Advanced Sustainable BIOfuels for Aviation

Deliverable D2.1: Biochar unit for agroresidues developed and ready for tests, with a capacity of 40-50 kg/h inlet feedstock

Consortium:

Acronym	Legal entity	Role
RE-CORD	CONSORZIO PER LA RICERCA E LA DIMOSTRAZIONE SULLE ENERGIE RINNOVABILI	CO
TRC	TOTAL RAFFINAGE CHIMIE SA	BEN
TRF	TOTAL RAFFINAGE FRANCE	BEN
SKYNRG	SKYENERGY BV	BEN
CENER	FUNDACION CENER-CIEMAT	BEN
ETA	ETA – Energia, Trasporti, Agricoltura Srl	BEN
CCE	CAMELINA COMPANY ESPANA S.L.	BEN
JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION	BEN

CO…Coordinator, BEN…Beneficiary

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Document Type		
PRO	Technical/economic progress report (internal work package reports indicating work status)	
DEL	Technical reports identified as deliverables in the Description of Work	**X**
MoM	Minutes of Meeting	
MAN	Procedures and user manuals	
WOR	Working document, issued as preparatory documents to a Technical report	
INF	Information and Notes	

Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	
CON	Confidential, only for members of the Consortium	

Table of Contents

1 Summary

The present document reports on the modifications carried out on the continuous carbonization pilot unit to comply with the specific requirements of the activities foreseen in BIO4A. During the first 12 months of the BIO4A project, the pilot unit underwent extensive hardware adaptations, specifically in the hot gas section (collector of pyrolysis gas, in-line filtering elements, heat-traced line, supports), measurement and control system, and chimney. The mechanical adaptations have been completed on time, and the biochar unit for agroresidues is now ready for test.

2 Description of the plant

The Carbonization pilot unit is a continuous biomass carbonization system based on fixed-bed, open-top, downdraft design, borrowed from the established fixed-bed gasification technology, operating in autothermal pyrolysis in the temperature range of 450 – 700°C and equivalence ratio (ER) in the range 0.1-0.2. By operating in open-top mode, the plant is intrinsically explosion-proof, as it cannot go in overpressure in case of fault. Figure 1 reports the unit block diagram, showing the main steps of the process: the pilot unit is essentially composed of three sections: (1) loading and conversion of biomass; (2) charcoal discharge and cooling system; (3) extraction and combustion of pyrolysis gas (vapors and permanent gases).

The plant, made in stainless steel (AISI 304 and 316), is designed for a capacity of up to 50 kg h^{-1} of biomass with up to 20 % (wet mass base) moisture content. Biomass and air enter co-current the reactor from the top through a non-hermetic gate valve, kept wide-open during normal operation; biomass is manually loaded in batches of 5-10 kg. Through the reactor, solid and pyrolysis gas flow downward, respectively extracted by a variable speed screw at the bottom and an ejector. Geometrically, the reactor consists of a vertical cylinder of 0.63 m diameter and 1.6 m high, externally insulated, and is connected at the bottom to the char discharge hopper (truncated pyramid) that is approximately 0.6 m high. The hot pyrolysis gas stream is not extracted at the bottom of the solid bed, as it is common with downdraft gasifiers, but it is instead withdrawn through a 3” (88.9 mm external diameter) connected 0.18 m above the bottom of the reactor, that is 1.4 m below the top opening (biomass and air entrance). This leads to the formation of two distinct bed zones: the first, relatively rich in oxygen, located above the pyrolysis gas extraction duct, and a second zone, oxygen depleted, below it.

The reactor is equipped with four K-type thermocouples: three (T_1, T_2, T_3) measure the axial temperature profile in the oxygen-rich zone, and one (T_8) measures the temperature of the produced charcoal in the oxygen depleted zone right before the char extraction screw. All the thermocouples have an insertion length in the radial plane of the reactor of approx. 5 cm, to limit the disturbance on the stratified biomass/charcoal bed and avoid the formation of bridges.

The charcoal discharge hopper (0.1 m^3, 70° slope walls) ends in a tilted screw conveyor, externally water cooled (AISI 304, 3 m x Ø250 mm, variable pitch, 32° slope), which unload the produced charcoal into an inter-changeable, air-tight barrel with an internal capacity of 0.2 m^3. Biomass residence time is regulated by the rotational speed of the screw (variable).

