Catalytic methanation of CO_2 over engineered biochar

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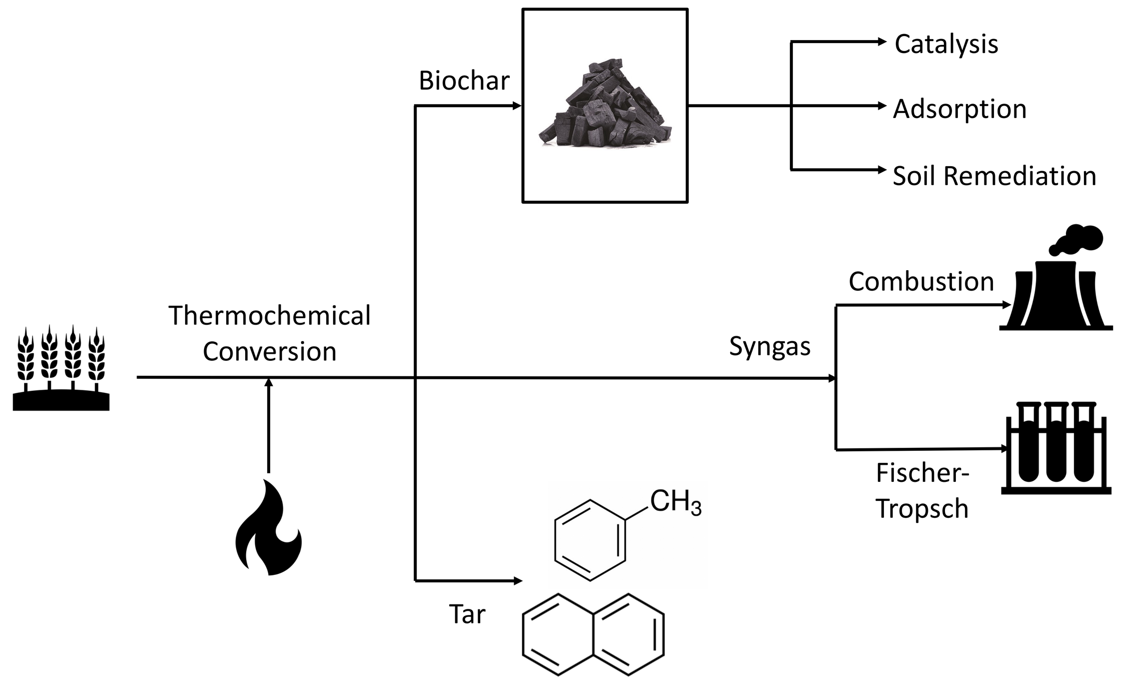
Motivation and Background

Increasing CO_2 emissions have led to climate change, which causes the heating of the globe, leading to drastic weather events causing political unrest, war, or famine.

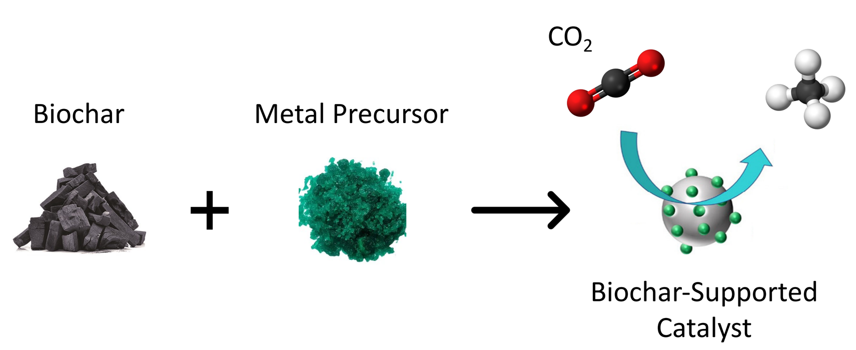


Biomass can be converted to green energy through thermochemical conversions creating biochar, tar or bio-oil, and syngas. Biochar is highly porous and tunable, making it desirable for several applications.

