BIOMASS FUELED GAS TURBINE DEVELOPMENT

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INTRODUCTION

Research and development on a 3000 kw wood burning gas turbine power generating system has progressed to the production stage. A system using a General Electric aircraft derivative gas turbine is being prepared for installation at Huddleston, Virginia. The generated power will be sold to the Virginia Power Company. The R&D system located at Red Boiling Springs, Tennessee, will be upgraded for operation with the General Electric engine. Tests were conducted with sugar cane bagasse with good results. Sorghum and sugar cane promise to be major sources of fuel in the future.

Sweet sorghum and sugar cane juices are readily converted to alcohol by yeast fermentation. Sweet sorghum can be grown throughout the United States as well as the tropic and temperate zones of the earth. These plants have the highest conversions of solar energy into biomass of any of the species in the plant kingdom, substantially greater than trees. With the use of bagasse as a fuel for gas turbines in the generation of power, it is possible for the income from power sales to reduce the cost of ethyl alcohol well below that for gasoline. The sorghum grain can be used for fermentation or food. The high volume, high temperature exhaust gases from the turbine can be used to concentrate the juice, make alcohol, dry the bagasse or generate steam for injection into the turbine. There is adequate heat to concentrate the juice and dry the bagasse for year-round use during the harvest period.

Growth of sugar cane and sorghum on the 66.4 million acres of land taken out of production in the U.S. between 1981 and 1988 can supply enough energy to generate 34 percent of the power that was generated in 1986, enough to supply increased power demands into the next century. At the current rates paid by Virginia Electric Power Company for power generated with renewable fuels, 25.4 billion gallons of alcohol can be produced from the profits earned on power sales, enough to supply gasohol to the entire nation.

The system, which can be located at any point where there is a power distribution line and a sorghum or sugar cane source, can provide jobs in the area and an alternative crop for farmers while saving billions of dollars on set-aside payments. At $20/barrel, approximately $8 billion would be saved on the trade imbalance by the reduction of oil imports.

BACKGROUND INFORMATION

Research on wood burning gas turbines was started by Aerospace Research Corporation in 1978. It culminated in the operation of an Allison T-56 gas turbine power generating system at a facility located in Red Boiling Springs, Tennessee. Over two million dollars in U.S. Department of Energy funds and a matching amount of private funds were spent in carrying out the program. In addition, gas turbine engines were furnished by the Air Force and Naval Air Systems Command. A view of the research and development facility is shown in figure 1.

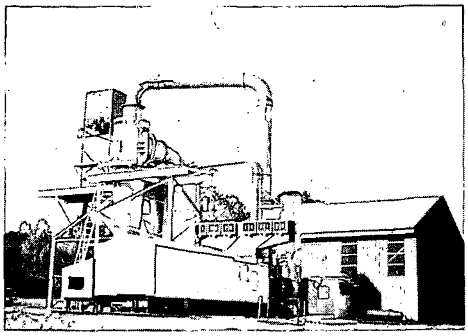

FIGURE 1 View Of Facility At Red Boiling Springs, Tennessee

Operational difficulties which resulted in learning curves peculiar to the system such as wood processing, conveying, drying, combustion, ash removal, engine starting, synchronization with the TVA power distribution grid, and development of emergency procedures are covered in reference 1.* Feeding a pulverized solid into a high pressure chamber and dealing with turbine blade fouling presented the greatest challenge. An anticipated problem that was most feared at the outset, eroding of the turbine blades, never materialized. In over 1500 hours of operation, no erosion has been detected. The measures taken to resolve the two problems and the approach taken with the General Electric LM 1500 gas turbine in meeting the problems are presented.

