarded the NMT Student Appreciation Award (2013), the DOE Summer Visiting Faculty-Student Fellowship at Sandia National Laboratories (2013) and the University of Illinois at Urbana-Champaign Outstanding Scholarship Award (2012).

Integration of Alternative Fuels and Turbine Research in an Undergraduate Classroom

Abstract

The purpose of this study was to evaluate the performance and emissions characteristics of jet-A, kerosene, and bio-blended fuels in a micro-turbine. Experiments were conducted by students as a part of the Experimental Methods in Aerodynamics course, which is designed to enhance the understanding of diagnostic methods and combustion processes in aerospace and alternative energy applications. Students designed and built the experimental apparatus in addition to conducting testing. Thrust, fuel consumption, exhaust gas temperature, and emissions data were collected while the micro-turbine was operating at the minimum and maximum engine RPM. Integrating the design, assembly, and testing of the micro-turbine into the curriculum showed to be an effective way to introduce students to many aspects of aerospace engineering, as well as, to teach diagnostic methods and techniques while exposing them to a research setting.

Introduction

As the energy demand increases worldwide, alternative energy sources to petroleum-based fuels have been extensively researched in recent years. Such alternative energy options include solar, wind, and biomass. In terms of biomass, biodiesel from various feed stocks; alcohols including ethanol, methanol and butanol; vegetable oils and blended fuels that combine diesel, biodiesel, alcohols and vegetable oils have been tested in compression ignition engines in detail. There is some work done in the literature regarding the operation of micro gas turbines with alternative fuels such as biodiesel and straight vegetable oils [1-4]. Because vegetable oils have a high viscosity, they cannot be used in gas turbines without fuel modification. Such modification can be done by preheating vegetable oils to the point where the viscosity is comparable to diesel fuel in order to achieve good fuel atomization, which affects combustion and emission characteristics. Although biodiesel has a lower viscosity than vegetable oils, it is still more viscous than diesel. Thus, some fuel preheat is needed in order to achieve satisfactory atomization [5]. However, if biodiesel is blended with jet fuel, kerosene or diesel, fuel preheat may not be necessary because of the overall low viscosity of the blended fuel. In this work, a micro gas turbine was operated on jet-A and kerosene as baseline fuels. Then, the fuels were mixed with 20 % of biodiesel and the blended fuels were evaluated in the micro-turbine in terms of performance and emissions characteristics. This project was done as part of a course assignment and eventually became a successful experiment to integrate alternative energy and turbine research in an undergraduate classroom in aerospace engineering.

Experimental Methods in Aerospace Engineering

The Mechanical Engineering Department at the New Mexico Institute of Mining and Technology offers a minor in Aerospace Engineering. As a part of the aero minor, the junior level laboratory course “Experimental Methods in Aerodynamics” is offered to use an experimental approach to solve problems and validate theoretical and computational results. The three-credit course has both lecture and lab sections. The course laboratory and simulation tools for experimental measurements, as well as, validations include:

- Uncertainties in measurement
- Review of fundamental equations of fluid dynamics, properties of gases and liquids, similarity laws
- Wind tunnels and water channels
- Use of pressure sensors including optically-reactive surface paint
- Measurement of skin friction by direct force sensors, Preston and Stanton-tubes, diffusion analogies, liquid crystals
- Flow visualization with laser light sheet using 2D and 3D PIV techniques
- Future trends; flow control, impact of microelectronic sensors and actuators
- Computational methods and extensive training and use of commercial CFD packages such as Flow-3D

The main objective of the course is to use experimental tools for solving problems in Aerospace Engineering. In addition, it is expected for students to:

- Learn about proposal writing and propose a project that can be finished by the end of the semester
- Design, document and conduct experiments for the proposed project
- Analyze and interpret their data
- Prepare scientific reports, present their work in the classroom, and if possible, disseminate the results at a conference

In the course, each team is supposed to write a proposal, work on the proposed/approved project and disseminate the results through reports and presentations. One of these proposed projects was to create a micro-turbine setup and use the project as a future lab session in the classroom to study the use of alternative fuels in turbines. The proposed experiment was setup in the Combustion Engines and Fuels Research Laboratory at the New Mexico Institute of Mining and Technology and was used to expose students to research in alternative fuels and turbines. The following sections explain this experiment along with its results in detail below.