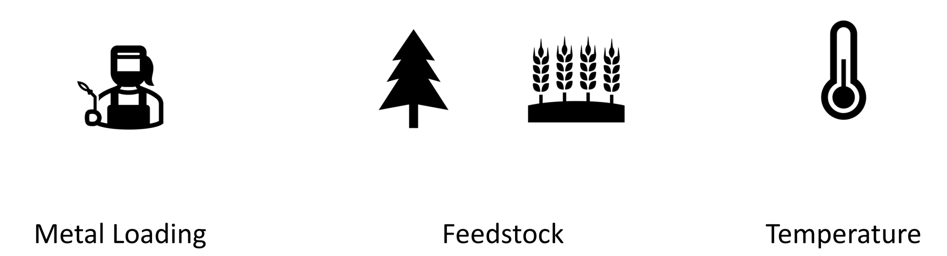
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Methanation Reaction

CO_2 can be captured and stored or converted into useful chemicals. CO_2 storage can be expensive, has limited storage, and can leak into local ecosystems. CO_2 can be converted into methane through the Sabatier reaction, by reacting it with hydrogen. Methane can be used in existing natural gas infrastructure.

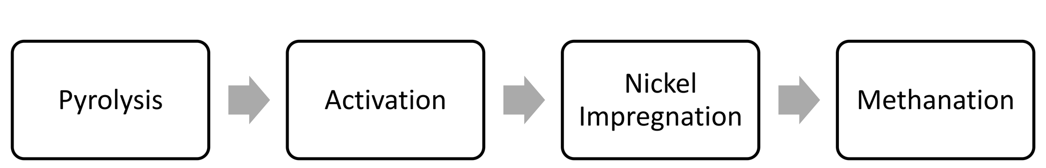


Biochar can be used as a catalyst support for the methanation reaction.



Biochar production processes can change the properties of biochar and its activity for catalytic methanation. This affects properties such as:

- Porosity
- Surface functional groups
- Metal-support interactions
- Metal dispersion
- Alkali and alkali earth metal (AAEM) concentrations



Research is required to determine the impact of biochar-based catalyst synthesis processes on their ability to catalyze the methanation reaction.

Objectives

The main objective of the research is to observe the impact of biochar catalyst synthesis processes on its ability to catalyze CO_2 methanation. The following synthesis parameters will be examined:

1. Pyrolysis Temperature
2. Pyrolysis Heating Rate
3. Biochar Feedstock
4. Nickel Loading

Research Methodology

- Douglas-fir and wheat straw were used to make biochar.
- Pyrolysis temperature was either 400 ˚C or 500˚C.
- Heating rate varied from 5 ˚C/min to 20 ˚C/min.
- Nickel loading varied from 5 wt.% to 10 wt.%.

All biochar specific surface areas were measured before and after activation and Ni-loaded biochars were tested as a catalyst for CO_2 methanation.