Modern aircraft engines which require very high power to weight ratios are designed for high turbine inlet temperatures and high compressor discharge pressures. As turbine blade cooling techniques, advanced materials, and more sophisticated design methods have become available the pressure ratios and allowable turbine inlet tempatures have increased to high levels. As a result, the modern aircraft deriviative gas turbines are less suitable for operation with biomass than the earlier models. The current need for low turbine inlet temperature and low combustor pressure with biomass makes the earlier models more compatible. The LM 1500 gas turbine fits well into the biomass picture.

THE ROTARY AIR LOCK FEEDER

The rotary air lock feeder is also referred to as a rotary valve. A schematic view of a rotary feeder is shown in figure 2.

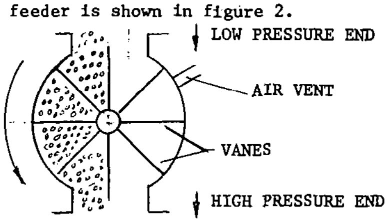

FIGURE 2 Schematic Of A Rotary Air Lock Feeder With Eight Wiper Vanes

* A list of references is included at the end of the paper.

Referring to figure 2, the tips and sides of the vanes are fitted with seals that compartmentalize particles fed into a low pressure sector for movement around to a zone of high pressure and thence into the combustor. A major effort was directed toward development of long lasting sealing methods and materials. Sawdust is an extremely abrasive material that requires special techniques that were developed in the program. To meet the 130 psig requirement of the R&D installation two air lock feeders operating in series proved adequate. To provide conservative design margins, it is planned to use two feeders in series for the 90 psig pressure requirements of the Huddleston installation as well as in succeeding installations up to 6000 kw.

TURBINE BLADE FOULING

At the outset of the R&D program reports on work involved with solids fueled gas turbine systems (References 2 through 5) were reviewed at length. The primary problem with coal fired turbines was erosion of the turbine blades. A secondary problem was fouling of the blades. In work performed by the Coal Utilization Research Laboratory at Leatherhead, England (Ref. 2) it was determined that single cyclones in series adequately cleaned the ash from the combustion gases to prevent erosion. Therefore, it was decided to use only single cyclones in the wood burning program. As a result, there has been no erosion of the turbine blades in the more than 1500 hours of operation with the gas turbines used in the R&D program. In the R&D performed by the Australians (Ref. 3) on brown coal it was found necessary to limit the turbine inlet temperature to 1200°F to avoid deposition of ash on the turbine blades. In the R&D performed at Leatherhead, England with stationery blades there was no significant deposition at 1450°F after 1000 hours of operation with black coal. In tests with pine sawdust in early operation at Roanoke with a small Garrett turbine no significant deposition occurred at 1450°F in 200 hours of operation. In tests with the Allison T-56 at Red Boiling Springs it was found necessary to periodically clean the turbine blades with milled walnut hulls when firing with a mixture of oak and poplar sawdust at 1450°F turbine inlet temperature. Above 1450°F the particles adhered to the blades snd could be removed only by scraping. The 1248°F turbine inlet temperature needed to produce 4000 kw with the LM 1500 gas turbine in the Huddleston installation is well below any problem zone for deposition with sawdust.

DISCUSSION OF LM 1500 GAS TURBINE PERFORMANCE AND FACTORS FAVORING ITS SELECTION

When the advancement was made from the Garrett 375 kw gas turbine to a larger engine, the Allison T-56-9 gas turbine selection was made on the basis of its perceived easy adaptability to the system and the availability of used engines from the U.S. Air Force. As the R&D program advanced, it became clear that the turbine inlet temperature would have to be restricted to 1450°F to avoid excessive turbine blade fouling. The turbine inlet temperature of the T-56-9 is 1700°F at its normal rated overall electrical output of 2332 kw. With a 1450°F turbine inlet temperature the output drops to 1500 kw, a value too low for economical operation.