Student Experiences

The Experimental Methods in Aerodynamics course was designed to encourage students to use critical thinking skills to design and run experiments relating to the aerospace field. Students were given a list of general topics to choose from by the instructor, but they had the freedom to approach their topic as they saw fit. The instructor made himself available for questions and advising, but otherwise was only involved for the project proposal, final presentation, and disbursement of funds for materials. This structure allowed students to learn firsthand about some of the difficulties faced when running experiments.

After the topic was chosen, students were tasked with designing an initial draft of their apparatus using SolidWorks, which would later be reevaluated for proper sizing. Students were also responsible for estimating a budget that would include all the necessary materials for the apparatus, the turbine, and diagnostic equipment. Once the vendors of the equipment were contacted and quotes were obtained, the students submitted their budget for department approval. Upon approval of the budget, the students began finalizing the design of their apparatus and evaluating its mechanical integrity. The final design had to meet the constraints of the budget, so the apparatus was built with scrap angle iron so that the majority of the budget for the apparatus could be used to buy high quality bearings and rods for the turbine to be mounted to. When fabrication of the apparatus was completed, the students had to mount the turbine to it and familiarize themselves with the operation and safety procedures for its use. The students purchased the turbine and had no experience with turbomachinery, so they invested a great deal of time interacting with the manufacturer to ensure that it was operated correctly.

After it was installed and operational, the next challenge was to find accurate diagnostic methods that could be used to measure the thrust, exhaust gas emissions, and exhaust gas temperature and still fit within a small budget. Digital force gauges were too expensive, so the students opted to use springs and measure their displacement to calculate the thrust. Displacement of the springs was measured with digital calipers multiple times during testing. A concern that students considered while designing the test apparatus was the influence of the various mechanical forces on the thrust measurement. Students conducted a mechanical analysis of the forces generated by the turbine to determine how those forces affected the measured thrust. Investigated factors included the friction experienced by the bearings and the translation of the thrust into axial force to compress the springs mounted on the rails of the apparatus. The Mechanical Engineering Department owned an exhaust gas analyzer, but its maximum operating temperature was below the exhaust gas temperature. To make it work, the students used section of pipe that was placed behind the exhaust nozzle of the turbine to allow the exhaust gasses to cool. The most financially straining diagnostic tool that had to be purchased was the data acquisition system for the thermocouple. The controller that came with the turbine also served as a diagnostic tool that measured fuel consumption, engine speed, and exhaust gas temperature.

After the apparatus was constructed, the turbine was mounted, and the diagnostic tools were in place, the students began testing. When the results were obtained, the course instructor helped analyze the data. The experiment and results were presented to the class at the end of the course in a presentation by the students. In addition to fulfilling their course requirements, the students authored this paper to present their work.

Experimental Procedure

Experiments were carried out using a JetCat USA P80-SE micro-turbine as shown in Figure 1. Its supporting hardware includes:

- Fuel control electronics
- GSU (display and programmer)
- LED I/O board
- ECU (electronic control unit)
- Miniature fuel pump
- Electronic starting gas valve
- Electronic fuel valve
- Fuel tubing, connectors and filters
- Starting gas tank
- Turbine mounting clamp

The micro-turbine start-up, fuel delivery and shut-down protocol consisted of the following steps [6]:

- Check fuel lines and filter for obstructions
- Mix 5 % turbine oil into the fuel
- Make sure the starting gas release valve is closed
- Plug the battery into the ECU
- Start turbine (automatically starts on propane and switches to desired fuel at ~5000RPM)
- Stop turbine
- Unplug the battery after the cooling process has finished

Measurements that were taken include exhaust HC, CO, CO_2, NO_x, exhaust gas temperature, fuel consumption, and the thrust of the turbine. These quantities were found using an EMS 5002 gas analyzer and the GSU that is also used to control the turbine's RPMs. The gas analyzer was calibrated using BAR97 gas. The GSU recorded the turbine's fuel consumption, as well as, the exhaust gas temperatures. The thrust of the engine was experimentally found by measuring the displacement of compression springs. For each test, the GSU was used to set the turbine's RPM to 40,000 and 125,000.

