MODELLING AND EXPERIMENTATION WITH A DIRECT FIRED 20 KWE GAS TURBINE WOOD GASIFIER

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ABSTRACT This paper is part of the CEEX national project "UBICENT". The objective of the project is to overcome technical, economic and environmental constraints for the utilization of significant amounts of woody biomass, specifically forest / wood biomass or hazardous forest fire fuels, in energy production. Our project is poised to test the Biomass Fuelled Micro Turbine approach to renewable energy production, and to demonstrate sustainable, competitive energy production through a micro-turbine system. The system uses a biomass combustor that fires a modified Garrett 30 ¡ 67 - 20 KW micro-gas turbine (the smaller size system provides benefits through fuel transportation cost reduction). The successful demonstration of the direct fired gas turbine will provide confidence and further investment in this high efficiency system. The current project status is presented, including theory, experiments and movies, divided in two major parts. The first presents calculation of the original and of the modified gas turbine combustor, together with original and partially modified gas turbine experimental characteristics. The second part presents a model of the wood gasifier and the geometric characteristics of an prototype built for the above gas turbine, thermal output 50 *KWt*, rated gas flow 125 *Nm3=h*, rated woody biomass, consumption 50 *Kg=h*, biomass size 50-100 *mm*. Preliminary experiments using this prototype, conducted in collaboration with CHANDERPUR WORKS, India, are also presented. In this stage, we consider the results to be satisfactory and the successful demonstration of the direct fired gas turbine will provide confidence and further investment in this high efficiency system.

1 INTRODUCTION

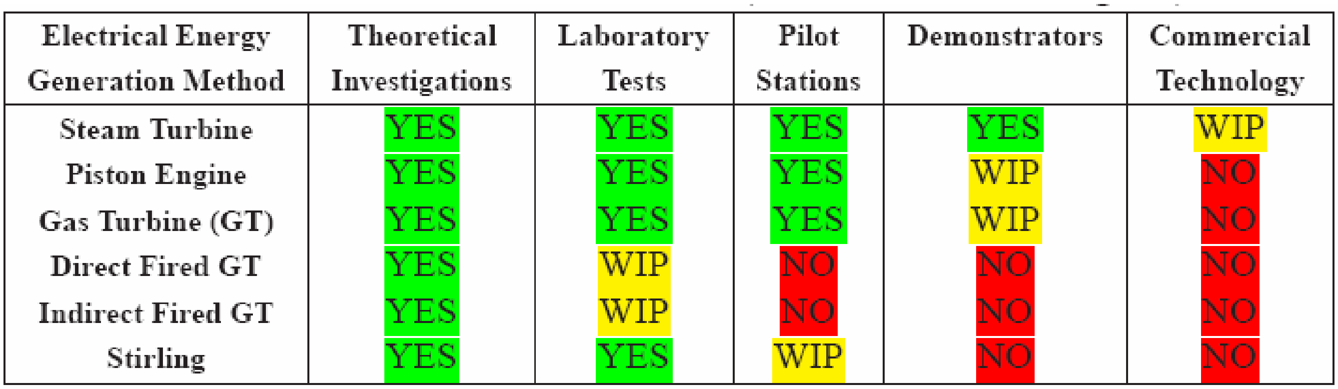
The objective of the project is to overcome technical, economic and environmental constraints for the utilization of significant amounts of wood biomass for energy production. The project is aimed at researching co-generation plants using biomass fuelled, gas micro turbines and to demonstrate sustainable and competitive energy production through a micro-turbine system using renewable energy sources.

The research team includes a number of specialists from a number of institutions and companies from Romania and from abroad: The National Research and Development Institute of Gas Turbines - COMOTI of Bucharest, Romania, The Technical University of Cluj - Napoca, Romania, The Technical University of Iasi, Romania, The ”Politehnica” University of Bucharest, Romania, The Applied Physics Institute of The Science Academy of Moldova, in Chisinau, The Technical University of Wroclaw, Poland, The Energy Research Institute of New Delhi, India, the Chanderpur Works Company of Yamuna Nagar, India, the Negura S.R.L. Company of Piatra Neamt, Romania, and the Pewo EnergieTechnik Company of Elsterheide, Germany.

