APPLICATION OF PILOT TECHNOLOGIES FOR ENERGY UTILIZATION OF AGRICULTURAL RESIDUES IN NORTHERN GREECE

by

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The enormous potential of agro biomass can be exploited to produce sustainable bioenergy. Proper management and further exploitation of this potential could lead to economically profitable approximations and solutions for the agricultural industry and even energy production industry. Gasification in-situ with energy production or pyrolysis of the above mentioned residues, under a non-oxidizing atmosphere for alternative fuels production could be a solution to the environmental problems that land filling or conventional combustion could create. The present work focuses on combustion and pyrolysis of cotton gin residues in Greece, as an alternative way of energy production. The purpose of presentation of a case study of the two alternatives methods (combustion and gasification or pyrolysis), by using cotton ginning waste as biofuel, is to show the appropriateness of new bioenergy sources by coupling them with energy production technologies. These technologies can be applied in northern Greece as well as in other Balkan or Mediterranean countries.

Key words: *biomass, agricultural residues, energy, Greece, combustion, pyrolysis, gasification*

Introduction

For Greece, agro-biomass utilization is considered to be a major issue, due to the considerably intensive regional agricultural activities. Crops by-products as fruit cores, rice husk, cotton gin waste, tree cuttings, straws, *etc.* provide a promising energy source for the country [1]. The energy production potential of the available agro biomass produced is much enough to cover the 10% of the annual oil consumption utilized for thermal applications [2]. The increased utilisation of biofuels for heat and power production has enjoyed increasing political support in Greece [3], as in all Europe. This has resulted in a large number of biofuels being proposed for energy supply without sufficient consideration given to their suitability for thermal conversion. Agricultural crop residues are usually left in the field or accumulated during sorting and cleaning of the product. One of the main difficulties in choosing the most appropriate method of valorising this by-product is the variability of the raw materials as well as their composition.

The paper describes combustion and pyrolysis/gasification – a conventional energy production method against an innovative one – as potential agricultural residues exploitation methods. It, also, presents a comparison between those treatments, when utilised as ways for renewable energy production. The aim of the present work is to strengthen the interest in agricultural residues potential for energy production in Greece through non-conventional, innovative and more environmental friendly methods. In that way the country would favourably contribute to Kyoto Protocol alignment and CO_2 and greenhouse gases abatement [4].

Exploitation for energy production

Combustion

Direct combustion of some crop residues is the simplest exploitation method for energy production and, at the present, dominates in biomass exploitation methods mainly for heat production reasons. Moisture of residues should not be more than 20%, if it is to be used for energy production. Combustion takes place after drying and before pyrolysis and gasification into the combustion chamber. But, even though combustion constitutes an easy way for energy and heat production, gives rise to several environmental problems related mainly to atmospheric pollution (ash production, gaseous emissions release of CO, SO_x, *etc.*). Most combustion systems accomplish low efficiencies (40%) and as a result there are considerable heat losses to the environment. Today, special combustors for agro residues (*e. g.* olive kernels) are quite common in Greece and in some cases replace power production units utilising common central heating systems with petroleum combustors. Their combustion chamber is slightly different of those utilizing conventional fuels and consists of a coil that carries the residues into the furnace, while a blower supplies excess air to sustain the combustion.

Some difficulties in residues storage and management appear to be in: the way and storage place that ensure that residues not get wet. Biomass combustors are usually designed in order to work, also, with conventional fuels or similar kind of biomass. Technology that dominates in large power production systems is integrated combined electricity and heat production systems [5]. Heat that released from combustion is in conjunction with a steam cycle with power production of 5-20 MW_e [6]. The most known technology of combustion is grade firing while, under more strict environmental obligations to energy efficiency commitments, fluidized bed combustion is considered more attractive [7, 8].

After several trials to more economic entrance of biomass combustion in the market, co-combustion with conventional fuels (*e. g.* lignite) is promoted. Advantages of this practise are: reduction of fossil fuel consumption, ensuring annual feeding of the mixture of fuels, environmental protection, and reduction of atmospheric pollution due to gaseous pollutants.