Figure 1. P80-SE micro-turbine

The turbine was mounted onto a bearing and rail system, which was attached to a steel frame as seen in Figure 2. Once started, the turbine's thrust pushes itself against the springs in the front of the rail system, and by using a set of digital calipers, accurate to one ten-thousandth of an inch, the compressed distance was measured and compared to the original spring length. A ten foot long aluminum tube was aligned with the exhaust to channel the hot exhaust gases allowing them to cool to a temperature that the emissions probe could withstand, about 350 ^{0}C.

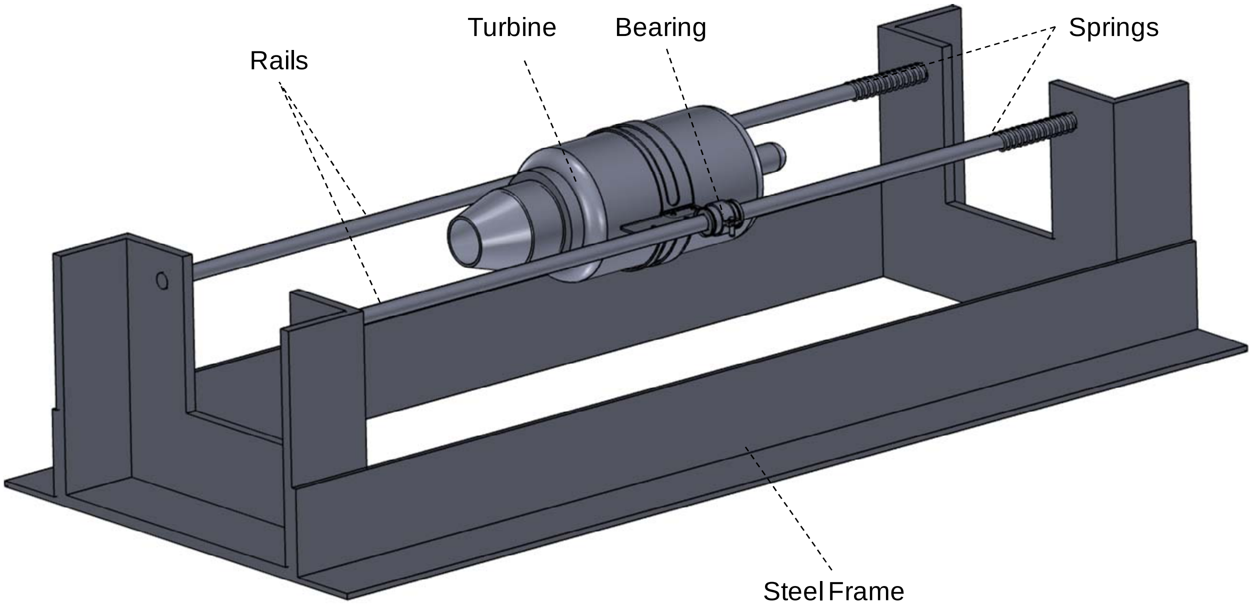

Figure 2. Solid model of the experimental setup.

Jet-A, kerosene, and biodiesel fuels were tested and mixed to make jet fuel-biodiesel, and kerosene-biodiesel blends with 20 % biodiesel in each mixture, as well as 5 % turbine oil in each fuel, as recommended by the manufacturer. These mixtures were compared to the baseline to look for advantages and disadvantages of each fuel. Table 1 shows the basic fuel properties of biodiesel used in this study in addition to jet-A and kerosene.

Table 1. Properties of Jet-A, kerosene, and biodiesel [4,7,8]

Fuels	Jet-A	Kerosene	Biodiesel
Heating Value (MJ kg^{-1})	42.8	43.5	40.5
Density @20 ^{0}C (kg m^{-3})	807	780	855
Viscosity @ 40 ^{0}C (mPa s)	0.88	1.4	4.57
Flash Point (^{0}C)	60	39	126
Cetane Number	55	39	52

The biodiesel used in testing was made from used cooking oil following the standard transesterification process, and it followed ASTM D6751 and met the standard specification.

