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Evaluation of the Energy Potential of the Gorse (Ulex Europaeus) in the Generation of Electrical Energy by Gasification

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The gorse (Ulex europaeus) is an exotic invasive species, coming from Europe. This species has been spreading in several sectors inside and outside the City of Bogota, where due to its easy adaptation it has caused alterations in the diverse ecosystems where it is rooted. Since of 2008, it was declared an invasive species for Colombia. Since then authorities have looked for multiple options for the management, control and restoration of the invaded areas. The alternatives commonly used for the management of invasive species such as gorse are eradication and control. Within the control exists the biological control, the chemical control and the physical or mechanical control. On the other hand, are prevention, cultural measures, and the implementation of the "Bradley" method, as a strategy that combines containment and reduction, among others. Bogotá Botanical Garden José Celestino Mutis is developing a different technique, called bio extrusion. This consists in passing the material through a high temperature that sterilizes the seeds, and produces a powder rich in nutrients that can be used as fertilizer for ecological restoration processes.

In this article, we propose the exploitation of the high heat value of the Gorse trunks in the production of electric energy through gasification, evaluating its energetic potential, to determine the energetic potential, the physiochemical characterization and adequacy of the gorse trunks. Subsequently, an electric power generation system was used with the Gasification Power Pallet PP20®. Five gasification tests were carried out. Afterwards was determined the lower calorific value of the Gorse, the percentage of biomass utilization, the kilogram/kWh generated, and the generated power curve. The cost of kWh generated in situ and the potential of electric power generation was determined by gasification in Bogotá.

Among the main results, it was obtained an 85% use percentage of available biomass (gorse). The physiochemical characterization determined that the gorse has a lower calorific value of 14017.97kJ/kg °C. The cost of kWh generated is around US $ 0.23. The use of gorse as fuel for production of electric energy by gasification is viable, due to its physiochemical characteristics such as its low percentage of humidity and ashes, its slightly acid character and high calorific value. Considering the different options to complement the eradication and control processes, gasification is a complementary choice because the rate of use of biomass is higher than other kinds (Just requires 0.26kg/kWh generated).

1. Introduction

The gorse is an exotic species that propagates fast. This displaces native species. Also presents pyrophilic characteristics (burns easily and to propagate the fire). It is listed as one of the 100 most invasive species according to the Invasive Species Specialist Group (ISSG) (Lowe, Browne and Boudjelas, 2000). Furthermore, it has been declared nationally as a highly invader exotic species (see: Resolution 848/2008 MAVDT). "It is possible that this invasion has tripled and we are talking about 15 thousand hectares in the capital district, equivalent to 20 thousand football stadiums ... as simple as that" said Dr. Claudia Pinzón, from the Botanical Garden of Bogotá, José Celestino Mutis (Noticias Caracol, 2017). According to a study carried out by Rodríguez C. (2008), in the District there are about 72,000 ha with a high probability of presence-invasion by gorse. Among the main characteristics of the gorse are: high reproduction rate, rapid growth, high

germination potential, high ability to disperse its seeds, and resistance to different environmental factors. ((Ríos Alzate, Pinzón Osorio, & Barrera Cataño, 2002), cited by (Beltrán- & Barrera-Cataño, 2014). In Bogotá, there have been several forest fires in recent years. In District about of 65 species of gorse has been identified (Beltrán- & Barrera-Cataño, 2014). Over time, it has become more difficult and expensive to treat. Gorse has become a concern by environmental authorities. An example of this is the promulgation of several laws like Colombia's national Resolution 848/2008 (MAVDT), Bogotá district Resolution 7615/2009 (SDA) and Cundinamarca state Resolution 469/2009 (CAR). These prohibited the production, planting and commercialization of Gorse and French broom. However, the normative and prohibitive actions are not enough. Therefore, Bogotá's environmental authority (SDA) along with José Celestino Mutis Botanical Garden have implemented periodic manual eradication days. Also, have generated several agreements with other public and private institutions, with three main objectives: a) prevention of forest fires in the city, b) generate programs for the eradication of gorse and c) generate proposals for ecological restoration of affected ecosystems. Due to the propagation versatility of this plant, there is no an inventory of it.

Different researchers have studied options to control, eradicate and give alternative uses to gorse. Among this, there is activated carbon production through pyrolysis, which can be used in the recovery of soils (Kaal, Martínez Cortizas, Reyes, & Soliño, 2012). Another alternative use is compost production through bio-extrusion (Alcaldía Mayor de Bogotá, 2014b). This process passes gorse through a thresher at high pressure and heat that sterilizes the seeds. Then is produced a powder rich in nutrients, that can be used as fertilizer for ecological restoration processes. On the other hand, is used the production of bioethanol and development of polymeric materials (Hernandez R. & Triviño C., 2016) (Bonilla O, 2016).).

