Electric field effect on the thermal decomposition and co-combustion of straw with solid fuel pellets

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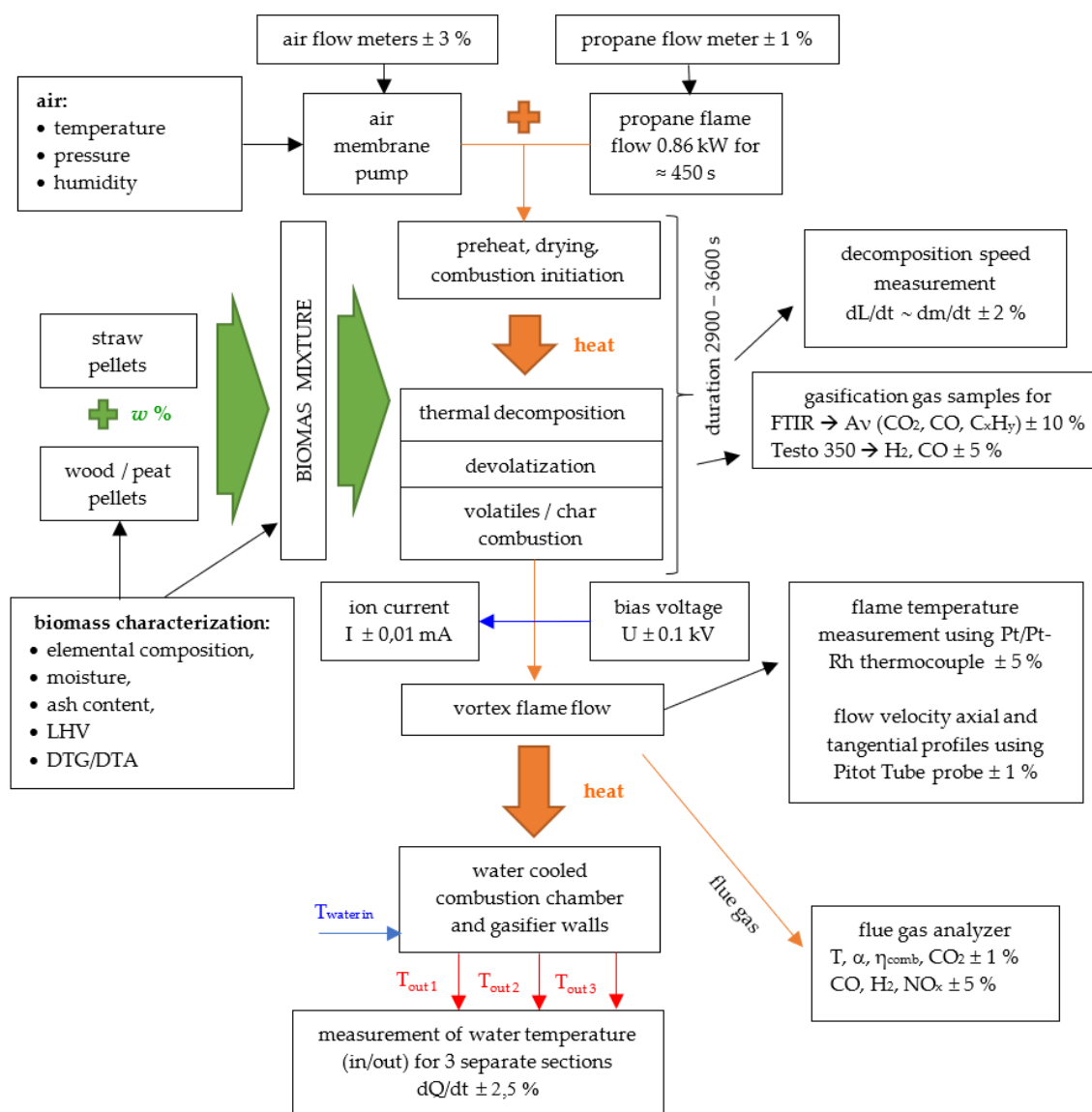## 1. The supplementary experiment description