$$X_{CO_2} = \frac{v_{CO_2,in} - v_{CO_2,out}}{v_{CO_2,in}}$$

$$v_{CO_2,out} = \frac{y_{CO_2} v_{CO_2,in}}{y_{CO_2} + y_{CO} + y_{CH_4}}$$

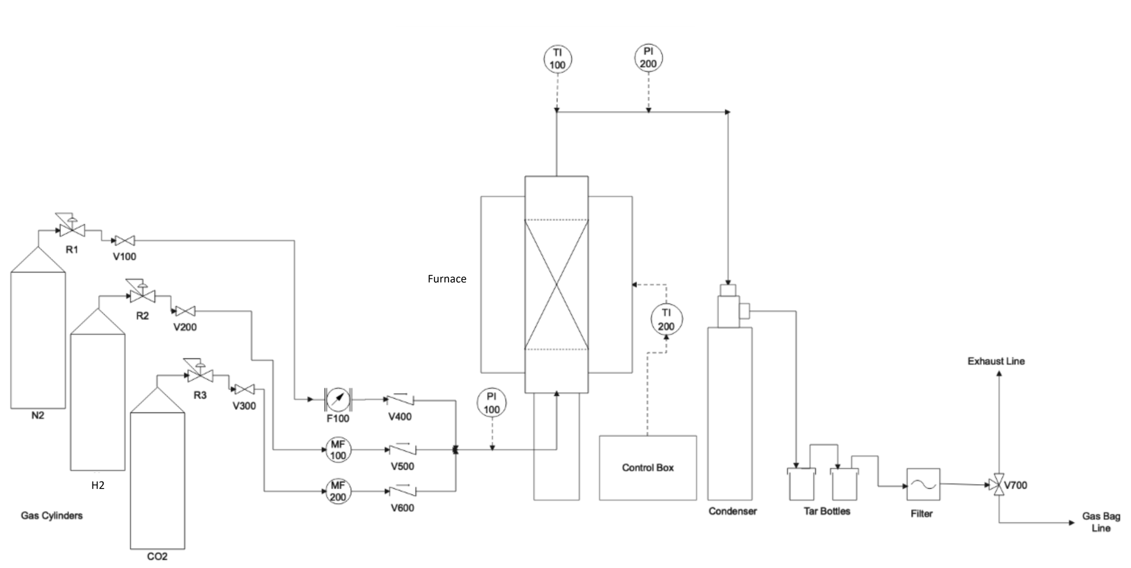
$$S_{CH_4} = \frac{v_{CH_4}}{v_{CO_2,in} - v_{CO_2,out}}$$

$$Y_{CH_4} = S_{CH_4} \times X_{CO_2}$$

X_{CO_2} : Carbon dioxide conversion
$v_{CO_2,in}$: Inlet carbon dioxide flow
$v_{CO_2,out}$: Outlet carbon dioxide flow
y_x: Outlet mole fraction
S_{CH_4}: Methane selectivity
v_{CH_4}: Inlet methane flow
Y_{CH_4}: Methane yield

Equipment

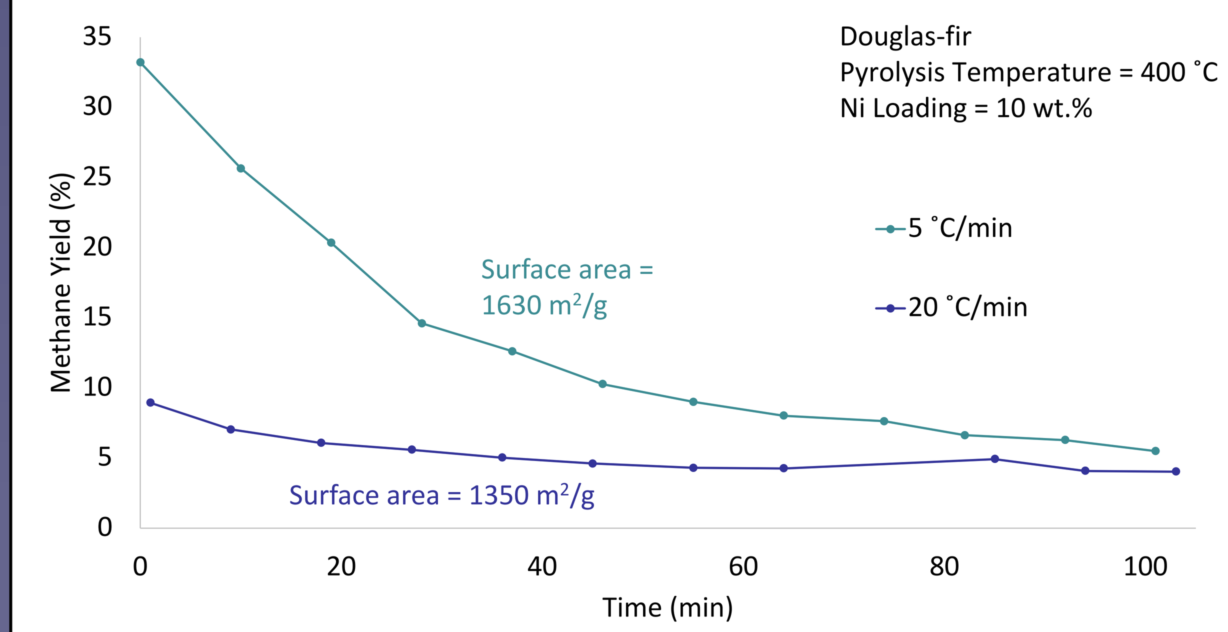
A fixed-bed, flow through reactor was used for pyrolysis, activation, and calcination.