2 NATIONAL AND INTERNATIONAL CONTEXT IN THE FIELD

The Directive 2001/77/EC Directive of the European Council from September 27th, 2001 established the strategic objectives concerning the renewable energy resources, observing the provisions of the Kyoto Protocol requirements, ratified by the European Union in 2002 and by Romania in 2001. Thus, the renewable energy contribution to the total reported primary energy consumption must reach 12% in 2010. In this context, worldwide, the interest in energy production from renewable sources is major, and is the goal of a large number of various technological studies. Pilot and demonstration facilities incorporating gasification technology and gas turbines have been and are currently under development in Scandinavia, the US, Brazil, and the EU. In Romania, a number of successful research projects have been conducted in the field of co-generation using micro gas turbines (1) but the biomass utilization as fuel is a new research topic, and there are no previous studies, yet. A summary of the status of these studies, developed by the Institute for Energy Economics and Rational Use of Energy, University of Stuttgart, 2003, is presented in Table **1**.

Table 1: **Research status in the field. (*WIP* =Work In Progress)**



Electrical Energy Generation Method	Theoretical Investigations	Laboratory Tests	Pilot Stations	Demonstrators	Commercial Technology
Steam Turbine	YES	YES	YES	YES	WIP
Piston Engine	YES	YES	YES	WIP	NO
Gas Turbine (GT)	YES	YES	YES	WIP	NO
Direct Fired GT	YES	WIP	NO	NO	NO
Indirect Fired GT	YES	WIP	NO	NO	NO
Stirling	YES	YES	WIP	NO	NO

3 THEORETICAL CONSIDERATIONS

From a chemical standpoint, biomass may be considered as composed of (2) cellulose, hemicellulose and lignin. The biomass thermal conversion has three stages: pyrolysis, gasification, and combustion. In a classical biomass burner, the amount of available oxidizer is sufficient to allow the completion of all three stages in a very fast succession, creating the impression of a direct biomass combustion (Figure **1**). In reality the processes involved in biomass combustion do not occur at the solid material surface, but at a certain distance from it, depending on the available oxidizer amount, on the biomass type and on the surrounding fluid velocity field (3). This happens because the chemical reactions involved in combustion can only develop in gaseous phase, when the fuel and the oxidizer are mixed at a molecular level.

The first step for achieving this mixture is the pyrolysis reaction. In the presence of the heat provided by the combustion gases, at temperatures in the range of 450 - 600 C (2), the organic molecules that form the wood material, unstable at high temperatures, are decomposed into gaseous compounds, vapor compounds that condense at temperatures below 400 C (4), and solid compounds, forming about 15 to 20 % from the initial solid mass, but with a high energetic content, about 50 % per higher per unit mass than the initial fuel (2). The energy consumption for heating and vaporizing the solid fuel (i.e. the heat of pyrolysis) is between 5 and 15 % from the fuel (dry wood) heat of combustion, the energetic efficiency of the process being particularly good. In classical burners, the gaseous and liquid compounds enter directly into the combustion process. In gasifiers, the pyrolysis products participate in an intermediate stage, the gasification, meant to create a gaseous combustible mixture, the so-called *producer gas* for air gasification, or *syngas*, for Oxygen gasification. The producer gas (or syngas) heat of combustion is of about $5{:}700\ J{=}kg$, lower than for classical fuels, such as gasoline or methane, and a typical producer gas composition is (5): Nitrogen (N_2): 50.9 %; Carbon monoxide (CO): 27.0 %; Hydrogen (H_2): 14.0 %; Carbon dioxide (CO_2): 4.5; Methane (CH_2): 3.0, and Oxygen (O_2): 0.6.

