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Evaluation of Torrefied Fruit and Vegetable Residues as a Sustainable Coal Substitute: Fuel Quality Characterization and ASTM D388 Classification

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DOST

INTRODUCTION & AIM

As of 2023, the Philippines' greenhouse gas emissions had increased by 49.9% compared with 2012, largely due to its coal-dependent energy infrastructure.

This study evaluates the fuel properties of biochar produced from market waste fruit and vegetable residues (FVRs) via torrefaction (200–300 °C) and benchmarks its performance against commercial coal standards.

Aim: To determine the fuel quality (proximate analysis and HHV) of torrefied FVR biochar and classify it using ASTM D388 to identify its comparable coal rank.

METHOD

Feedstock → Market waste fruit and vegetable residues

Preparation → Washed, chopped and dried

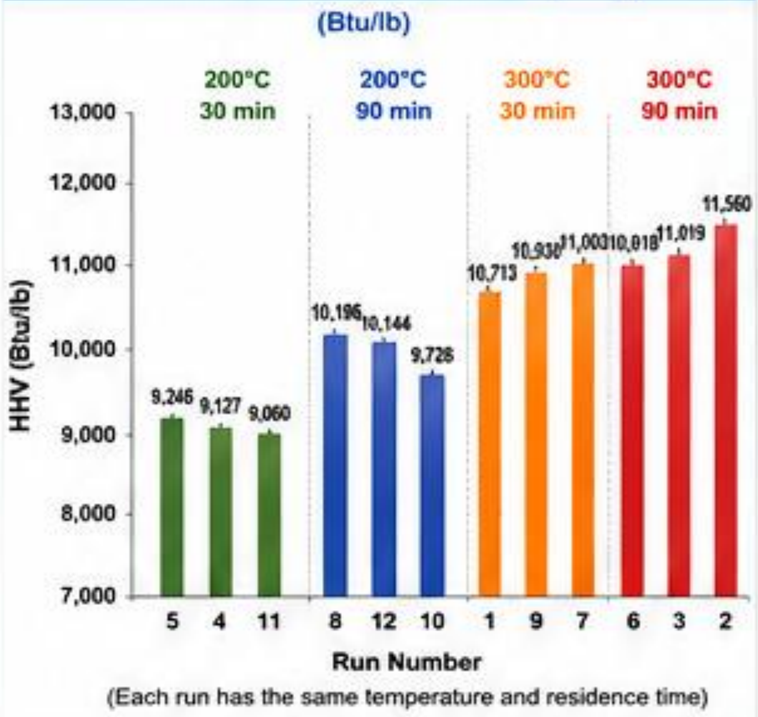
Torrefaction → 200–300 °C; Residence time: 30 or 90 min (11 experimental runs)

Characterization
- Proximate analysis (ASTM D1762)
- HHV (ASTM D5865)
- ASTM D388 classification

Fuel properties considered: Moisture, Volatile Combustible Matter (VCM), Ash, Fixed Carbon, Higher Heating Value (HHV), Fuel Ratio (FC/VCM).

RESULTS & DISCUSSION

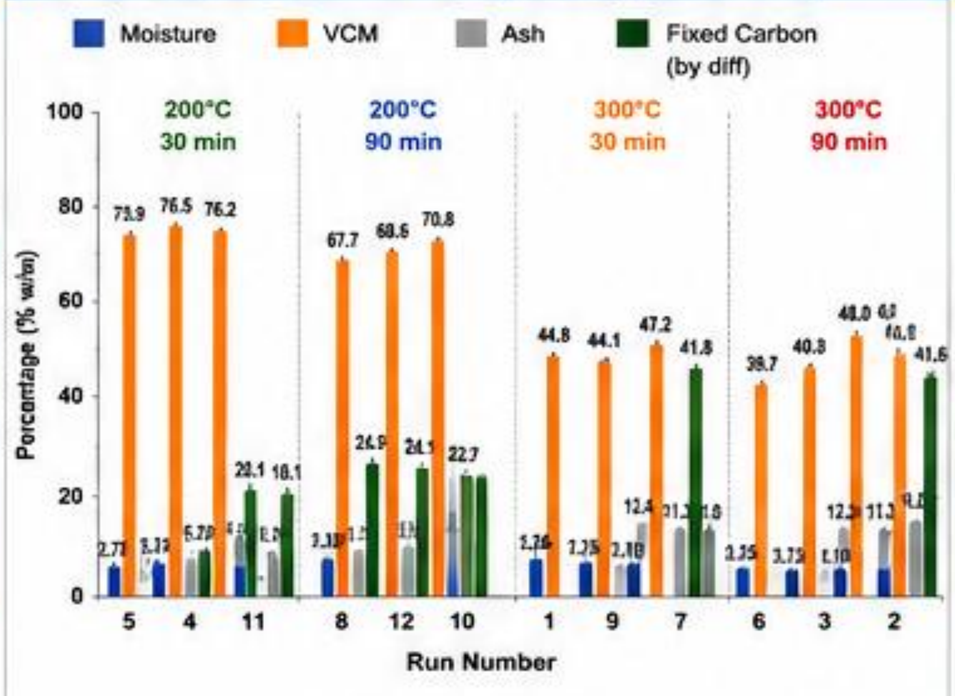
1. HIGHER HEATING VALUE (HHV)



(Each run has the same temperature and residence time)