A search for a more suitable gas turbine from standpoints of availability, adaptability to wood fueling, and electrical output led to selection of the General Electric J-79 gas generator and companion power turbine. The combined gas generator and power turbine was given the designation LM 1500 by General Electric. For aircraft propulsion the hot gases leave the engine at high velocity, propelling the airplane forward. For use in power production the hot gases are ducted to a power turbine. A favorable feature of a two shaft arrangement, such as this one, is that the gas generator can operate efficiently at part load by adjusting its speed downward while the power turbine operates at the required constant speed for power generation. The compressor efficiency is high over a broad range. This is made possible by adjustment of variable stators in the first six stages of the compressor. By adjustment of the stators to match the compressor speed and air flow, rotating stall is avoided and good compressor efficiency is maintained. Rotating stall is a phenomenon associated with flow separation on the compressor blades as the angle of attack on the blades increases with changes in rotative speed and air flow. Compressor efficiency over the speed range results in economical operation over a wide range of power production. Detailed information on turbine inlet temperature, compressor discharge pressure, and wood feed rate as a function of power output was derived from General Electric specification MID-S-1500-2.

Turbine Inlet Temperature - Figure 3 shows a straight line relationship between

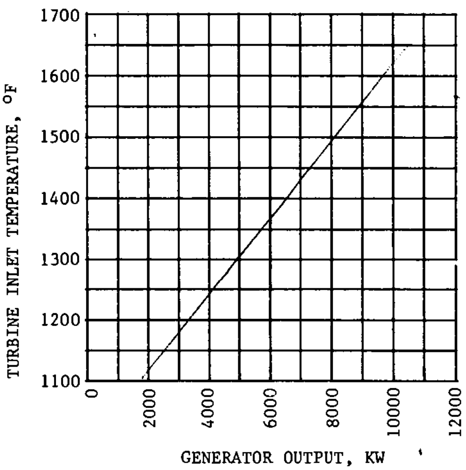

FIGURE 3 Plot Of Turbine Inlet Temperature Versus Generator Output With The G.E. LM 1500 GAS TURBINE At 1000 ft. Altitude And Compressor Inlet Air At 70°F

turbine inlet temperature and generator output. This characteristic provides a significant amount of latitude in operation with untried species of plants or sources of fuels such as clean waste. For example, it can be safely predicted that in the worst case the turbine inlet temperature of 1200°F required for a 3400 kw output will not result in excessive or difficult to clean accumulations on the turbine blades. Mininum performance guarantees would be warranted in such cases. With most wood species a 7000 kw output probably can be tolerated.

Compressor Discharge Pressure - Figure 4 shows a straight line relationship between compressor discharge pressure and generator output. The primary concern with pressure is the feeding of solid fuel into the combustion chamber. The demonstrated maximum sustained pressure in the R&D system is 130 pounds per square inch. Thus, the ability to sustain feeding of sawdust from 3000 kw to approximately 7500 kw is assured. The pressure required to produce the 4000 kw projected for the production facility now being prepared for installation at Huddleston, Virginia is only 90 psig.

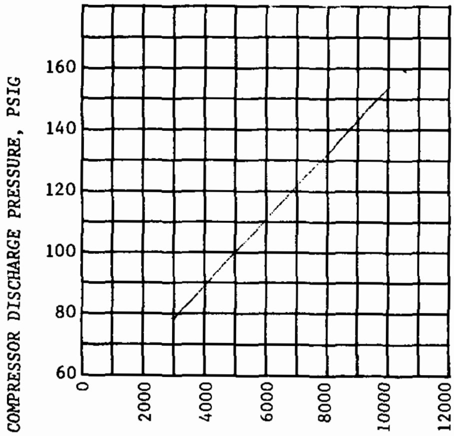

FIGURE 4 Plot Of Compressor Discharge Pressure Versus Generator Output With The G.E. LM 1500 GAS TURBINE At 1000 ft. Altitude And Compressor Inlet Air At 70°F

Wood Feed Rate - The wood feed rate in figure 5 is based upon a heat value of 8,200 Btu/lb for sawdust. The heat value ranges from 8100 Btu per pound for oak to 8,600 Btu per pound for yellow pine. Green sawdust as delivered from the mill averages