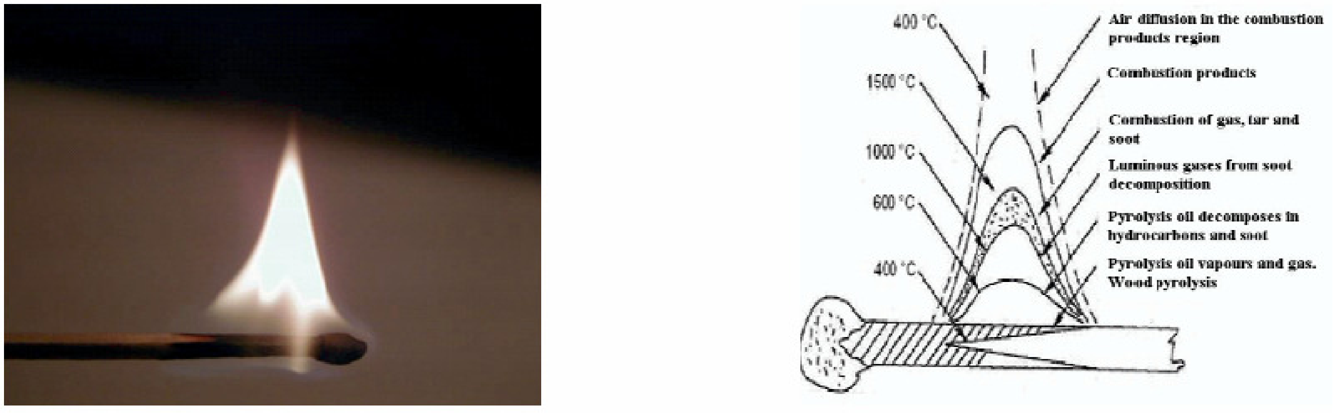


Figure 1: **Match stick combustion**

The conversion of the solid material resulting from the pyrolysis (pyrolysis charcoal) into gas, occurs according to (4) either the Bodouard (1) or the water-gas (2) reactions.

$$C + CO \rightarrow 2CO \tag{1}$$
$$C + H2O \rightarrow CO + H2 \tag{2}$$

For biomass gasification, after the pyrolysis process is completed, most of the resulting material (75 % to 90 % of the fuel mass) is in the form of volatile compounds. The conversion of these products into gas (the actual gasification process) can be globally described through the following chemical equation (assuming thermal equilibrium):

$$CH1.4O0.6 + 0.35O2 \rightarrow 0.4CO + 0.6H2 + 0.4CO2 + 0.1H2O + 0.2C \tag{3}$$

A schematic representation of the gasification process is presented in Figure **2**

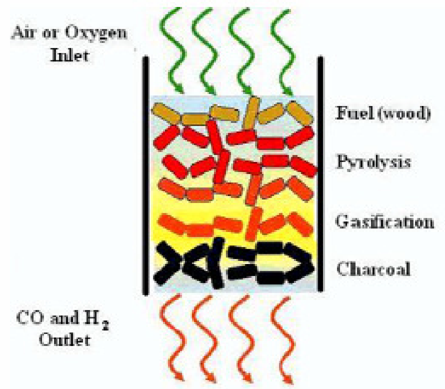


Figure 2: **Gasification process schematics**

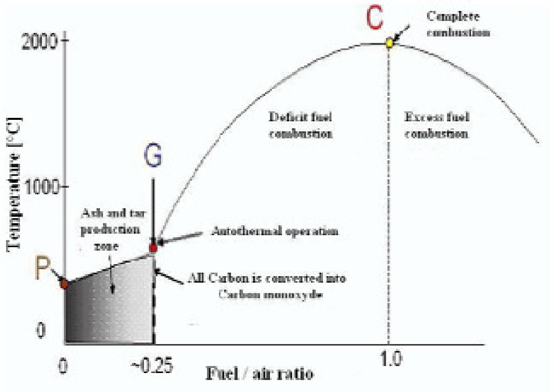


Figure 3: **The Reed - Desrosiers diagram**

The completeness and, hence, the efficiency of the gasification process depend, fundamentally, on the fuel / air (or Oxygen) ratio (equivalence ratio). If the ratio is to large, important amounts of soot and tars result, while if it is too small, the pyrolysis charcoal is consumed too fast and part of the producer gas is burned in the combustion process. The position of the fuel / air optimum depends on a number of factors, such as (2): the water content of the fuel, the biomass type, and the air mass flow rate through the gasifier. For a better understanding of the key influence the fuel / air ratio plays in the gasification process, Figure **3** presents a diagram defining the equilibrium temperature of the biomass decomposition reaction, as a function of the equivalence ratio (2). In Figure **3**, points ”P”, ”G”, and ”C” represent, theoretically, the optimum equivalence ratios for, respectively, the pyrolysis, gasification and combustion processes.

