Chapter 15
Renewable Fuel Production From Cistus Ladaniferus Shells: A Pyrolysis Study

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ABSTRACT

Cistus ladaniferus shells, an underutilized forest residue from the Mediterranean region, have significant potential for biomass energy production due to their high organic content, making them ideal for pyrolysis and combustion processes. This study examines the slow pyrolysis of these shells in a fixed bed reactor, evaluating the effects of temperature, heating rate, and particle size on process efficiency. The experiments were conducted at temperatures between 300 °C and 500 °C, heating rates from 10 to 70 °C min−1, and particle sizes ranging from 0.3–3.5 mm. The highest liquid yield of 53.31% was achieved at 450 °C, with a particle size of 2–3 mm and a heating rate of 40 °C min−1. The bio-oil produced, with a calorific value of 37.05 MJ kg−1, was analyzed using Fourier-transform infrared (FTIR) spectroscopy, revealing its chemical composition. These findings suggest that bio-oil from Cistus ladaniferus shells holds strong potential as a renewable energy source and for industrial applications.

1. INTRODUCTION

The global energy deficit is an increasingly critical challenge driven by escalating energy demand, dwindling fossil fuel reserves, and the urgent need to mitigate environmental degradation. Renewable energy sources have emerged as a sustainable alternative to address these issues. Among them, biomass stands out due to its abundance, carbon-neutral characteristics, and versatility in producing bioenergy. Pyrolysis, a thermochemical process that decomposes organic material in the absence of oxygen, is a particularly promising technology. This process yields three primary products: bio-oil, a liquid fuel that is easy to store and transport; biochar, a carbon-rich solid with applications in agriculture and carbon sequestration; and syngas, a combustible gas that can be used for energy production. These products

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contribute to reducing reliance on non-renewable resources while offering avenues for waste valorization and circular economic development.

The family Cistaceae consists of five genera *Cistus, Helianthenum, Fumana, Halimum*, and *Tuberaria* identified through the study of fruit and stigma (Bouamama et al., 2006), with Cistus and *Helianthenum* being the most common. These herbaceous or woody plants, which include nearly a hundred species, are found across the Mediterranean basin and its islands. To develop natural resources, we focus on cistus shells from the northern region of Morocco, which will be pyrolyzed in a fixed bed reactor. Pyrolysis of cistus generates carbon-rich solid products (char), condensable gaseous products (tar), and non-condensable gases (hydrocarbons). As a key part of renewable energy, pyrolysis offers the benefits of bio-oil, a liquid product that is easily stored, transported, and used as a fuel, energy vector, or chemical source. We conducted a study on the slow pyrolysis of cistus seeds (El Farissi et al., 2017) at temperatures ranging from 300 to 500 °C, with heating rates between 7 and 28 °C min^{-1} and particle sizes from 0.075 to 0.6 mm. The highest yield of liquid products (52.2%) was achieved at 450°C, with a particle size of 0.3 to 0.6 mm and a heating rate of 21 °C min^{-1}.

Moralı and al (Moralı et al., 2016; Ugur Moralı, 2015)studied the pyrolysis of residues charm (*Carpinus betulus L.*) in the optimal conditions of pyrolysis, physical and chemical characteristics of the bio-oil and bio-char, the experiments were carried at pyrolysis temperatures of 400, 450, 500, 550 and 600 °C, and with a heating rate of 7, 15, 30 and 50 °C min^{-1} and nitrogen flow with an average of 50,100 and 150 cm^3 min^{-1}. The highest yields of bio-oil and bio-char are equal to 24.67% and 40.30% respectively. The product yields were obtained at heating rates 7, 15, 30 and 50 °C min^{-1}, and in the final pyrolysis temperature of 550°C. The carbonization yield was decreased from 34.04% to 32.43% and the produce of gas increased from 16.59% to 17.34% with the increase in the heating rate of 7 °C min^{-1} to 50 °C min^{-1}. Bio-oil yields were 22.04%, 22.13%, 22.67% and 22.90% respectively with the same heating rate.

Yakup Kar et al (Şen & Kar, 2011) studied the pyrolysis walnut shells with the sand in a temperature ranges from 350 to 550 °C with a constant heating rate of 40 °C min^{-1} and the particle diameter between 1 to 2 mm. Co-pyrolysis experiments were performed on the walnut shell sand mixtures with different ratios ranging from 5 to 30% At an operating temperature of 450 °C. The yield of bio-oil increases with increasing temperature from 350 to 450 °C and the bio-oil reaches a maximum efficiency of 21.51% by weight to 450 °C, from temperatures above 450 °C. The yield of bio-oil fell by 17.34 and 15.47% by weight. For temperatures from 500 to 550 °C lower bio-oil yields at high temperatures can be attributed to the formation of volatile secondary pyrolytic cracking reactions, resulting in higher efficiency and lower gas bio-oil yield. The gas yield decreased from 42.58% to 37.93% by weight with an increase in temperature from 350 to 450 °C, then increased from 37.93% to 45.88% by weight in parallel by the increase in operating temperature of 450 to 550 °C. Pyrolysis of apricot kernel shells which are studied by İlknur Demiral et al (İlknur Demiral*, 2014) in a fixed bed reactor has pyrolysis temperature ranges from 238 to 550°C without sweep gas with a lower heating rate of 10 at 50 °C min^{-1} in relation to the final pyrolysis temperature 238 to 400, 450, 500 and 550 °C without sweep gas. For the lower heating rate of 10 °C min^{-1}, the carbonization yield is increased from 35.2% to 29.4%, as the final pyrolysis temperature was raised from 400 to 550 °C. When the pyrolysis temperature is increased from 350°C to 700 °C, the carbonization yield decreased from 38.3% to 24.1% with a heating rate equal to 7 °C min^{-1}, the decrease in the yield of carbonization with increase in temperature could be due to either a larger primary decomposition of biomass at a temperature above or in the secondary decomposing coal. T. H. Mohammed et al. demonstrated the viability of pyrolysis processes on castor shell and castor seeds at temperatures ranging between 400 to 600 °C with a constant heating rate of 70 °C min^{-1} and particle