Pyrolysis/gasification

Gasification takes place under higher than pyrolysis temperatures (800-1200 °C) and the presence of an oxidizing agent (usually air), in lower quantities of that needed for stoichiometric combustion. Pyrolysis consists the first step in every gasification system. Achieved efficiencies are higher that combustion but the technology is still expensive due to lack of confidence in the gasification process and technology [9].

When impose higher than pyrolysis temperatures, biomass molecular bonds break down and re-reformed in a mixture of permanent gases – that mainly consist of H_2, CO, CO_2, and CH_4 and traces of light hydrocarbons (C_2H_6, C_2H_4, *etc*.). Percentages of those gases in the synthesis gas depend on several factors like *e. g*. gasification medium (air, steam, oxygen or mixtures of them), quality of agro residues (low moisture content, high heating value, proximate and ultimate analysis), heating rate, gasification temperature, *etc*. [10].

Gasification with air produces a mixture of gases with H_2 content 3 to 7%. As referred above, during the first gasification steps, process passes drying and pyrolysis zones, where moisture and volatile products are released and right after production of synthesis gas is achieved. This gas is generated due to conversion of CO and H_2O to CO and H_2, and usually characterizes CO and H_2 in the whole mixture of permanent gases [11].

Air gasification gives lower percentage in hydrogen content in synthesis gas mixture, in relation to steam gasification and that happens due to steam reforming of CH_4 to H_2 and CO. Lower heating value of syngas production is caused due to the N_2 content of air that dilutes further produced gas mixture. Syngas is not recommended for distribution through pipes but it is suitable, after thorough cleaning, for exploitation in internal combustion engines, turbines and lately fuel cells, systems that are attractive for energy production and are going to play a significant role in energy production from biomass. As it concerns fluidized bed reactors, the problem that appears to be a drawback in their efficient utilization, is tar production. Tar is formed in the temperature range between 700-900 °C and disturbs bed fluidization. Another critical point in large scale application of thermochemical treatments for biomass is gas cleaning from tar and other suspended solids that come from fluidized bed or chars [11, 12].

Application of pilot technologies in northern Greece – Case study of cotton ginning wastes

Research and pilot activities are focused on clean combustion with reduced CO_2 emissions and gasification of biomass. Furthermore, pyrolysis and gasification techniques (for the production of liquid and gaseous fuels, respectively) establish a new approach for a more efficient utilization of biomass. In short term, biomass combustion and gasification will enable the large-scale implementation of bioenergy.

In an effort to develop and apply reliable and cost effective combustion technologies in Greece, with innovative reduction of atmospheric pollutants and small scale and cost effective gasification units (<1 MW) for electricity generation, using feed-stocks focus on self-running processes and taking on board the socio-economic dimension of the country, our research was conducted towards the study and presentation of cotton gin waste energetic utilization with combustion and pyrolysis/gasification. The results of running combustion plant and those obtained in bench scale for pyrolysis/gasification are presented bellow.

In the present study, cotton ginning waste have been taken as the feedstock of a combustion and pyrolysis process which is the first phase of gasification, in order to assess both, a conventional and an alternative method in terms of environmental impact (emissions Kyoto agreement). Cotton gin wastes, one of the most abundant in Greece, can be used for energy utilization either by combustion and steam generation or by pyrolysis/gasification. The magnitude of cotton cultivation in Greece has reached today the value of 40.000 square kilometres from which are produced 1.200,000 tons of cotton seeds. From the ginning of this quantity derive 12,000 tons of cotton gin wastes, namely 4200 tons of equivalent petrol. Furthermore, the total amount of cotton stalks that remains after the collection of the seeds is 350 kg per square kilometre offering a heat content of 17,640 kJkg. The production of cotton stalks reaches 1.400,000 annually, amount that corresponds to 408,000 tons of equivalent petrol. Proper management and exploitation of this potential could lead to economically profitable approximations and solutions for the agricultural industry. Furthermore, pyrolysis and gasification techniques for the production of liquid and gaseous fuels establish a new approach for a more efficient utilization of biomass [5, 7, 11].