4 PROJECT STATUS

4.1 Gas Turbine Engine

As the main purpose of this project is to conclusively demonstrate the micro gas turbine engines operation fuelled by biomass, the main issues related to the selection of the research equipment are:

1. Gas turbine engine power: 20-30 KWe;
2. Operational resource: As high as possible;
3. Fuel: Allow gaseous fuel operation;
4. Design: Easy to dismantle, re-design, and modify;
5. Price: Acceptable for the project budget.

Hence, the selected gas turbine was the $Garrett\ 30-67$ turboengine, part of the $EMU\ 12 = E\ 20Kw$ electrical generator, presented in Figure **4**.

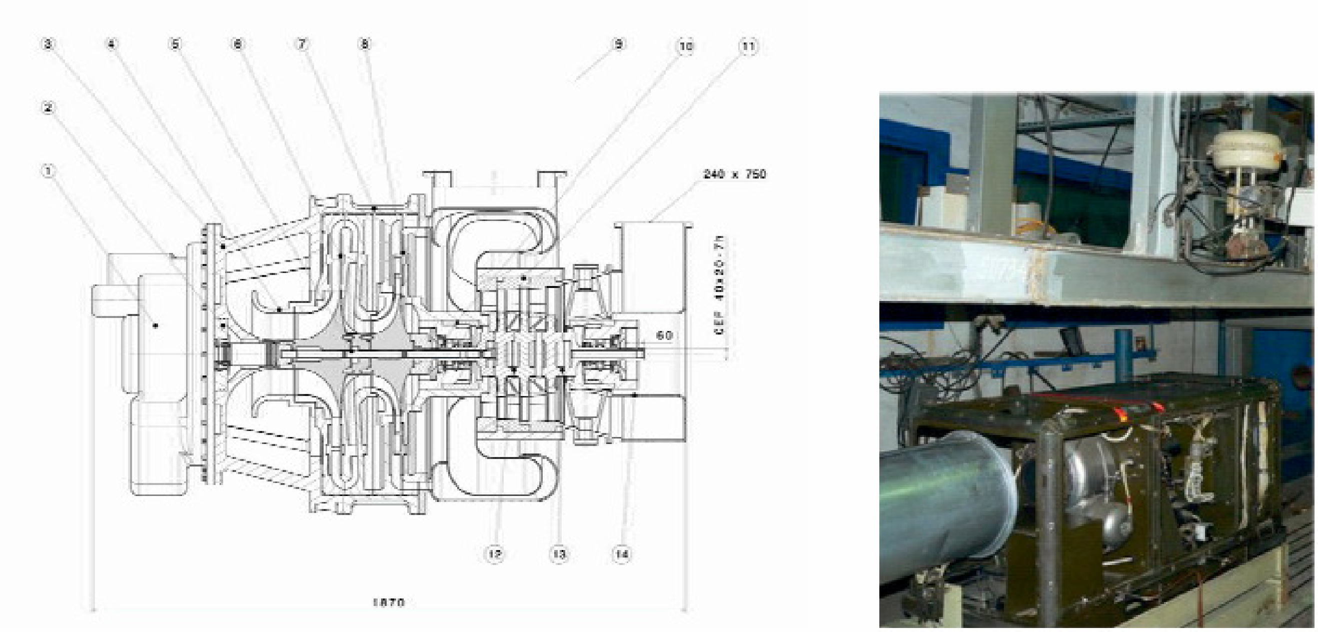


Figure 4: **The Garrett 30-67 gas turbine engine**

For the selected engine fuelled with aviation petroleum and operating on the engine characteristic, a set of experimental measurements (6) for the exhaust gas chemical composition and temperature has been conducted. The results of the measurements are presented in Figures **5** and **6**: An infrared survey of the operating engine was also conducted during the experimentation, using an FLUKE SmartView infrared camera model $Ti45FT$, with a 20 mm, $F\ 0.8$ lens, at an emissivity setting 0.95. The camera was calibrated through comparison with classical thermal sensors measurements up to an rms deviation between measurements of below 2 %.