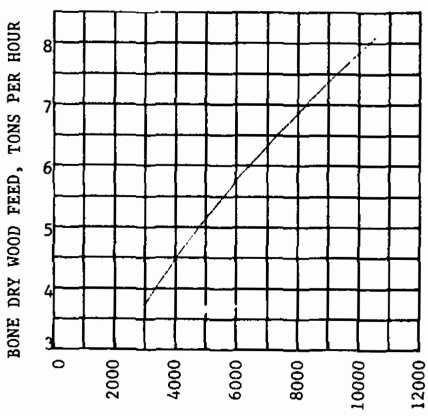

FIGURE 5 Plot Of Wood Feed Versus Generator Output With G.E. LM 1500 GAS TURBINE At 1000 ft. Altitude And Compressor Inlet Air At 70°F

approximately 45 percent water content. Trailers 40 ft. long normally deliver on the order of 25 tons of green sawdust per load. For the 4000 kw output projected for the Huddleston facility five trailer loads per day will be required. Shelter for approximately fifty truck loads will be needed to assure continued operation in the winter months when sawdust delivery can be erratic due to weather conditions.

ENGINE DURABILITY

A question frequently arises as to the life of an aircraft derivative gas turbine in stationary power applications. The answer is that the lower power output and lower turbine inlet temperature that are projected for this application make for very favorable longevity for the LM 1500 gas turbine. A twelve year life or greater before overhaul is predictable. The gas generator in the stationary application is never exposed to the extreme power requirements and high turbine inlet temperatures that exist during airplane take off. The primary requirement for long engine life in stationary applications is adequate filtration of the air entering the compressor.

SUGAR CANE AND SWEET SORGHUM FUELS

Sweet sorghum which is highly drouth resistant can supply two to three times as much fiber energy per acre as trees in some areas in addition to the sugar produced for alcohol and grain for food. The yield from sugar cane, in the areas where it can be grown, is even higher than from sweet sorghum. A further advantage is that there is no stigma attached to its use as a fuel, as there is with trees. This renewable fuel will result in a zero net increase in carbon dioxide. Based on the published research results (Reference 6) for sweet sorghum, the 66.66 million acres taken out of production between 1981 and 1988 can supply the energy to generate 34 percent of the power generated in 1986 in the U.S. The annual payment for setting land aside is estimated to be over $5 billion. Much more additional acreage can be easily devoted to sorghum as an alternative crop. Besides providing fuel for electric power the grain and sugar can produce in excess of 25.4 billion gallons of ethanol which equals fifteen percent of the energy supplied from imported oil. Intensive cultivation of sugar cane and sorghum in states bordering the Gulf of Mexico can result in tripling these outputs.

SUMMARY

The General Electric LM 1500 gas turbine has been chosen for use in the wood burning power production system because of its highly compatible performance characteristics, the ease with which it can be mechanically adapted to the system, and its ready availability. Salient points are as follows:

1. The 4000 kw power output projected for the production system being readied for installation at Huddleston, Virginia can be achieved with a 1250°F turbine inlet temperature and compressor discharge pressure at 90 psig. Both are well below the 1450°F turbine inlet temperature and 130 psig compressor discharge pressure found acceptable in the R&D program.

2. Power outputs up to 7500 kw can be achieved with oak sawdust while remaining below the 1450°F turbine inlet temperature and 130 psig compressor discharge pressure found acceptable in the R&D program.

3. There is adequate distance between the compressor and turbine to adapt the engine to the external burner required for wood and other biomass fuels.

4. J-79 gas generators are readily available on the overhaul and used market. New power turbines are available from manufacturers. In addition, a limited number of

serviceable complete LM 1500 sets are available for immediate use.

5. Both the Red Boiling Springs and Huddleston facilities are ideally located for demonstration of combined electrical power and fuel alcohol production from sweet sorghum.

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