Additionally, Bio-fibers production as an alternative use, particularly cellulose fibers, which can be the base for value-added products (Celis et al., 2014). Then again, for energy production has been research the use of gorse in the production of biogas. This material has an estimated potential energy production of 36.9 ± 19.3GJ/(ha · year) through biodigestion (Costa, Oliveira, & Alves, 2016). Bogotá Botanical Garden José Celestino Mutis reported in 2010 that to intervene one hectare invaded by gorse had a value of approximately COP$ 27,000,000 (Camelo S., 2015). Currently, the cost of the ecological restoration process due to the gorse infestation is COP$ 79,764,024 per hectare (Alcaldía Mayor de Bogotá, 2014a).

In the context of the actions to control and eradicate the gorse, the present article raises the gasification process as a mean for the valorization of the gorse. This is due to its combustible properties for energy production, but not as a business option.Gasification process consists in the transformation of a solid organic material into a gaseous product called synthesis gas, through a thermochemical decomposition, taking place in an oxygen-poor environment. This gas is used for thermal or electrical purposes like generation of electric energy on a large or small scale. Their composition will vary according to the biomass used, the operational variables and the technology used (gasifier characteristics) (Sánchez de Toledo, 2015). Gasification yield can be around 70-80% (Ruiz Bermejo, 2013), and depends on the gasification agent used. Thus, the advantages and disadvantages of the process vary mainly with the type of gasifier used.

2. Materials and methods

2.1 Power Pallet ® PP20 gasification system

The system consists of a reactor GEK TOTTI series, an automation system and a motor coupled to a generator. This can be divided into two components, the thermochemical transformation (with air as gasifying agent) and the generation of electric energy by a gas motor. The gasifier has a downstream fixed bed reactor. This equipment can produce a continuous rated power of 15kW at 50Hz and 18kW at 60Hz, at nominal consumption of 1.2kg/kWh. According to the operations manual, the biomass used must meet the following requirements: Particle size between 0.5 and 1.5in; fixed carbon content around 20% by weight; ash content less than 5%, moisture content not exceeding 30%, and not less than 10%, measured on a dry weight basis; restriction temperature between 800°C – 1000°C; temperature in the top of the basket between 700°C – 800°C.

2.2 Physiochemical analysis

The physiochemical characterization was carried out based on the following norms: moisture content (ASTM E871), determining the ash content (ASTM D 3174), pH (Sandermann and Rothkamm Method), heat output power (Standard D2015-89 (00))

2.3 Preparation of the thorny biomass sample

Before the gasification process, the biomass must undergo a process of enlistment as the drying, crushing and sieving.

- Drying: Drying was done naturally, to carry out a loss of moisture contained in the gorse by evaporation, thus, the meteorological conditions strongly influence the drying of the biomass.
- Granulometric Reduction: The process was developed to achieve the appropriate particle size, in accordance with the equipment restrictions, which were mentioned previously. See figures 1 and 2.
- Screening: Subsequently, grading was performed to discard particle sizes higher and lower than the manufacturer's recommended. For this, two meshes of 0.5 and 1.5in were used. The different sizes obtained are shown below.

Figure 1. Gorse trunks

Figure 2. After granulometric reduction and screening

3. Test

When the biomass satisfied the manufacturer requirements, gasification and electric power generation tests were developed. The measured parameters were: Internal temperature (°C), reduction temperature (°C), outlet power (kW), global yield (%), biomass consumption (kg), work time (hours), electric energy (kWh). The results obtained from the physiochemical characterization of the gorse stems used in the gasification tests to produce electrical energy are shown below. Physiochemical analyzes of biomass: Moisture = 9.7%, Ash content = 4.5%, pH = 6.7, Lower calorific power = 14017kJ/kg, Exploitation percentage = 85%. Moisture percentage is approximately 10% indicating that it is within the specifications established for the gasifier operation. The moisture showed by gorse (dry base), is optimal for the process (10% - 30%), because when biomass presents a high moisture content, the heat generated would be used to remove the water, causing a reduction in the thermal efficiency. The ash content was 4.48%, which means that it is within the allowable limits for the operation, being the maximum permissible 5%.

The temperature of restriction, shows the behavior of the temperature in the combustion zone, reached a value of 800°C in 25 minutes. In the reduction zone was produced synthesis gas, the temperature must be around 750°C. The average temperature of the system was of 540°C obtained with the gorse and a maximum

of 794°C. On the other hand, the production of residues was evaluated, because this was a conditional of the quality of the combustion of the gorse. About 72% of the residues were char because particles did not react in the gasifier. The tars produced was related with the temperature process, whose average production was 13%, where lower temperature means higher tars production. The power generated by the gorse gasification has a maximum power value of 13.8kW and a minimum value of 7.5 kW.