Results of two case studies are given below. The pilot combustion results are referred to cotton gin industry in northern Greece in the province of Anchiallos which is an outskirt of Thessaloniki the capital of central Macedonia region. The results from pyrolysis concern a laboratory study in the department of Chemical Engineering of the Aristotle University in Thessaloniki. The purpose of the following presentation of two alternatives methods (steam generation and pyrolysis for bioenergy) by using cotton ginning waste as solid biofuel is to show the possibility of using agricultural wastes for energetic uses applied in northern Greece.

Direct combustion of biomass (cotton gin waste) and steam generation

An investigation regarding the energy and environmental performance of an implemented biomass combustion unit was conducted, in a cotton gin industry. Energy utilization of cotton gin waste is a major aspect for cotton gin industries, since in each ginning period which lasts three and a half months, normally from October to mid January, the generated waste quantities according to recent data (tab. 1) reach the 9.6% of the total processed seed cotton [5]. In the cotton gin industry in which the project took place, the quantities of processed seed cotton reach the 30,000 tons per period. Considering the 9.6% of that, the produced amount of biomass waste comes up to 2,900 tons [5].

The available energy content of the produced biomass, considering the higher heating value which equals to almost 16,000 kJ/kg, reaches the 48,000 GJ, which equals to 1067 equivalent tones of liquefied petrol gas (LPG), the type of fuel utilized to cover the thermal power needs of the ginning process [5]. The economic benefit coming from the substitution of LPG and the resulted industry's energy independence contributed towards the direction of investing on the energy utilization of the produced cotton gin waste. The characteristics of cotton gin waste are presented in tab. 2.

Table 1. Proximate and elemental analysis of cotton gin waste [2]

Proximate analysis	
Higher heating value [kJ/kg]	16,000*
Moisture [wt.%]	13.0*
Ash [wt.%]	13.3*
Elemental analysis	
C [wt.%]	41.2
H [wt.%]	5.0
O [wt.%]	34.0
N [wt.%]	2.6
S [wt.%]	traces
Heavy metals [wt.%]	traces

* Dry basis

Table 2. Cotton gin industry production data [5]

Products/by products	Quantity
Total processed seed cotton	30,000 tons
Cotton fiber (32 wt.%)	9,600 tons
Cotton seed (54 wt.%)	16,200 tons
Cotton gin waste (9.6 wt.%)	2,900 tons

A 7.0 MW thermal power unit implemented in order to utilize the produced amount of cotton gin waste, replacing the existed fossil fuel thermal power generation system. The biomass utilization unit consisted of a combustion chamber designed for the direct combustion of cotton gin waste, a low pressure (1.3 bar) steam boiler of 10 ton/h steam production capacity, the appropriate machinery for the handling and feeding of biomass, the pollution control system, and the ash disposal system. The produced steam was utilized for the production of 110 °C hot air, required in the various levels of cotton gin drying processes. The replacement of fossil fuel was complete since the contribution of cotton gin waste reached the 100% of the thermal needs, while the amount of utilized waste reached the 50% of the available cotton gin waste produced during the ginning period [5]. For the energy utilization of this specific biomass an efficient combustion system that has been developed taking into account the physical properties of cotton gin waste (tab. 1).

The technology for lignite combustion has been adapted for combustion of biofuels and waste products. Combustion of biomass is more complex than coal combustion, due to the inhomogeneity, variation in moisture content, and composition of the feedstock. Chain-grate boilers and fluidized beds are commonly used to improve the efficiency of combustion and heat transfer, whilst meeting environmental standards. Cotton gin waste can be used as fuels and burned successfully to produce steam for direct use in cotton ginning unit. The steam produced is used to drive cotton ginning process, for process heating, and for grid-connected electricity production. The direct combustion of biomass is the most used method; however, gasification/pyrolysis comparing to combustion is a more environmental friendly process [5]. Table 3 presents results obtained from a unit operating in Greece concerning steam generation from cotton gin waste. The steam produced from a total of 30,000 tons of proceed waste is 10 ton/h and the energy efficiency obtained is 80% [5].