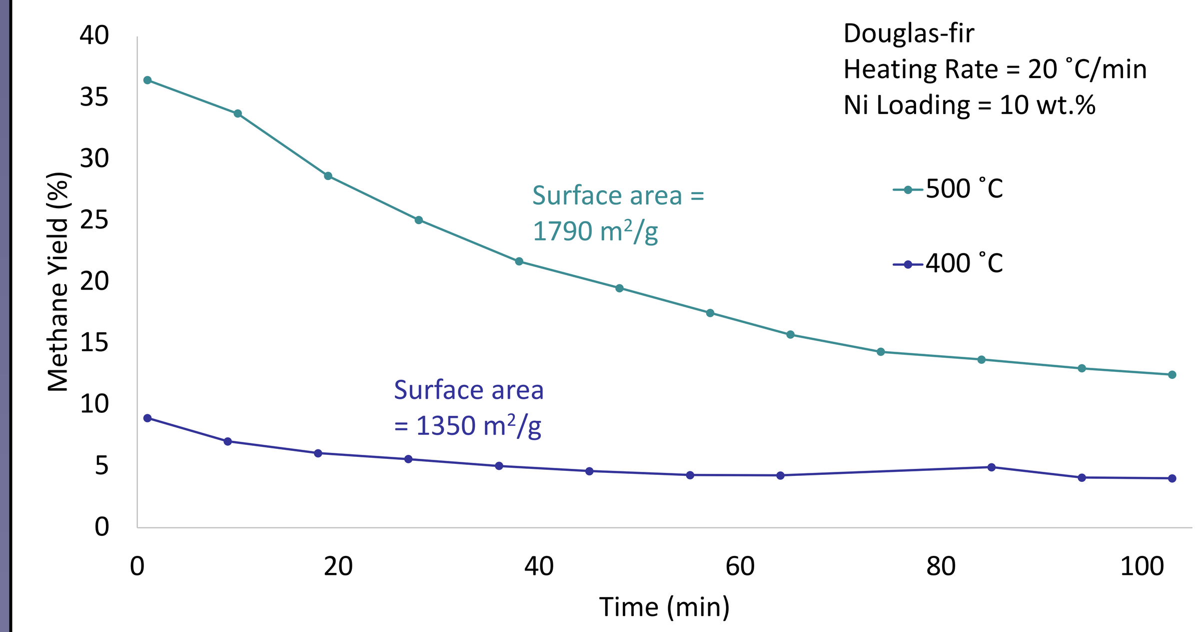
Specific surface area was measured using the Brunauer-Emmett-Teller (BET) method. Nitrogen desorption and adsorption curves were obtained using a pore size analyzer and liquid nitrogen (77 K).

A micro gas chromatograph was used to evaluate the composition of the gas stream.