4. Results analysis

The physiochemical characterization of the gorse, confirmed the high energetic potential of this type of biomass. The percentage of moisture obtained was at an optimum level, since it is so low that it does not incorporate additional costs into energy and economic methods for drying. As for the ash content, due to its low percentage, there will be no slag formation, so this parameter will not affect the energy generation efficiency. Besides, some parts of the equipment will be susceptible to corrosion due to the slightly acidic pH. However, much of the equipment used was made with mild steel, which is highly resistant to corrosion. The behavior of the heating ramp shows that the system reaches the desired operating temperature in less than 30 min, which allows the start of the electric power generation quickly. Thus, a lower biomass consumption is allowed during the stabilization of the gasification process. This is it because of the low moisture content and the calorific value of the gorse.

The gorse responded positively as fuel in the gasification process, due to its high calorific value. This is around 14048kJ/kg, close to those presented by biomass such as firewood, wood chips, almond husks, rice husks, among others (Gómez González, 2008). The system is designed for a consumption of 1.2kg/kWh for wood chips and coconut shell, walnut and hazelnut. In the case of the gorse, the consumption per kWh generated is around 0.26kg, which is four times smaller. Therefore, the associated costs will be smaller due to the low consumption of biomass. The gorse allowed the delivery of a power of 11kW, which is about 55% equipment's capacity.

Among the advantages presented by the gorse gasification, the constant power delivered to the network is remarkable, this due to its great calorific power, among other indicators that shows the high energy potential of this vegetal residue. The utilization percentage is highly representative, given the minimal percentage of particle size required. It should be clarified that the granulometric reduction was carried out manually, because the stem size is small enough to employ a chipper. Currently, there is no availability of information regarding the amount of gorse at a regional level. Despite this, the use of the gorse in Bogotá Botanical Garden, responds to a regional strategy for risk management by the gorse invasion. This solution employs a gasifier with an operation of 6 hours per day that can give treatment to 30.9 - 34.2 tons of gorse per year.

The economic evaluation was carried out for the generation of electric energy using the gorse stalk and the Power Pallet PP20® system. The cost per kWh generated is around US $ 0.23, which allows to reach break-even point inside a 20-year horizon for the project. Besides this, the project is an alternative to control invaded areas generating employment, offering possibilities of economic growth to affected areas, minimizing the risk of natural disasters associated with forest fires, finally the use of unconventional sources of energy will be promoted. It is evaluated that possibly today there are 15,000 ha invaded by the gorse in Bogotá. Therefore, the evaluation of the estimated energy potential per hectare was carried out, taking into account that: for every m2 there may be between 10 or 20 of trunks gorse (Amaya V. & Renjifo L., n.d.),, of which 80% is utilized; and that the potential for use of the gorse is 85% of the total available after the granulometric reduction. The potential estimated was of around 52 GJ / ha * year.

Table 1. Comparison between gorse valuation alternatives

Alternative	Initial Invest	Sub products	Product	%
Bio-extrusion	$1565 USD/m3	None	Compost: from 8,4m3/ha to 40m3/ha (ANLA, 2014)	100%
Production of methane by Bio-digestion	$72,8 USD/kWh	Solid fertilizer	Thermal energy: 7,5 ton/ha* year can produce 56,2 GJ/ ha*year (Costa, Oliveira, & Alves, 2016)	60%
Production of electric energy by gasification	$111,2 USD/kWh	Ash and tars	Electric energy: 7,5 ton/ha*year can produce 52 GJ/ha*year	85%

Table 1 shows the comparison of different alternatives of recovery or utilization that allow a complete eradication and control of the gorse, according to what is reported in the literature. It can be observed that in the production of compost, the total biomass available is used; however, it is necessary to consider the low

cost of a 50kg package of compost in the economical evaluation of this alternative. If we compare the two alternatives of energy generation, we can establish that biodigestion costs are cheaper than gasification. However, it must contemplate that the percentage of biomass utilization is lower in the gasification, so there is a greater energy potential through this technology.

5. Conclusions

The use of the gorse as fuel to produce electric energy by gasification is viable, due to its physiochemical characteristics such as its low percentage of humidity and ashes, its slightly acid character and high calorific value. Considering the different options to complement the eradication and control processes, gasification is a conspicuous choice because the biomass utilization is high and the low consumption per kWh generated (0.26kg/kWh). This means that there is a high-energy availability. However, it is recommended to combine the generation energy with the production of compost, to take advantage of the remaining 20% of the biomass that is not used in the gasification.

The gorse gasification is an alternative of valorization that must be contemplated as complementary to the processes of control, eradication and ecological restoration of zones invaded by this bush. Since the law prohibits its reproduction, the implementation of a gasification system must be in-situ and the energy generated should be consumed by neighboring populations or used for self-consumption, to reduce transport costs and the risks of propagation.

Finally, exist a potential of energy generation estimated of 52 GJ/ha*year, which would allow to provide electric power to around 7 houses, which on average, are composed of four people, whose daily consumption is about 5 kwh, and keeping in mind that the system will work, 19 days, 6 days a week and 51 weeks a year.

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