Results and Discussion

Performance and emissions characteristics of the micro gas turbine running on jet fuel, kerosene, jet fuel/biodiesel and kerosene/biodiesel are discussed below in detail. Thrust, thrust specific fuel consumption (TSFC), exhaust gas temperature and basic exhaust gas emissions are also reported.

Thrust

Thrust force as a function of turbine speed is shown in Figure 3. As expected, the turbine creates more thrust as the fan speed increases. In fact, by increasing the speed approximately three times, thrust increased about nine times for all the fuels. Also, biodiesel blended fuels created slightly better thrust than the baseline fuels.

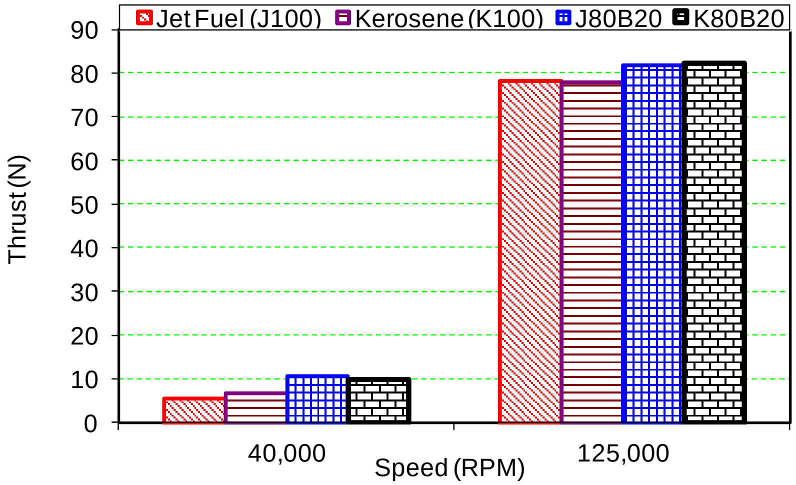

Figure 3. Thrust as a function of turbine speed

Thrust Specific Fuel Consumption (TSFC)

Figure 4 shows the effect of fuel type and fan's RPM on thrust specific fuel consumption (TSFC). TSFC decreases as the turbine speed increases. This is expected and means that the turbine becomes more fuel efficient at higher speeds.

Overall, jet fuel and kerosene have higher TSFC than biodiesel blended fuels, especially at low speed. At higher speed, the difference becomes insignificant. From the results, the micro-turbine is more fuel efficient if it runs on biodiesel blended fuels. Another interesting observation is the magnitude of TSFC for the micro-turbine. TSFC changes between 0.2 kg/N-hr and 0.7 kg/N-hr. However, large commercial gas turbines are very efficient and usually have TSFC of 0.1 kg/N-hr. This shows that the micro gas turbine used in this study is not as fuel efficient compared to commercially used turbines; although, it is a perfect tool for investigation of fundamentals and educational teaching and research purposes.

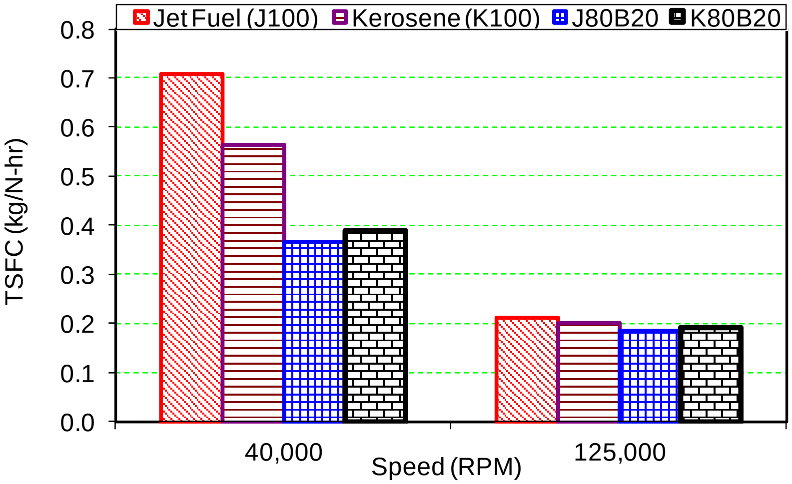

Figure 4. Thrust specific fuel consumption (TSFC) as a function of turbine speed

Exhaust Gas Temperature

Turbine exhaust gas temperature increased with respect to turbine speed due to heat release from the turbine combustor as seen in Figure 5.