Table 3. Steam generation data concerning energy utilization of cotton gin waste – Case study in northern Greece [5]

Biomass fuel	Cotton gin waste
Calorific value	14,700 kJkg [1]
Combustible mater	72 wt.%
Moisture content	13 wt.%
Ash content	15 wt.%
Steam boiler thermal power	7.0 MW
Biomass fuel energy contribution	100%
Energy efficiency	80%
Steam production	10 ton/h
Total processed seed cotton	30,000 ton
Cotton fiber (32 wt.%)	9,600 ton
Cotton seed (54 wt.%)	16,200 ton
Cotton giw waste (9.6 wt.%)	2,900 ton

Environmental effects of biomass combustion

Biomass combustion emissions are generally much lower than the acceptable limitations. According to 88/609 EC [5, 12] instruction emission limits are 400 mg/Nm^3 for SO_x, 650 mg/Nm^3 for NO_x, and 50 mg/Nm^3 for particles.

The analysis of cotton waste combustion emissions from the existing unit in northern Greece has shown that those emissions are lower than the limits instructed by EC directive (tab. 4).

Table 4. Cotton gin waste combustion emissions analysis [11]

Gas		Cotton gin wastes	
Composition	[mg Nm^3]	Composition	[wt.%]
HCl	64	Moisture*	47.13
SO_x	126	Dry solid	52.87
NO_x	203	Dry ash composition	[wt.%]
Solid particles	45	Combusted material	9.40
		Uncombusted material	90.60
Solid particles composition in heavy metals	[ppm]	Ash composition in heavy metals	[ppm]
Ni	299	Ni	119
Cr	523	Cr	126
Cd, Pd	traces	Cd, Pd	traces
Zn	299	Zn	203
Mn	657	Mn	804

* The high percentage is due to the water sprinkled for drifting avoidance

Pyrolysis/gasification

Technical development, differences in systems, energy efficiencies, and the different principles of gasification are elaborated in view of the operation with biomass. Gas purification is one of the parts of biomass gasification systems, which still need research and substantial demonstration efforts. By-products of combustion and gasification are generally mentioned and possible solutions are indicated as far as possible in the framework of this study.

Pyrolysis is another option for waste-to-energy that is being investigated and the first step in gasification process. Pilot projects using pyrolysis for wastes, potentially have very high-energy efficiency. Combined pyrolysis and gasification systems and combined pyrolysis and combustion have also been developed and implemented. Gasification includes two processes:

– pyrolysis, which releases volatile compounds of the fuel, and
– char conversion – carbon remaining after pyrolysis reacts with steam and/or oxygen (combustion).

The advantages of gasification are the operation at a lower temperature and wider variety of feedstocks than direct combustion systems. It can produce a BTU gas that is interchangeable with natural gas, while produces nitrogen free gas and less landfill waste.

Experiments of cotton gin waste have been performed in a laboratory scale reactor in order to investigate the yields in products (gas, liquid, and char) [12-14]. The effect of temperature on yields of pyrolysis products are depicted in fig. 1. The impact of process temperature on the calorific value of the resulted gas mixture is depicted in fig. 2.

As shown in fig. 1, char yield decreases as temperature rises, approaching 48 wt.% when temperature is 550 °C. Total gas quantity

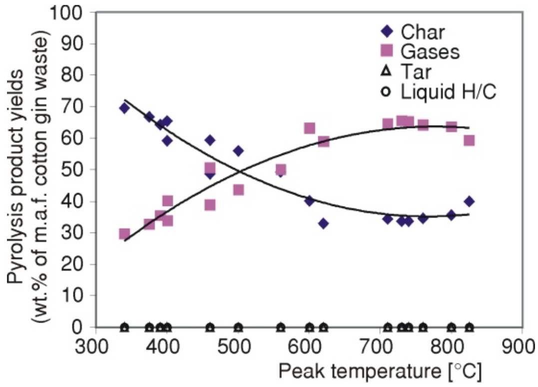

Figure 1. Effect of temperature on yields of pyrolysis products from cotton gin waste [11]