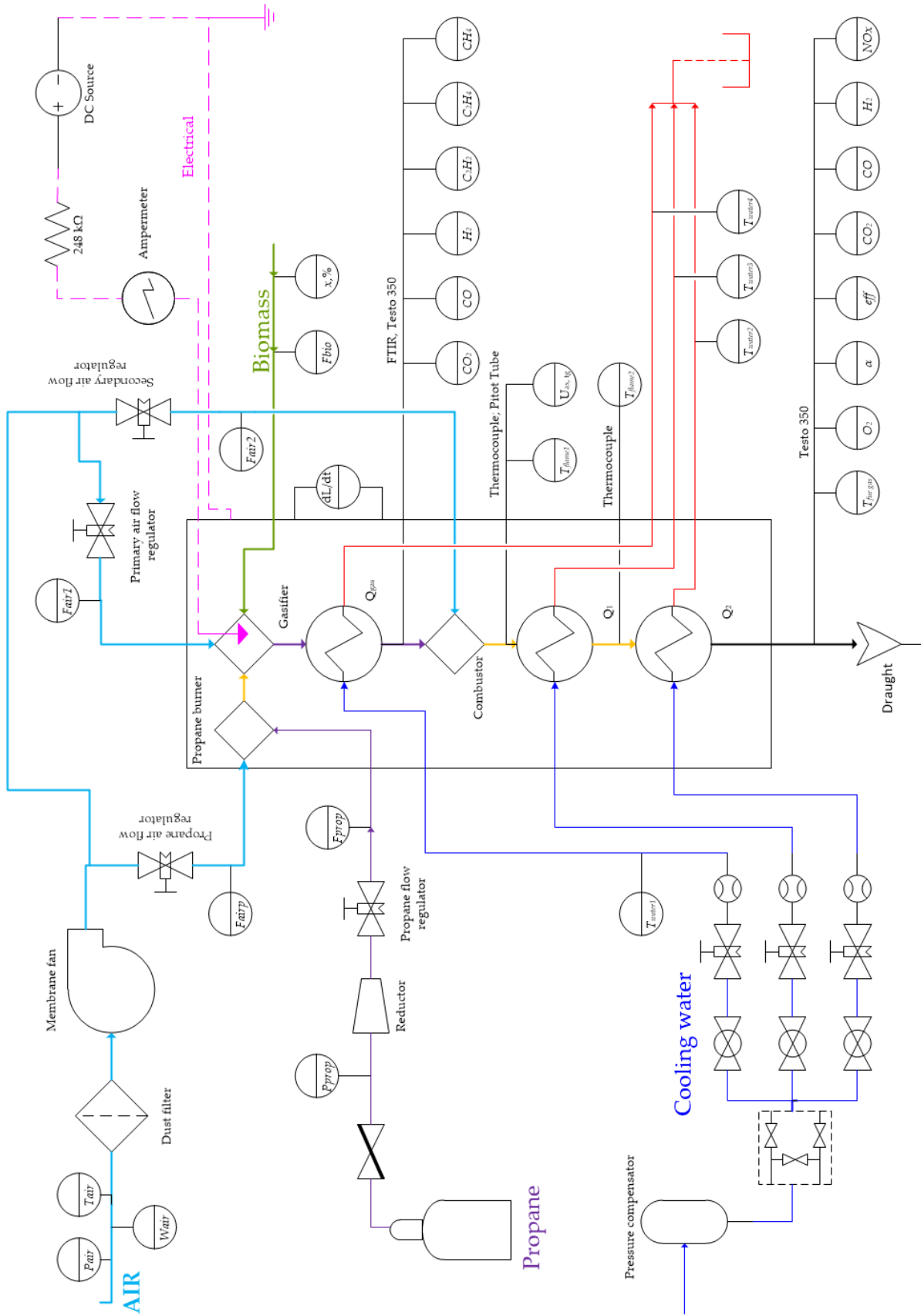**Figure S1.** The diagram of a schematic description of the experiment.

