Universität Rostock
Traditio et Innovatio

Aus der Professur für Abfall- und Stoffstromwirtschaft
der Agrar- und Umweltwissenschaftlichen Fakultät

Thesen der Dissertation

Electrical power generation from residual biomass by combustion in externally fired gas turbines (EFGT)

zur Erlangung des akademischen Grades
Doktor der Ingenieurwissenschaften (Dr.-Ing.)
an der Agrar- und Umweltwissenschaftlichen Fakultät
der Universität Rostock

vorgelegt von
M.Sc. Mathhar A. A. Bdour
geboren am 30.05.1987 in Irbid (Jordan)

Verteidigung am 29. Juni 2017

1. A modern micro scale externally fired gas turbine technology is discussed for electrical power production. This concept concentrates on processing solid biomass residues for energy utilization. This step becomes in the envelope of improving renewables investigation. The designed plant is capable to provide 15 kW_{th} based on biomass pellets combustion, this size superficially discussed in literature.

2. Gas turbine cycle follows the Brayton concept. The experimental part consists of pellets combustion burner as the heat source in gas turbine cycle. On the other hand, the rest of cycle components are modeled as real time simulation, this concept is described by hardware in the loop integration. Hardware in the loop can simulate the real components, and does the control process as well. This integration provided more flexibility in components parameters optimization. Also costly and technically effective for discussing the externally fired cycle with relatively accurate results.

3. The cycle is modeled for declaring the initial results, then, pressure and air mass flow are mapped as a function of the turbine inlet temperature. The procedure in mapping is by variating pressure from 1.4 – 8 bar, and air mass flow from 0.001 – 0.045 kg/s. the produced matrix includes both parameters optimum values at each turbine inlet temperature. This mapping is performed for both 50 and 100 % input power values, also for different heat exchanger difference values. It is seen that pressure map depends on only the turbine inlet temperature in a linear line. On the other hand, air mass flow is exponentially varied with turbine inlet temperature, the exponential line should also multiplied by a factor for different thermal power ranges.

4. Modeling methodology handled components main parameters like compressor and turbine efficiencies, heat exchanger thermal transfer and terminals temperatures, pressure drop, and rotational speed as well as rotor diameter. In addition to temperatures and power analysis.

5. Electrical power produced is highly dependable on the combustion temperature. It is possible to reach more than 2 kW_{el} at 1500 K. The heat exchanger difference has influence on the electrical power at low temperatures, however, this influence decreases with high temperature values.

6. The produced electrical power is around 1.4 kW at 950 K turbine inlet temperature. Pressure and air mass flow are adjusted to 3.4 and 0.021 kg/s respectively. The electrical efficiency is 10 % at the previous conditions. Efficiency can be improved by decreasing the heat exchanger difference and the combustion temperature as well. Both values are linked to burner design and the materials ability of high temperatures firmness.

7. The dynamic model of both compressor and turbine is adjusted to work 0.81 polytropic efficiency. At 3.5 bar, compressor and turbine isentropic efficiencies are 0.78 and 0.83 respectively in the steady state. Higher devices efficiencies improve the electrical efficiency, it also can compensate the low combustion temperatures.
8. The heat exchanger temperature difference is tested for flue gas temperature values in the range of 930-960 K. It is seen that for 50 K, 100 K, 150 K, and 200 K the achieved electrical power is 1.25 kW, 1.5 kW, 0.9 kW, and 0.8 kW respectively. This clearly shows the rule of the heat exchanger on the total electrical generation, also shows the effect of accumulated dirt's with time.
9. Thermal heat transferred through the heat exchanger is calculated to be around 10 kW. Referring to the 15 kW_{th} entered the cycle, the heat exchanger efficiency is about 66 % for the reference case. In order to have electrical power production, it is necessary to guarantee heat of more than 4.5 kW_{th} to be transferred through the heat exchanger, meanwhile.
10. Compressor consumes 3.3 kW_m for the reference case, which is necessary to increase the pressure to 3.4 bar. Air temperature after compression is between 450-460 K. On the other hand, turbine delivers 4.9 kW_m, the hot air leaves with a temperature of 750 K. The waste heat from the turbine can be exploited in further cycle for efficiency improvement.
11. The initial start of the plant requires around 30 min. This time is necessary to heat up all components for the steady state. The response to load variations is relatively slow, for example, the plant needs around 6 min to go from the minimum to maximum electrical power value. The slow behavior is proved to be due to the combustion process itself. All cycle components have faster response to transient cases than combustion, so it is assumed that the combustion process is the dominant one in the transient states.
12. Combustion is performed at under pressure around 16 Pa for all pellets types. It is seen that the resulting electrical power of straw is 0.9-1 kW at lower than 800 K turbine inlet temperature. This means an electrical efficiency of 6.7 %. Torrefied pellets can provide around 1.1 kW_{el} at around 850 K flame temperature. The reason of having lower electrical power from torrefied than wood is that volatile matter content in torrefied pellets is lower. This affects the flame length from the burner tube, which is in turn affects the entered flue gas temperature.

13. Based on oxygen content in the flue gas of 11-12.5 %, wood combustion emits higher CO in the flue gas compared to than straw and torrefied pellets. It is seen that NO_x is the lowest when wood is combusted. While straw combustion has relatively high NO_x emissions. CO_2 emissions are between 6-8 % of the volume of the flue gas for all fuel types.

14. It is seen that the rotational speed is calculated to be more than 155 thousand rpm as expected from literature, which is relatively high compared with other plants with higher thermal power range. This value could be reduced by increasing the turbine diameter or using a gear box, both solutions have constraints of pressure loss and vibration respectively.

15. Plant capital cost could be relatively higher than other renewables investigation, however, it is considered a reliable source due to the storage ability of the raw material. For instance, pelletizing is a good method of shaping and storing, torrefaction of biomass is further improvement on pellets properties. Currently, pellets are used in a commercial form for heating purposes.