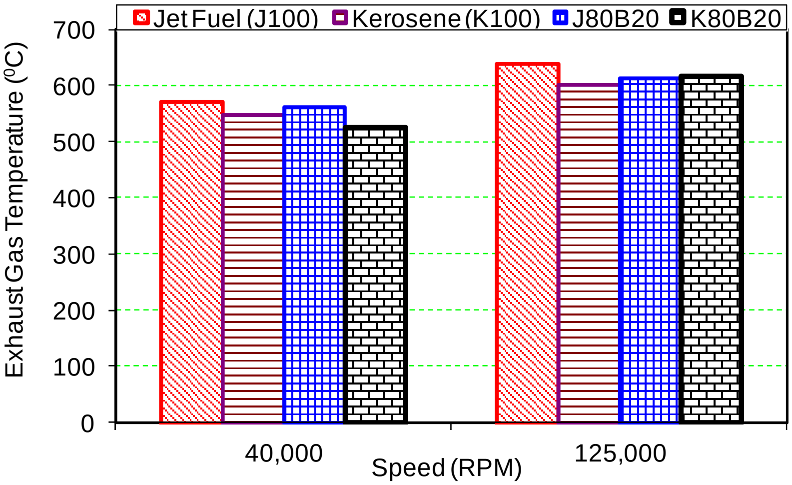

Figure 5. Exhaust gas temperature as a function of turbine speed

Maximum exhaust gas temperature was obtained with jet fuel. But, the difference between the gas temperatures with regards to the fuel type is not significant.

Exhaust Gas Emissions

Unburned HC, CO, CO_2 and NO_x emissions at low and high turbine speeds are seen in Figure 6. HC emissions decrease as the turbine speed increases because of higher temperatures and better combustion at higher speeds. Also, biodiesel blended fuels reduce HC emissions as compared to jet fuel and kerosene and the baseline fuels. CO emissions increase as the turbine speed increases. Jet fuel shows the highest CO emissions. Adding biodiesel to jet fuel decreases

CO emissions, while there is an increase in the case of adding biodiesel to kerosene. Since there is an increase in combustion temperature due to higher heat release from the turbine combustor at a higher speed, higher NOx emissions are seen at the higher speed. Jet fuel shows the highest CO_2 emissions at both speeds, and CO_2 emissions increase with respect to the turbine speed due to higher fuel consumption.