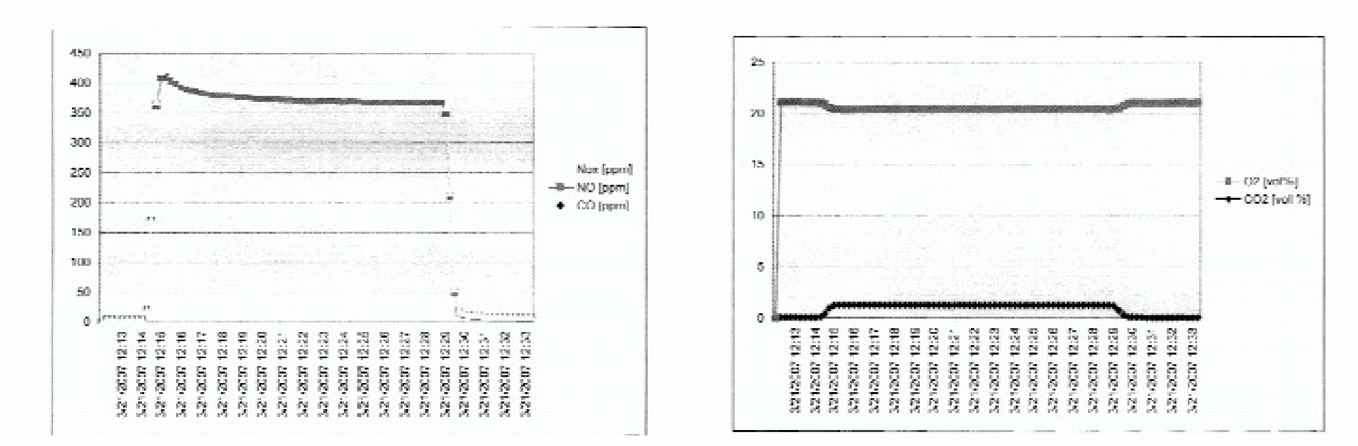


Figure 5: **Garrett 30-67 exhaust gas composition**

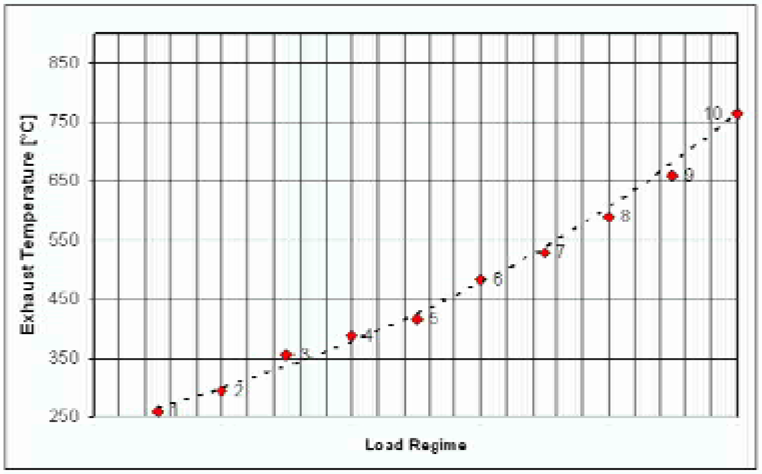


Figure 6: **Exhaust gas temperature. Regime 1 represents operation without load, and regime 10 the maximum load (20 kW)**

Figure **7** shows a picture of the exhaust nozzle of the engine operating idle (left), and at a load of 8.55 kW (right). The central part of the Figure shows the infrared view, while the edges represent normal light view. is given can be found in Table **2**.

Region	Location	Average temperature idle	Average temperature loaded
A	Exhaust duct	51.2 C	–––
B	Engine exit section	247.9 C	365.0 C
C	Engine compressor	101.6 C	114.9 C
D	Combustion chamber housing	121.5 C	–––

Table 2: **Location of the temperature measurement regions**

As expected, temperatures are higher for the loaded regime than for the idle one. Obviously, temperature T_B is a reasonable estimation of the turbine exhaust gas temperature (generally noted as T_4), and temperature T_C is a good estimation of the compressor exhaust gas temperature (generally noted as T_4). Temperature T_A, the exhaust gas temperature in the duct, can provide information about the engine excess air, by comparison with T_B. T_D, which is an estimate of the temperature of the dilution air surrounding the combustion chamber flame tube, is slightly higher than T_C, due to the flame tube radiation.

