AKADEMIA GÓRNICZO-HUTNICZA
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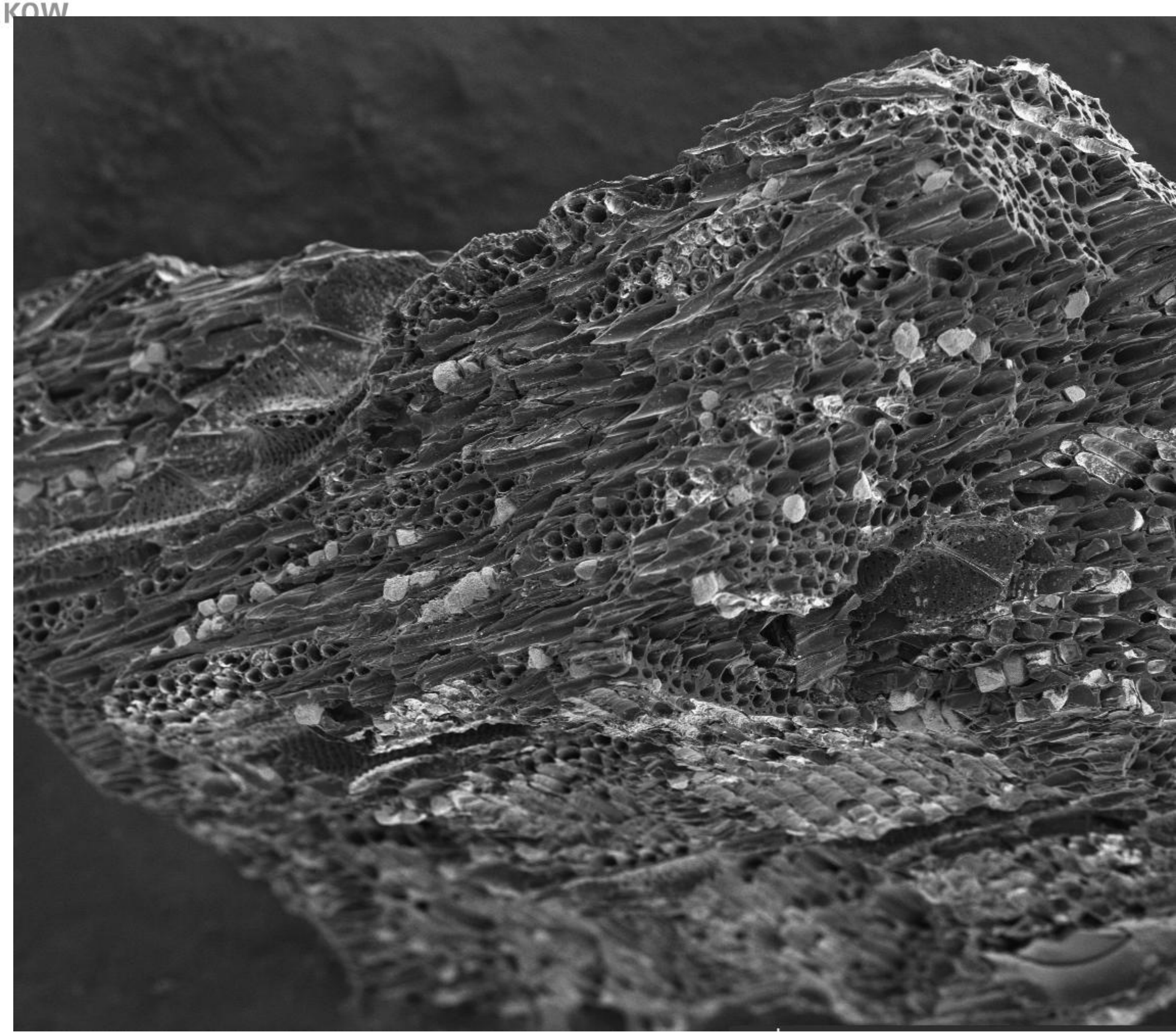

Thermochemical conversion of food waste toward production of new porous materials