Once withdrawn from the reactor, the pyrolysis gas passes through a cyclone for abatement of entrained dust, a butterfly valve, an air-blown ejector and a torch, where it is combusted. A valve is installed after the cyclone for tar sampling. The whole line is externally heated by 9 electric heaters in order to avoid tar condensation. The torch is equipped with two LPG pilot burners rated for approx. 5 kW each. The ejector is driven by pre-heated compressed air (delivery pressure 2-4 bar gauge, temperature up to 450 °C). The suction pressure at the ejector suction port can be regulated by adjusting the motive-air flowrate and pressure of the ejector, while the flowrate of the pyrolysis gas can be regulated by operating on the aperture angle of the butterfly valve on the gas line, thus adjusting the pressure loss above it. Five K-type thermocouples are installed along the gas line.

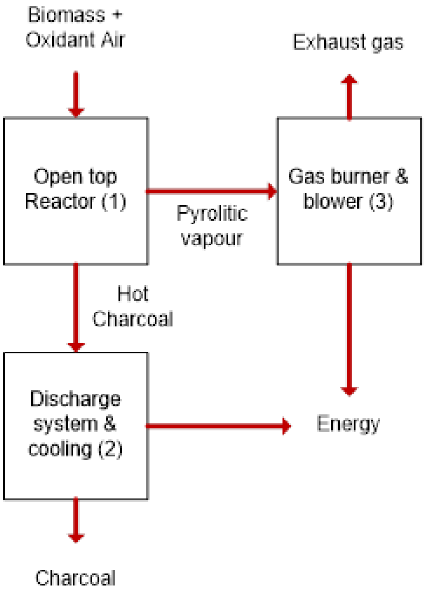

Figure 1: Block diagram of the carbonization pilot unit.

3 Details of the modifications carried out

Figure 2 reports the old configuration of the carbonization unit, while in Figure 3 it is shown in detail the pyrolysis gas line before the modifications herein reported.

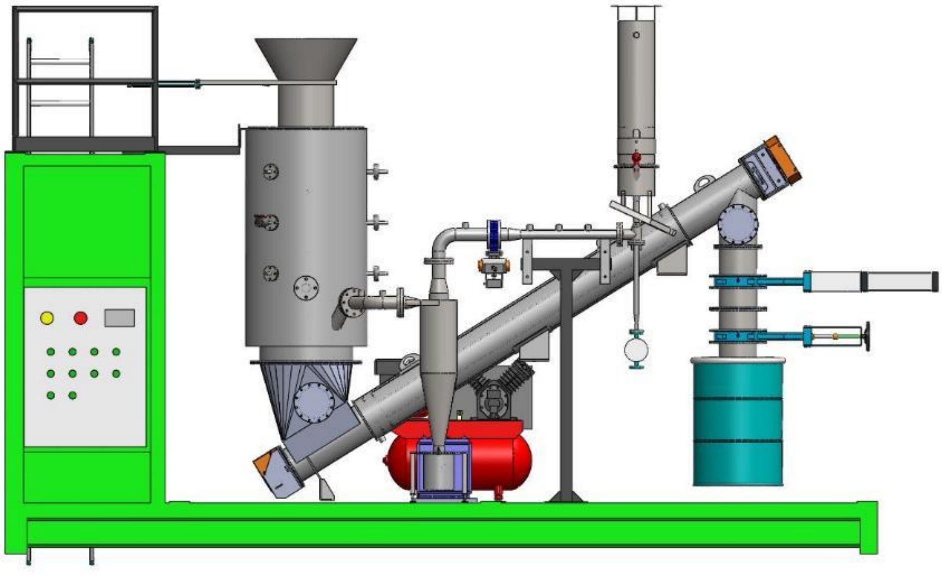

Figure 2: 3D model of the old configuration.