Figure S2. The technological scheme of the equipment and measurement instruments.

2. The discussion about the measurement data acquisition and accuracy, the experiment repeatability and uncertainty

The experimental study of the effects of wheat straw co-gasification and co-firing on the development of the main combustion characteristics includes complex **time-dependent measurements** of flow velocity component (u, w), flame temperature (T), composition of gasification gas (CO_2, CO, H_2 C_2H_2, C_2H_4, CH_4) and of flue gas (volume fractions of O_2, CO_2, mass fractions of CO, H_2, NOx), biomass weight loss rate (dm/dt, g/s) and heat power with a total collected heat from the experimental device.

The **local measurements** of the flame and flow characteristics were made online using a special holder for the diagnostic tools equipped with a precise micro manipulator which allows moving the diagnostics tools in the radial direction across the flow.

2.1 Data acquisition and processing

The combustion of the discrete portions of the biomass in the experimental setup allows to eventually analyze different stages of the biomass thermal decomposition and combustion of volatiles. The complete thermochemical conversion of the discrete portions of wheat straw, softwood and their mixtures are lasting about 2900 s, while the thermochemical conversion of peat and its mixtures with straw is lasting up to 3600 s.

The time-dependent measurements data collection is carried out once per second using online loggers unique for each measurement, then processed using MS Office Excel. The averaged values of the different parameters for separate stages of the thermochemical conversion are calculated in the definite period of time relying on the kinetics plots.

2.1.1. Biomass characterization

The elemental composition (C, H, N contents) of softwood, wheat straw, bog peat biomass types were measured using the Vario Macro elemental analyzer (ELEMENTAR Analysensysteme, Germany) and analyzed according to the LVS EN 15104:2011 standard. The ash content was measured as a residue after treatment at 830 ± 10 K in a Carbolite ELF 11/6B furnace according to the LVS EN 14775:2010 standard [20]. The higher heating (HHV) and lower (LHV) values of the pellets were calculated by the regression equation proposed by Friedl et al. [21]. The thermal decomposition of the biomass pellets and their mixtures was studied in the temperature range 300–900 K by differential thermogravimetric and thermal analysis (DTG/DTA) in an oxidative atmosphere (50 ml·min^{-1} air flowrate) using the Metter Toledo Star System TGA/SDTA 851e at a heating rate of 10 K·min^{-1} [20].

2.1.2. Air flow

The primary and secondary air supply (and a propane air flow) is measured using Testo 6441 flowmeters with an accuracy ± 1 l/min, which is ± 2.5-3% considering air supply 30-40 l·min^{-1} to the separate pilot device sections. The same method ad accuracy is provided for ensuring appropriate air supply to the propane burner.

2.1.3. Ionic current

The DC source provide bias voltage regulation from 0 to 1.8 kV with a step 0.3 kV, but ionic current amperemeter measuring accuracy is 0.01 mA. Considering the lowest ionic current and the highest at 0.6 kV and 1.8 kV the measurement error could possibly reach ± 1%.

2.1.4. Thermal decomposition rate

The experimental study of the biomass mixture thermal decomposition involves complex time-dependent measurements of the biomass height (L) in the gasifier (dL/dt, mm·s^{-1}) using the

moving rod with a pointer. From the measurements of dL/dt and volume density of the biomass mixture, the mass loss rate (dm/dt, $g \cdot s^{-1}$) of the mixture was estimated with the accuracy $\pm 2\%$.