Figure 7: **Infrared view of the Garrett 30-67 engine exhaust nozzle**

Figure **8**, shown below, provides the working temperature of the electrical generator, at a load of 8.55 kW.

Figure 8: **Electrical generator temperature**

Since the goal of the project is to operate the gas turbine fuelled by producer gas, the combustion chamber of the engine had to be modified to accommodate the gaseous fuel, different in some specific respects (such as mixing time and length scales, flame length, flame temperature, air dilution pattern, and so on) from the liquid fuel for which the gas turbine was originally designed.

A three-dimensional view and the assembly drawing of the re-designed combustion chamber are shown in Figures **9** and **10**. Several constructive solutions are currently considered for the gas turbine operation:

1. Producer gas fuelling of the gas turbine;
2. Dual fuelling (petroleum and producer gas) of the gas turbine;
3. Producer gas fuelling of the gas turbine with post-combustion system fuelled by producer gas;
4. Dual fuelling (petroleum and producer gas) of the gas turbine with post-combustion system fuelled by producer gas;

A numerical simulation of the post-combustion system was carried on using the standard producer gas composition presented previously in order to asses the flame stability under real-life operating conditions and to assist the post-combustion design. For this a rectangular duct fitted inside with a triangular prism acting as flame stabilizer was numerically simulated using a

Large Eddy Simulation technique. Details on the used numerical algorithm are given in a previous paper (7) The geometry of the simulated device was chosen to match the geometry of the selected gas turbine exhaust and is presented in Figure **11**.