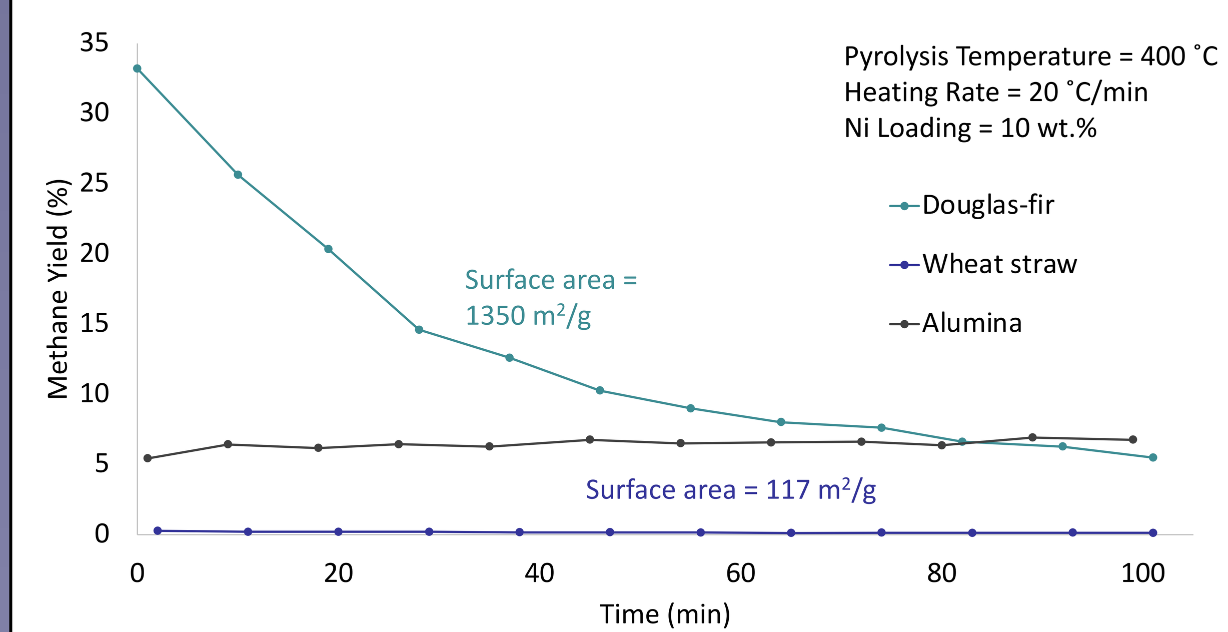
Key Results



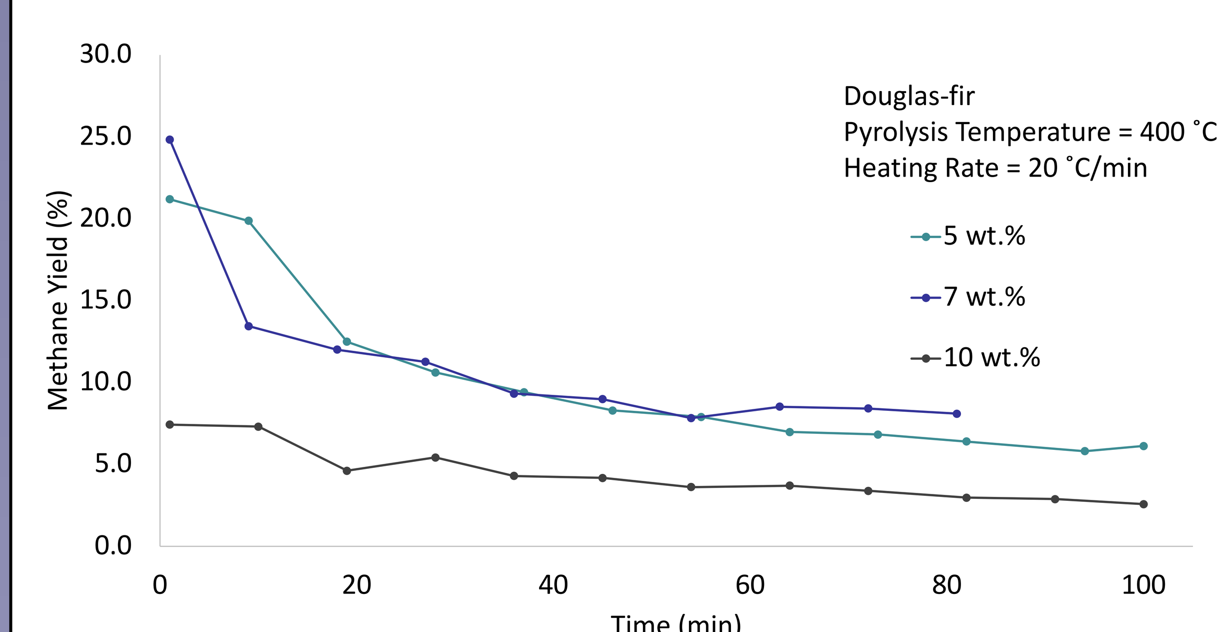
Methane yield increases as the heating rate during pyrolysis decreases.