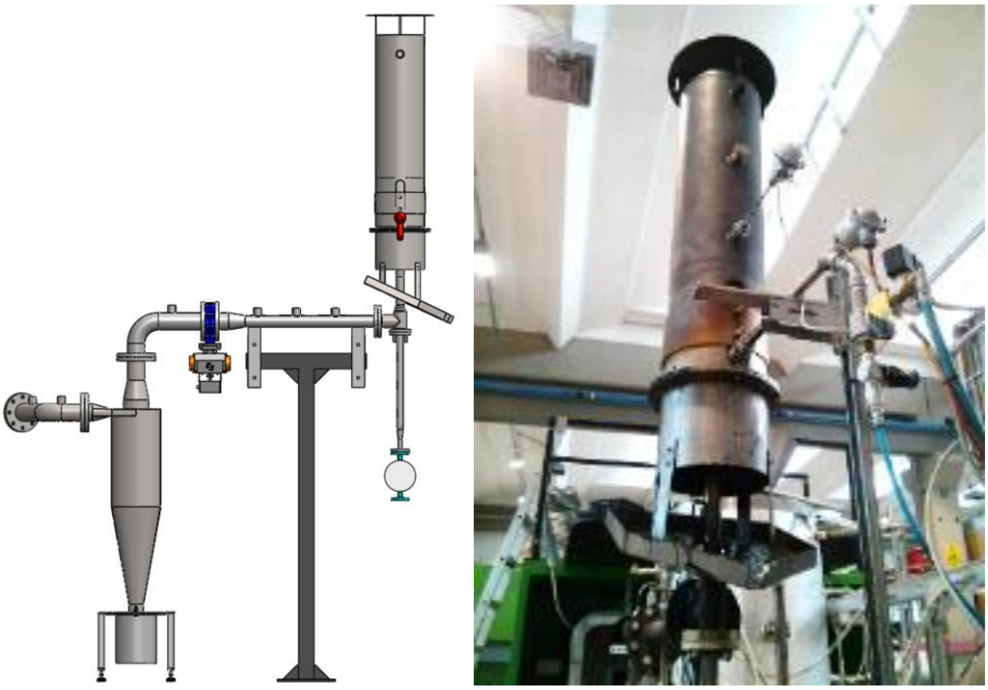

Figure 3: 3D model of the old hot vapours line (left) and picture of the torch in the previous configuration (right).

In the previous configuration, some failures and blockages of the gas line occurred at cyclone inlet when small woodchips were used as feedstock. The main reason behind this occurrence is that the char bed was partially sucked with pyrolysis vapours from the reactor into the gas line. Indeed, small carbonized woodchips are very light and at high flow rate part of the bed was dragged from reactor. No issues were found when operating with larger woodchip. In order to allow the operation with agro-residues, which are generally smaller in size compared to wood chips, a large number of modifications have been carried out on the pilot unit.
Elements that underwent major overhauling or complete redesign within the scope of BIO4A:

1. Addition of a second pipe for pyrolysis gas withdrawal;
2. Redesign of the pyrolysis gas line between the reactor and the cyclone, including the filtering elements at the reactor's ports and expansion joints;
3. Redesign of the pyrolysis gas line between the cyclone and the chimney, including addition of temperature measurement points, pressure taps, band heaters for heat-tracing;
4. New high-temperature butterfly valve for flow-rate control of pyrolysis gas;
5. New stainless steel chimney, including a second LPG pilot burner (new) and ancillary equipment;
6. Design, construction and installation of a shutter to regulate the secondary air passage after the primary combustion zone, to extend the operability in case of low LHV pyrolysis gas, which are typically experienced during transient operation (ramp-up and shut-down);
7. Redesign of the plant control and data acquisition systems (both software and hardware).
8. Extension of the loading platform to comply with HSE regulations;
9. Civil and structural modifications needed to implement the new plant configuration (cyclone support, heat-traced section support, frame for chimney support

Each point of the above list was designed internally by RE-CORD with the aid of 3D CAD software (Solidworks) and was built by specialized suppliers. The assembly of each single elements in the pilot unit was carried out at the RE-CORD premise.
Figure 4 shows two assembly views of the modified pilot unit, while in Figure 6 are depicted two pictures of the plant.

The main elements numbered in Figure 4 are the following:
3. Assembly of the ejector heaters housing
4. Cooling and screw conveyor group
5. Char discharge assembly
8. Upper support of the torch assembly
9. Assembly of pipe-torch support
10. Cyclone-side support
20. Pyrolysis gas group
22. Compressor
In Figure 5 and Figure 7 are respectively reported the drawings and pictures of the whole plant and detailed view of the pyrolysis gas line before the cyclone.