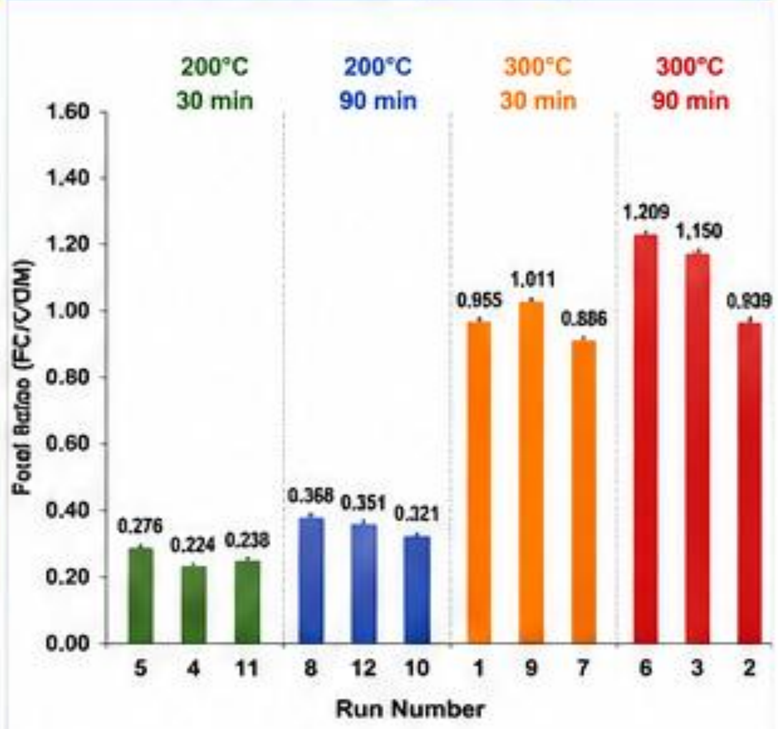
Maximum HHV of 11,560 Btu/lb at 300°C for 90 min, comparable to bituminous coal.

2. PROXIMATE ANALYSIS (% w/w, as received)



- Fixed carbon increases with temperature and residence time.
- VCM decreases as torrefaction severity increases.
- Moisture remains below 5% for all samples.
- Ash content ranges from 5.75% to 14.20%.

3. FUEL RATIO (FC / VCM)



Fuel ratio (FC/VCM) increases from 0.22 to 1.21, indicating improved combustion stability.

4. ASTM D388-12 COAL RANK CLASSIFICATION

Property	Lignite	Sub-bituminous	Bituminous	Anthracite
Calorific Value (kcal/kg)	< 4,600	4,600 – 6,400	5,800 – 8,300	No specific limit under ASTM
Moisture Content (% as received)	30 – 75%	10 – 30%	1 – 10%	< 5%
Fixed Carbon Content (% dry basis)	No limit	No limit	< 86%	> 86%
Volatile Matter (% dry basis)	No limit	No limit	> 14%	> 14%

Biochar at 200°C is classified as Sub-bituminous coal.
Biochar at 300°C is classified as Bituminous coal.

Source: ASTM D388-12

5. CLASSIFICATION OF BIOCHAR PROPERTIES WITH COAL STANDARDS

Temperature / Residence Time	Run	Proximate Analysis (% w/w)				Heating Value (kcal/kg)	Coal Type (ASTM D388)
		Moisture	VCM	Ash	Fixed Carbon (by diff)		
300°C 90 min	6	3.93	39.7	12.3	48.0	6,069.61	Bituminous
	3	3.71	40.8	12.3	46.9	6,125.76	Bituminous
	2	4.19	44.3	14.2	41.6	6,426.52	Bituminous
300°C 30 min	1	4.71	44.8	12.4	42.8	5,955.65	Bituminous
	9	4.12	44.1	11.3	44.6	6,076.28	Bituminous
	7	3.73	47.2	11.0	41.8	6,116.86	Bituminous
200°C 90 min	8	2.68	67.7	7.36	24.9	5,668.23	Sub-bituminous
	12	3.71	68.6	7.29	24.1	5,639.32	Sub-bituminous
	10	3.68	70.8	6.47	22.7	5,408.06	Sub-bituminous
200°C 30 min	5	2.77	73.9	5.75	20.4	5,140.10	Sub-bituminous
	4	3.21	76.5	6.32	17.1	5,073.95	Sub-bituminous
	11	3.70	76.2	5.70	18.1	5,036.70	Sub-bituminous

CONCLUSIONS

- FVR-derived biochar demonstrates HHV values ranging from 9,060 to 11,560 Btu/lb, comparable to sub-bituminous to bituminous coal.
- Fixed carbon increases and VCM decreases with higher torrefaction severity, improving fuel ratio from 0.22 to 1.21 and indicating better combustion stability.
- Biochar produced at 200°C is classified as Sub-bituminous coal, while biochar at 300°C is classified as Bituminous coal (ASTM D388).

These results show that torrefied FVR biochar can serve as a renewable coal substitute in existing coal-fired systems with minimal modification.

FUTURE WORK / REFERENCES / ACKNOWLEDGMENT

Future Work

Investigate long-term combustion performance, emissions characteristics, and co-firing optimization in industrial boiler systems.

References

1. American Society for Testing and Materials (ASTM). (2012). ASTM D388-12: *Standard classification of coals by rank*. ASTM International.
2. American Society for Testing and Materials (ASTM). (2013). ASTM D1762: *Standard test method for chemical analysis of wood charcoal*.
3. American Society for Testing and Materials (ASTM). (2019). ASTM D5865: *Standard test method for gross calorific value of coal and coke*.

Acknowledgment

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