2.1.5. Gasification gas composition

The composition of the volatiles produced at the thermal decomposition of the biomass mixtures was measured at the outlet of the gasifier by a FTIR spectroscopy method. The 50 ml gas samples were extracted with a 50 s time interval and analyzed using the Varian Cary 640 spectrometer at the MIR spectral range for CO_2 (668 cm^{-1}), CO (average of 2115 and 2169 cm^{-1}), C_2H_2 (729 cm^{-1}), C_2H_4 (949 cm^{-1}), and CH_4 (3017 cm^{-1}). Additionally, at the outlet of the gasifier, CO and H_2 were measured with the gas analyzer Testo 350. Analyzing separate stages of the thermochemical conversion of the biomass the measurement method error can reach up to $\pm 10\%$ considering the rate of occurrence of certain stages of combustion and the rate of gas sampling. The measurement method accuracy can be increased by increasing the number of samples over a period of time.

2.1.6. Vortex flow velocity

The local measurements of the axial (u) and tangential (w) flow velocity components were made using a Pitot tube and Testo 435 flowmeter, providing continuous online data monitoring (once per second) with an accuracy of $\pm 1\%$. The data collection is proceeded at the stable self-sustaining combustion (usually after 900 s). The data collection for each local point lasts about 20 s. During each experiment the full axial (u) and tangential (w) flow velocity components radial distribution can be acquired twice. The Testo 435 flowmeter specification is available on the main webpage.

2.1.7. Flame temperature

The Pico logger recorded the local temperature measurements from the Pt/Pt-Rh thermocouples with an accuracy of $\pm 5\%$ providing data online registration. The data collection is proceeded at the stable self-sustaining combustion (usually after 800-900 s). The data collection for each local point lasts about 30 s. During each experiment the temperature radial distribution can be acquired twice.

2.1.8. Flue gas composition

The local measurements as well as the time-dependent measurements of the flue gas composition: mass fraction of unburned volatiles (CO, H_2), volume fraction of the main combustion product (CO_2), mass fraction of NO_x pollutant, combustion efficiency (η_{comb}) and of the air excess ratio (α) were made by the Testo 350 gas analyzer. In accordance with the Testo 350 specification, the O_2, CO_2 volume fraction was measured with an accuracy of $\pm 1\%$ and the mass fraction of CO, H_2 and NO_x with an accuracy of about $\pm 5\%$. The data collection is proceeded at the stable self-sustaining combustion (usually after 800-900 s). The data collection for each local point lasts about 30 s. During each experiment the flue gas composition radial distribution can be acquired twice. Delays in determining each of the parameters are taken into account in accordance with the specification of the measuring device. The gas analyzer Testo 350 specification is available on the main webpage.
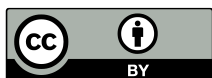
2.1.9. Pilot device heat power

The pilot device heat power was calculated from the calorimetric measurements of the cooling water for the separate device sections (gasifier and two combustion chamber sections). The water flow was measured using flow meters with the accuracy $\pm 2.5\%$ and the measurements of the temperature of in and out flow were made with the accuracy $\pm 1\%$ by thermo-sensors AD 560, along with online data registration by the Data Translation DT9805 data acquisition module and Quick DAQ software.

2.2. Repeatability and uncertainty

As one can see from the experimental schematic (Figure S1), the measurement of 23 simultaneous parameters is performed during the experiment lasting up to 3000 s for each biomass mixture and for various applied bias voltages. Totally about 60 experiments have been performed and big data has been processed and analyzed to provide an extensive research both on co-combustion of solid biofuel and electric effect on flame. The experiment is performed with one variable: straw-to-wood/peat for the experiments of co-firing or bias voltage of the axially inserted electrode for the experiments of electric field effect on the flame. The experiments are performed for the session of one variable in a row and are repeated at least three times to prove the stability and repeatability of the effect gained throughout the experiment.

The results obtained using the experimental device was approbated during long scientific work, publishing the results in the scientific journals and representing them at the scientific conferences. The approbation of the technology of the electrodynamic control for biomass combustion has been tested on burners of different configurations and different capacities.