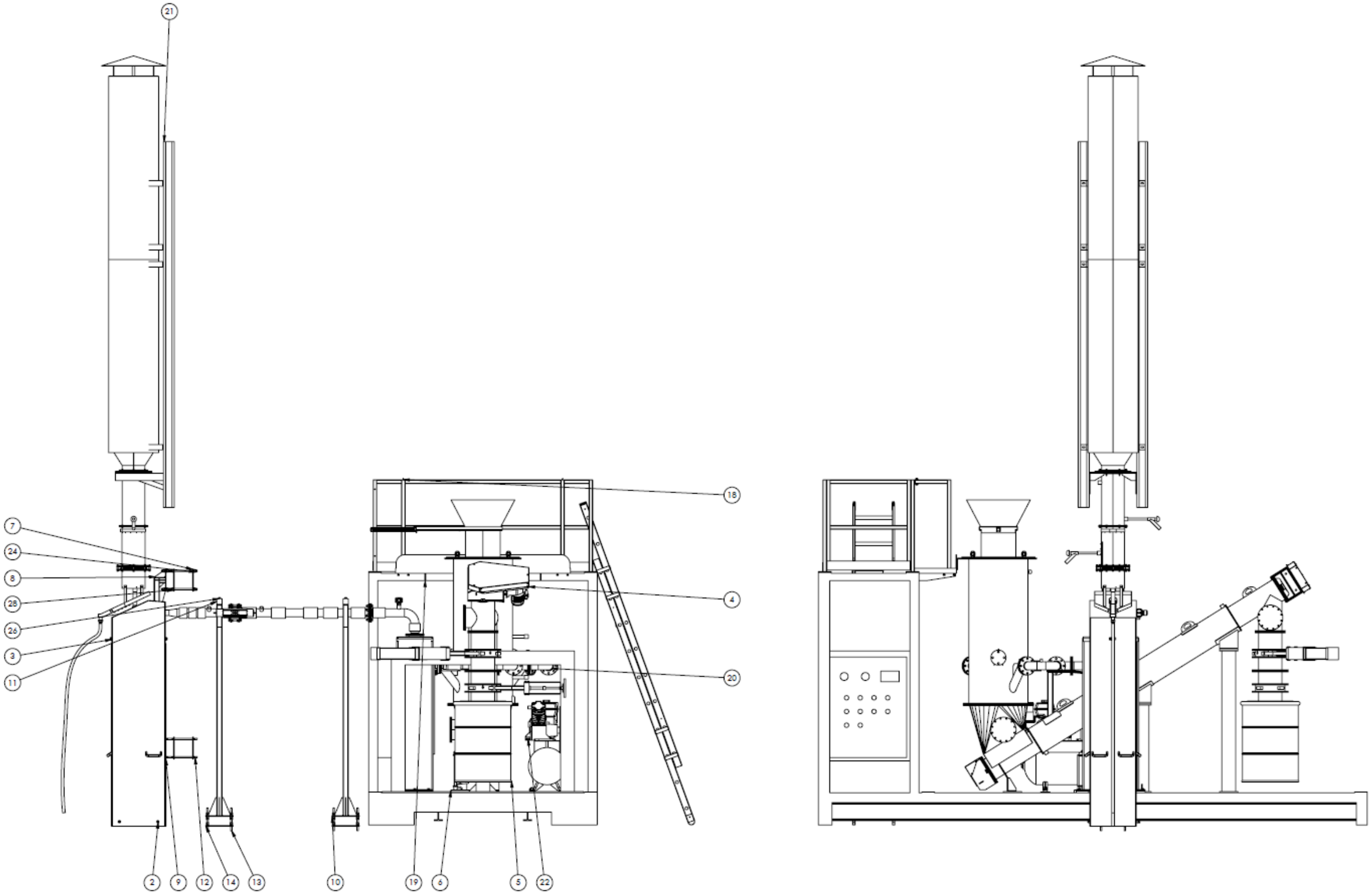

Figure 4: Side and front view of the pilot unit after the modifications.