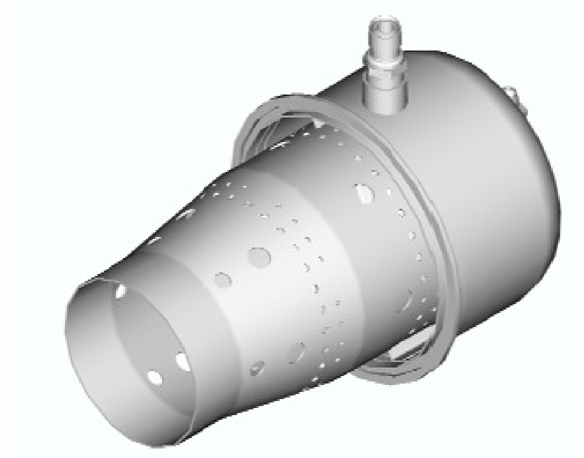


Figure 9: **Three-dimensional view of the redesigned combustor**

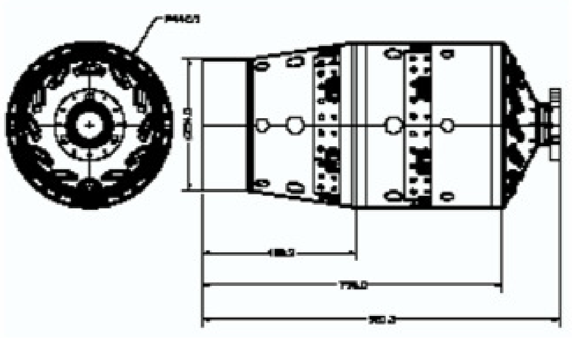


Figure 10: **Assembly drawing of the redesigned combustor**

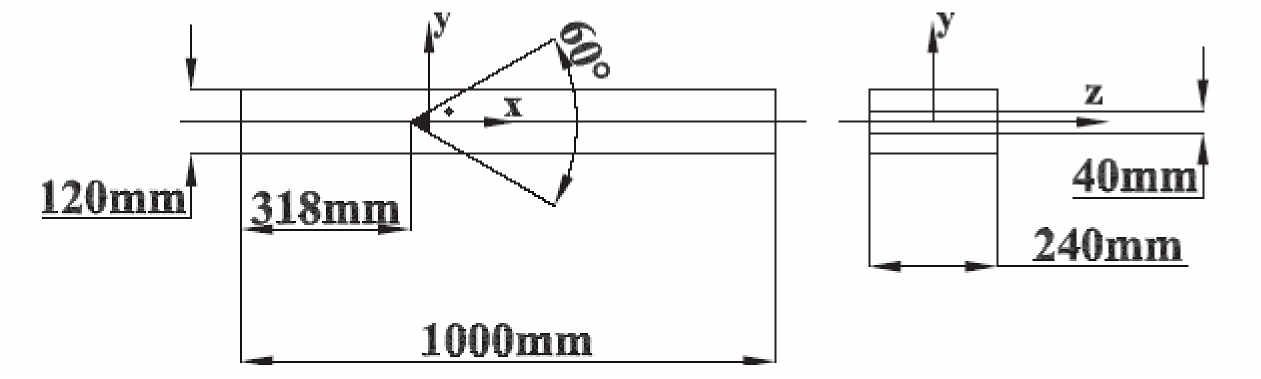


Figure 11: **Geometry of the LES domain**

Sample results are presented in Figure **12**, showing the vorticity field (in solid color), the flame reaction rate (the black lines) and the mean fluid temperature (the color lines).

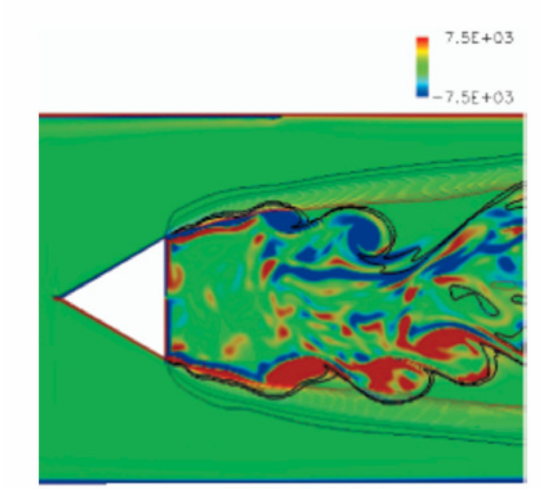


Figure 12: **Post-combustion flame Large Eddy Simulation**

4.2 Gasifier

A general model of the gasification process was developed for the project. The model aims at predicting the producer gas composition, the conversion efficiency, the producer gas heat of combustion, the optimum temperature in the reduction zone, and the relative volumetric gas and air flow rates, as functions of the equivalence ratio, the relative humidity and the ash content, presumed known. The model is based on a global gasification reaction model, on the material balances for Carbon, Hydrogen and Oxygen, and on the heat balance of the gasification process, assumed adiabatic. Sample results of the numerical simulation results carried on using the model are presented in Figure **13**. The Figure shows the variation of component gas concentrations, heat of combustion, energy conversion efficiency, and the specific gas flow rate. The details of the model as well as extended model validation results are given in a previous paper (8). The gasifier installation used for this project is the result of a common research project of the National Research and Development Institute of Gas Turbines - COMOTI of Bucharest, Romania, The Energy Research Institute of New Delhi, and the Chanderpur Works Company of Yamuna Nagar, both from India.The assembly drawing of the gasifier installation is shown in Figure **14**.