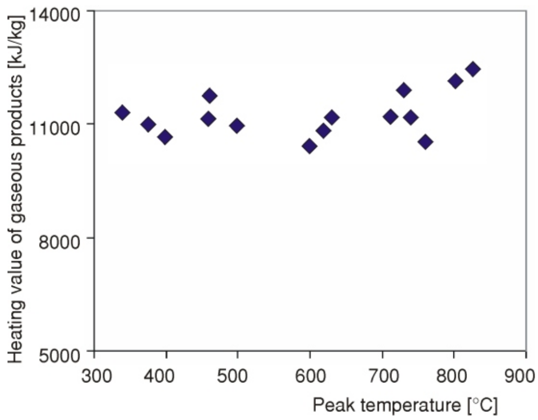

Figure 2. Effect on the heating value of gaseous products from cotton gin [7]

increases with temperature and at 550 °C reaches 48 wt.%. Tar and HC production remains negligible. Chromatographic analysis shows that produced gas consist of H_2, CO, CH_4, CO_2, and C_2H_4. The major product is CO (fig. 3), the production rate of which decreases as temperature rises in controversy with H_2, which increases with temperature (fig. 4). Participation of CO_2 is less significant compared to the rest of the components and its yield rises slightly with temperature [15-17].

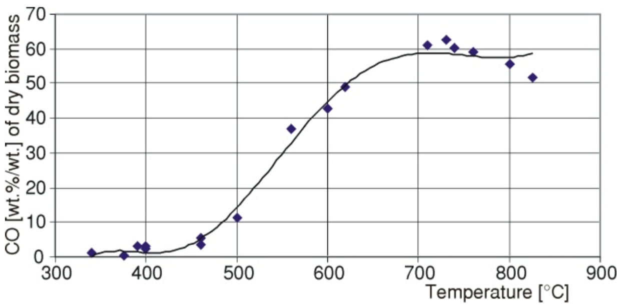

Figure 3. Effect of temperature on CO yield

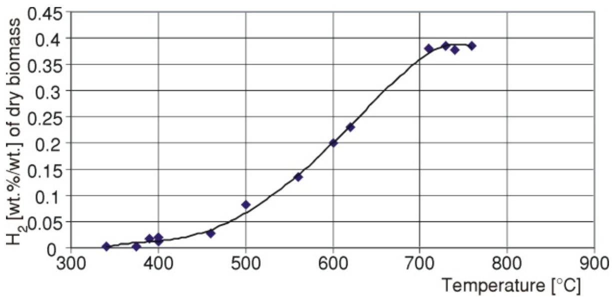

Figure 4. Effect of temperature on H_2 yield

Pyrolysis of cotton gin waste seemed to give very low yields in tar and liquid H/C (almost negligible) probably due to considerable cellulose amounts contained. This fact encourages biomass utilization via gasification [18, 19].

The amount of hydrogen in biomass is about 6-6,5 wt.% compared to almost 25% for natural gas. The processes involved in producing hydrogen from biomass resemble the processes in production from fossil fuel. Under high temperatures, the biomass breaks down to gas. The gas consists mainly of H_2, CO, and CH_4 (methane) [17].

The gas product from biomass is considered "neutral" with respect to greenhouse gas, as it does not increase the CO_2 concentration in the atmosphere. The mixed gas can also be used in fuel cells for electricity production. Compared to conventional processes for production of electric energy from biomass or waste, integrated gasification fuel cell systems are preferable. Electrical efficiency over 30% is possible for these systems [15, 18], while this is not possible using traditional technology.

Conclusions

Greece's opportunity to exploit its huge agricultural residues stocks seems very attractive. Under national commitments on EU obligations over alignment with Kyoto protocol, gaseous emissions abatement and climate change prevention, Greece could exploit its agricultural residues in environmental friendly and economic viable way, for energy production. Optimization of well known combustion techniques and combination of agricultural residues' thermochemical treatments through closed cycles with ICE, turbines, and even fuel cells, could probably lead to an economic reasonable and technologic viable way of sustainable energy production.

Some weaknesses like low repeatability, high capital costs, huge agricultural residues volumes that generated in rural areas could be solved through co-combustion/gasification of biomass and conventional fuels, decentralized and modular form of energy production systems and a very good established waste management/logistics system.

By-products from different thermochemical treatments *e. g.* gasification against combustion gives better limits in CO_2 emissions and it is widely known that is considered CO_2 "neutral" with respect to air pollution problems. It doesn't increase CO_2 concentration in atmosphere, as the CO_2 released from gasification, is already the inherent amount that biomass gained from atmosphere with photosynthesis.

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