Methane yield increases as pyrolysis temperature increases.

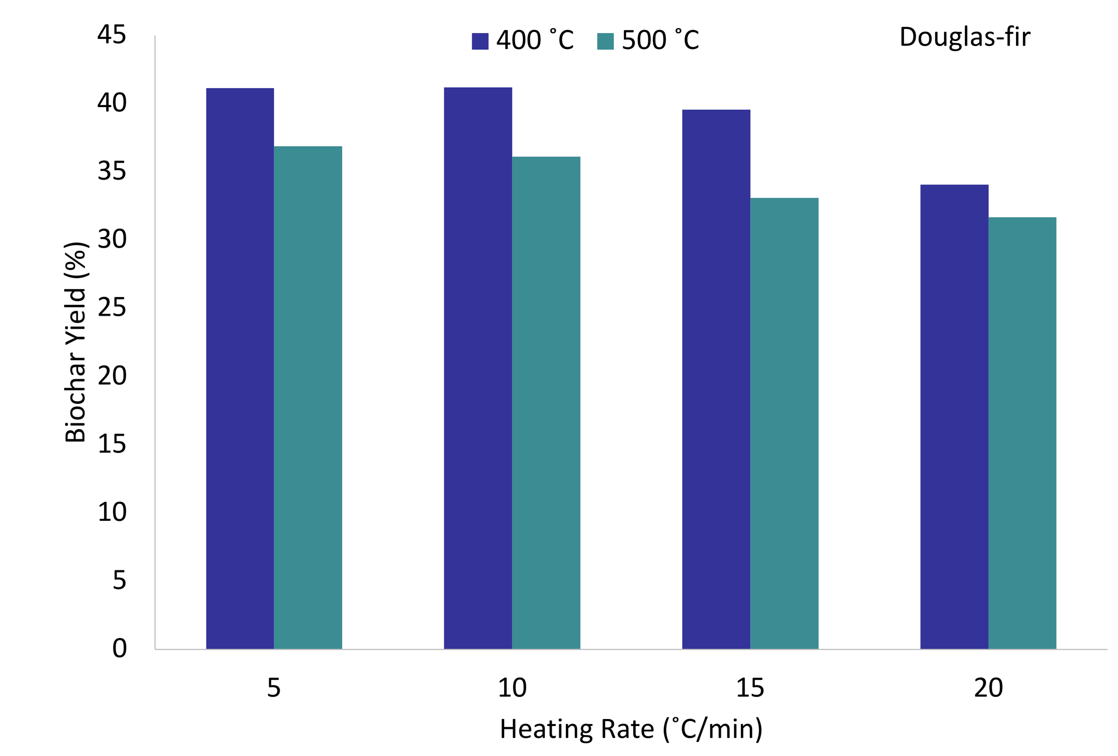


Methane yield is higher with Douglas-fir biochar vs. wheat straw biochar. Douglas fir initially outperforms standard catalyst support alumina.