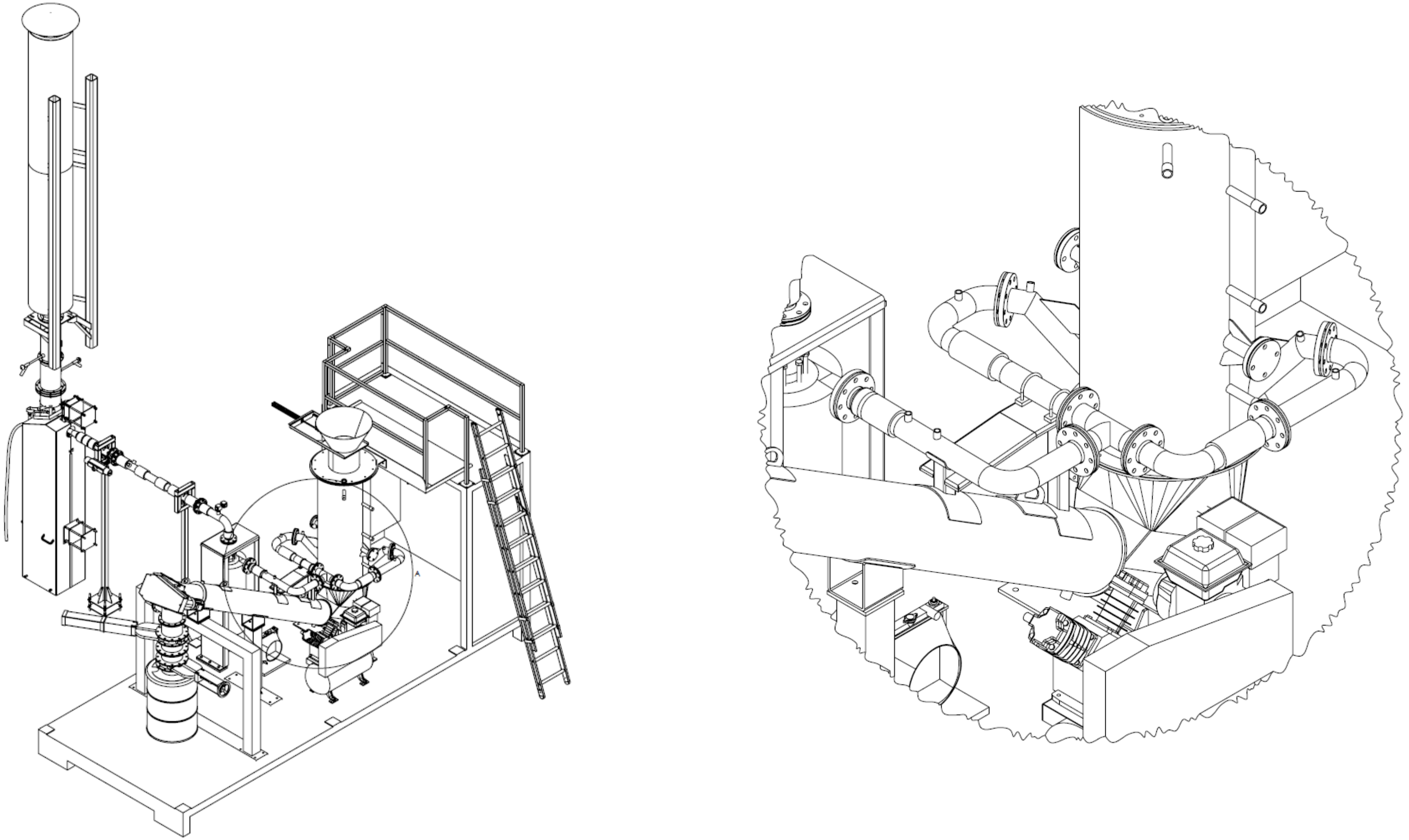

Figure 5: Drawing of the new configuration and detail of the vapour extraction section from the reactor (right).

Figure 6: Picture of the new pilot configuration. Insulation removed to show the construction details.

Figure 7: Picture of the new pilot configuration (up) and detail of the vapour extraction section from the reactor (bottom). Insulation removed to show the construction details.