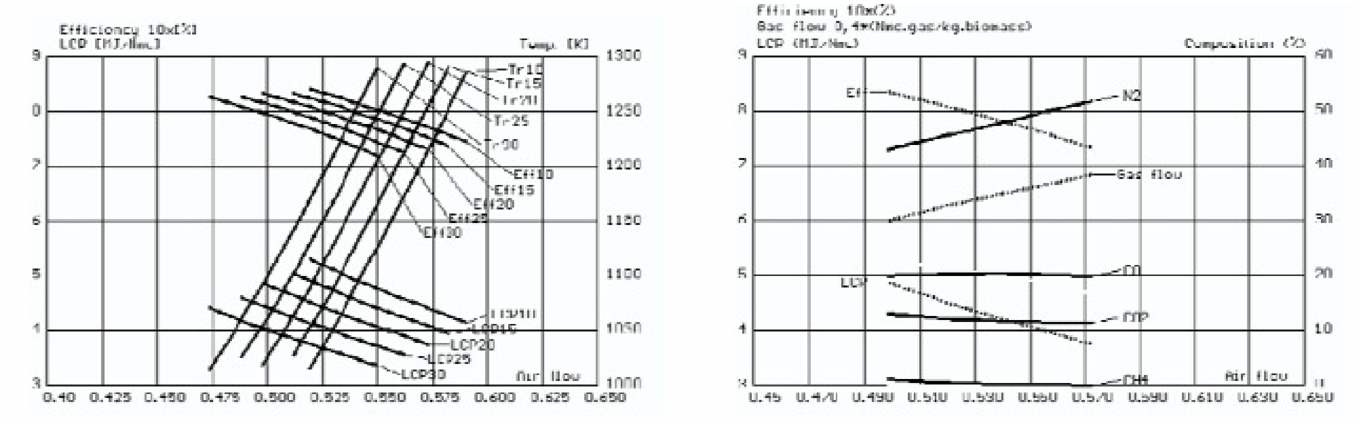


Figure 13: **Results of the gasification numerical simulation**

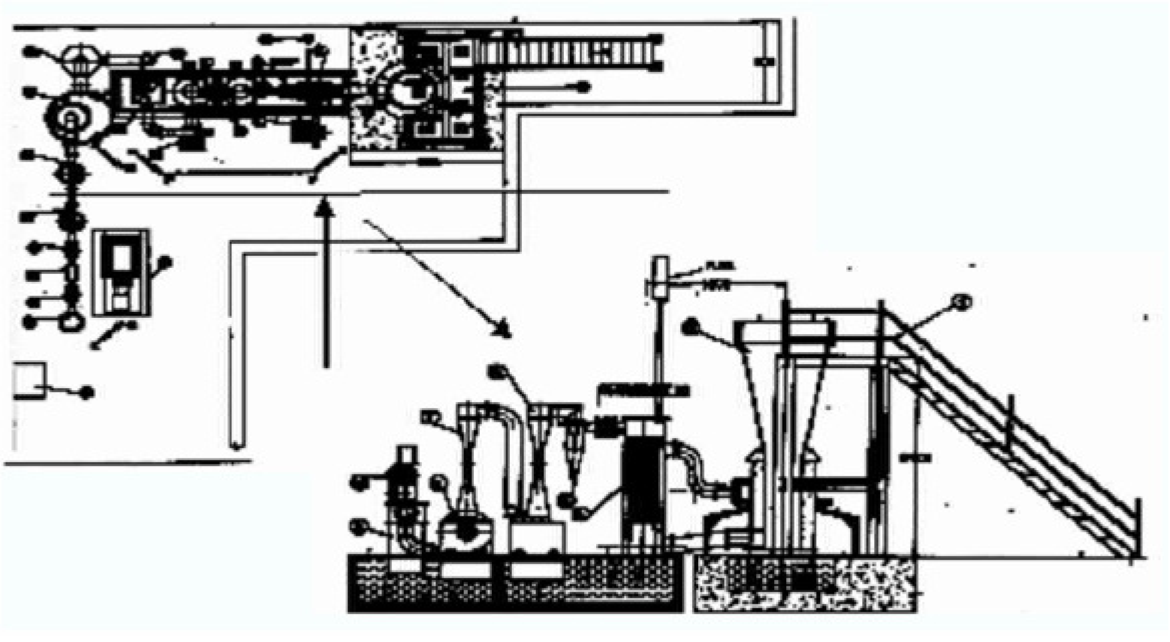


Figure 14: **Gasifier installation assembly drawing**

5 CONCLUSION

The results obtained so far are promising in what concerns the wood biomass utilization for cogeneration using micro gas turbines. A gas turbine suitable for the process was selected and experimental measurements describing its operation using liquid fuels were conducted. A new combustion chamber designed for producer gas operation was designed and will replace the combustor currently powering the gas turbine. Also, a numerical simulation of a post-combustion system that will be used to increase co-generation plant efficiency was conducted using standard producer gas composition. A gasification theoretical model was developed and validated and a gasifier installation was designed and is currently being manufactured in India. The next stages of the project will include the completion of the gasifier manufacturing, experimental measurements of the gasifier at its manufacturing place, the gasifier installation at the project leader facility, the manufacturing of the re-designed combustor and its installation in the gas turbine engine, the design and the manufacturing of the post-combustion system, experimental measurements of the gas fuelled gas turbine with and without post-combustion, and the numerical simulation of the post-combustion using the measured producer gas and exhaust gas composition data.

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