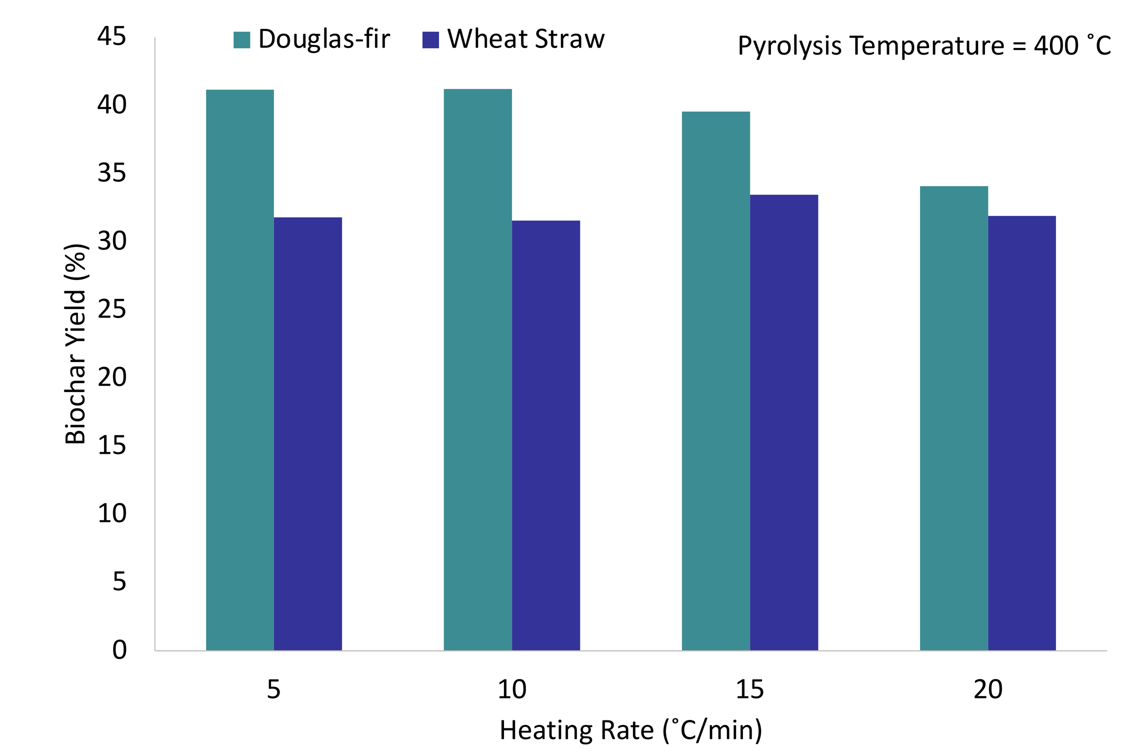


Methane yield is unchanged when nickel loading is increased from 5 wt.% to 7 wt.%, but decreases when it is further increased to 10 wt.%.

Key Results



Biochar yield increases as heating rate decreases. Biochar yield increases as pyrolysis temperature decreases.



Biochar yield is higher with Douglas-fir biochar vs. wheat straw biochar.

Key Conclusions

- Methane yield is higher at lower heating rates because the specific surface area is higher and mesopores are more abundant than micropores.
- Methane yield is higher at greater pyrolysis temperatures because the specific surface area is higher, and the porous network is better developed.
- Methane yield is higher over Douglas-fir biochar-based catalysts because the ash content is lower, and the specific surface area is higher.
- Methane yield is higher over 7 wt.% Ni compared to 10 wt.% Ni because Ni particles can agglomerate and block pores in higher loading sample. Methane yield is unchanged at 5 wt.% Ni because there are less Ni particles for catalysis, but also less blockage of pores.
- Decreasing pyrolysis temperature and heating rate will allow higher recovery of biochar but may lead to lower methane yield.
- Douglas-fir has a higher biochar yield than wheat straw because its lignin content, and hence fixed-carbon content, is greater.
- Biochar-based catalysts have the potential to outperform popular metal oxide-supported catalysts such as alumina for methanation.