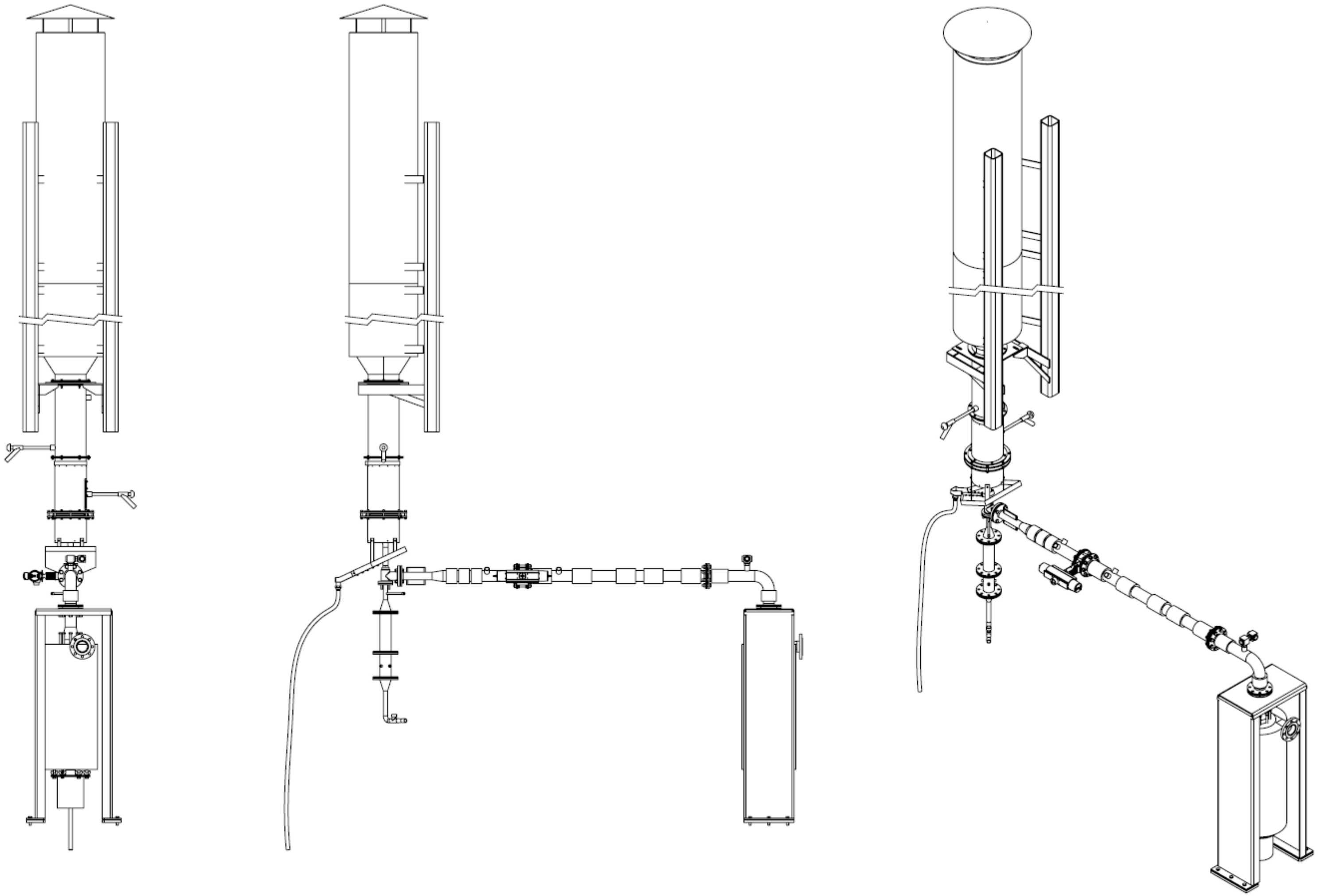

Figure 8:Drawings of the new hot vapours line.

Figure 9: Pictures of the new hot vapours line: new torch (left) and new vapours line with electric heaters (right). Insulation removed to show the construction details.

Figure 8 and Figure 9 depict the new hot vapour line configuration, from the cyclone to the new chimney. The line was equipped with 9 electric band heaters (4 x 300 W and 5 x 600 W) in order to maintain the gas flow at an average temperature higher than 400 °C, so to avoid pyrolysis vapours condensation and ensuring the proper functioning of the butterfly regulation valve. Indeed, during operation with the previous configuration, the latter experienced problems due to excessive fouling and now was replaced with a new one, able to withstand high temperature and fouling. The torch was redesigned and modified so to include a second pilot burner for a more efficient combustion. In addition, a shutter between the two burners was installed in order to control and tune the secondary airflow.

4 Conclusions

Continuous carbonization pilot unit was modified and overhauled within the scope of BIO4A to allow the production of biochar from biomass (agroresidues). The plant was modified in its hot gas line, with the addition of filtering elements ahead of the cyclone and band heaters to prevent the formation of condensate and compensate for the increased length of the gas line, that was required to operate the unit indoor while venting the pyrolysis vapours to the torch and then chimney. Structural and electric parts underwent extensive modifications too, along with the control and data acquisition systems. **The unit is therefore ready for testing with agroresidues**.