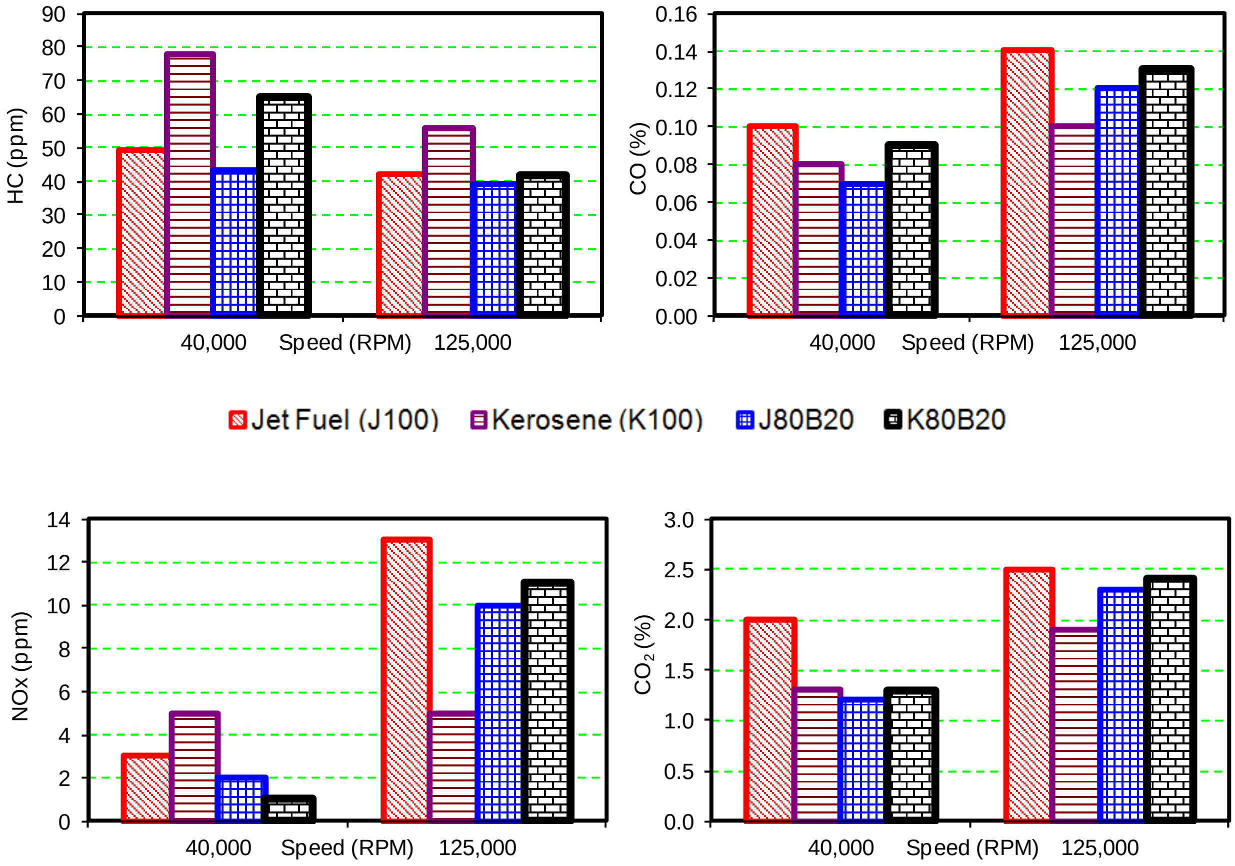

Figure 6. Exhaust gas emissions as a function of turbine speed

Conclusions

The performance and emissions characteristics of a micro gas turbine running on jet-A, kerosene, jet-A/biodiesel and kerosene/biodiesel were studied as part of a class project in Experimental Methods in Aerodynamics at the New Mexico Institute of Mining and Technology. The course requires each group of students to work on a project throughout the semester. The purpose is to expose students to the real-world by teaching them how to write proposals, work on their proposed research-based projects by building and setting up the experiments from scratch, and disseminating their results via technical papers and presentations. The micro gas turbine project proved to be an effective real-world research project for students to integrate alternative fuels and turbines research. Students used their writing and oral presentation skills, hands-on knowledge, as well as, experimental and theoretical backgrounds that they built during their college careers. Integrating all these aspects into one project showed to be an effective way to expose students to real-world experience. Due to the overall outcome and success, the project was implemented into the curriculum as a mandatory experiment for all students.

References

1. Nascimento MAR, Lora ES, Correa PSP, Andrade RV, Rendon MA, Venturini S, Ramirez GAS. Biodiesel fuel in diesel micro-turbine engines: Modelling and experimental evaluation. Energy 2008;33:233-240.
2. Chiaramonti D, Rizzo AM, Spadi A, Prussi M, Riccio G, Martelli F. Exhaust emission from liquid fuel micro gas turbine fed with diesel oil, biodiesel and vegetable oil. Applied Energy 2013;101:349-356.
3. Prussi M, Chiaramonti D, Riccio G, Martelli F, Pari L. Straight vegetable oil use in Micro-Gas Turbines: System adaptation and testing. Applied Energy 2012;89:287-295.
4. Gupta KK, Rehman A, Sarviya RM. Bio-fuels for the gas turbine: A review. Renewable and Sustainable Energy Reviews 2010;14:2946-55.
5. Al-Shudeifat MA, Donaldson AB. Combustion of waste trap grease oil in gas turbine generator. Fuel 2010;89:549-553.
6. Instruction Manual V6.0J2 ECU, JetCat USA, LLC, 2008.
7. Yilmaz N. Performance and emission characteristics of a diesel engine fuelled with biodiesel-ethanol and biodiesel-methanol blends at elevated air temperatures. Fuel 2012;94:440-3.
8. Aydin H, Bayindir H, Ilkilic C. Emission from an engine fueled with biodiesel-kerosene blends. Energy Sources, Part A 2011;33:130-137.