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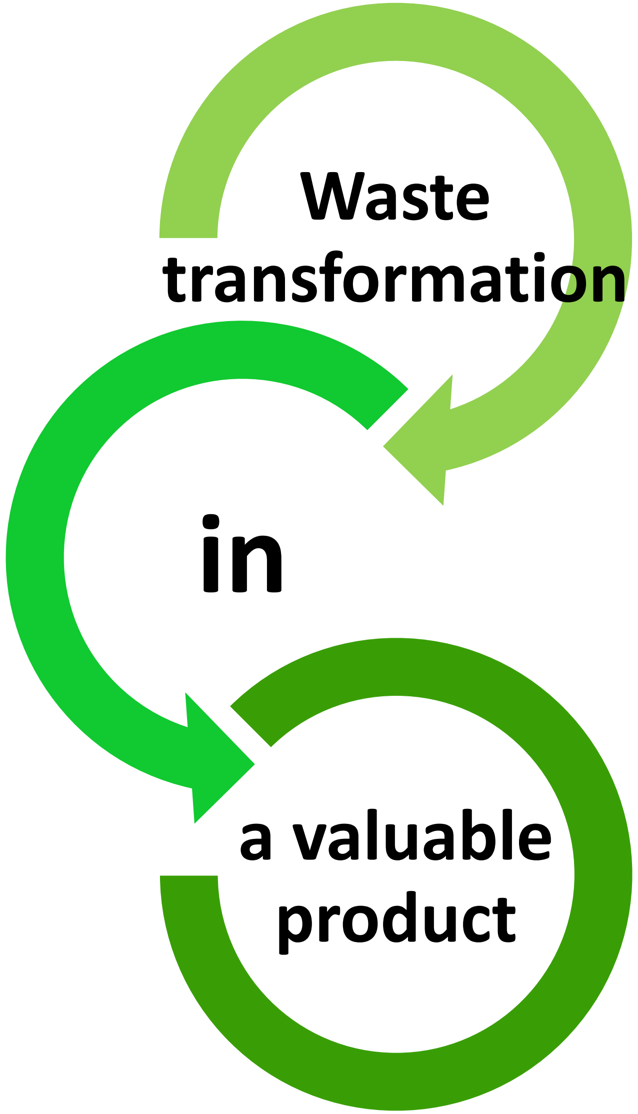
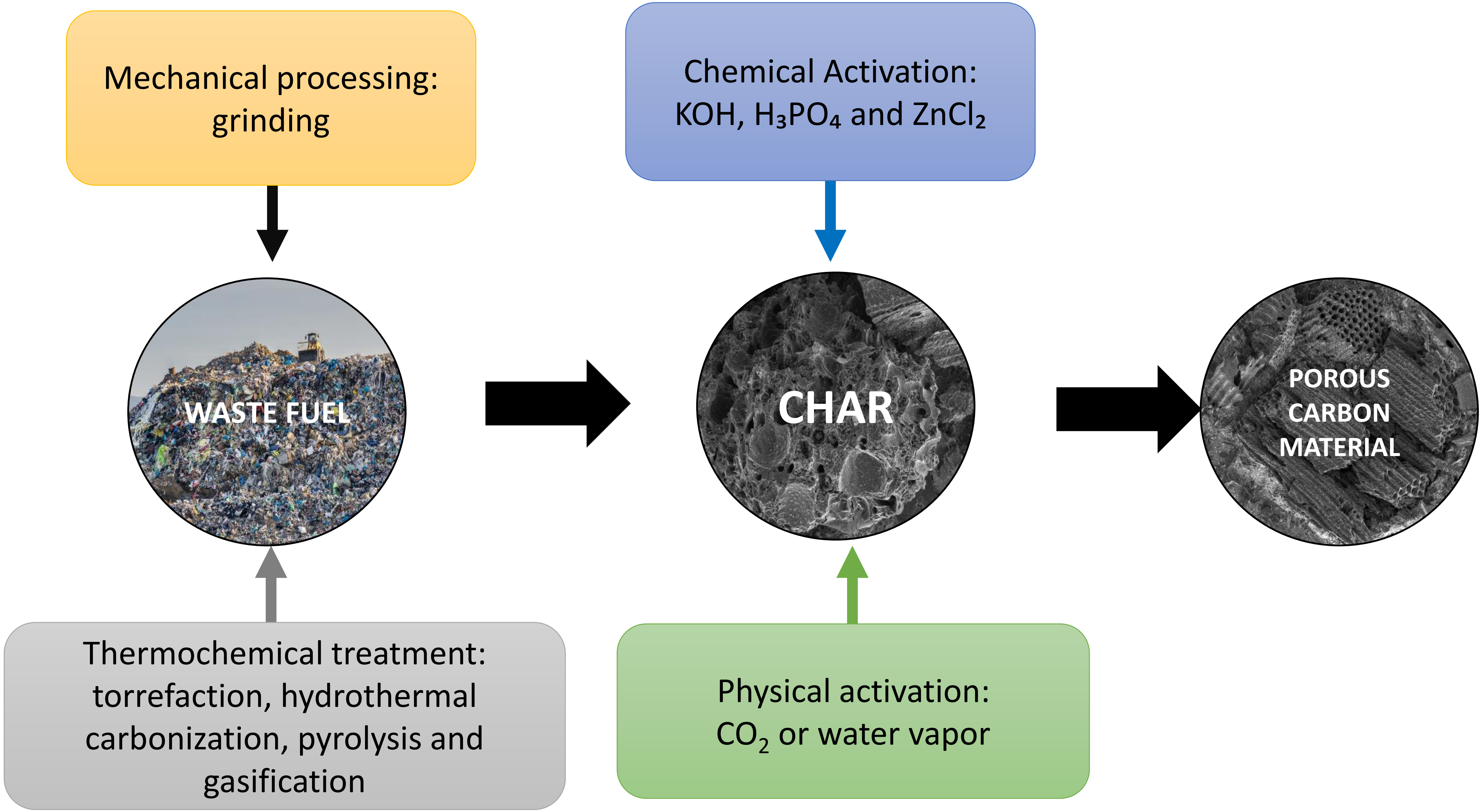
International Energy and Environment Conference (IEEC),
09.09.2025

Food waste alone causes 10% of greenhouse gases

Circular economy



Synthesis of porous carbon materials from waste fuels



Scope of the studies

Study: Production and Applications of Activated Carbon from Food Waste

Goal:

Analysis of food waste thermochemical activation using both phisical and chemical methods. Heavy metals and organic contamination capture efficiency. Methanol uptake.

- Raw feedstock characterisation:proximate and ultimate analyses, fiber analyses, chemical composition of ash
- Pyrolysis – biochar synthesis
- Steam and CO_2 gasification of biochars, at 800-900 °C and 15-30 min.
- Chemical activation using H_3PO_4 and $ZnCl_2$ or KOH.
- Scanning electron microscopy (SEM) for determination of morphology and structure of biochars and activated biochars.
- Thermal stability of the biochars and activated biochars.
- Structural analysis of the biochars and activated biochars.
- Adsorption efficiency of lead and phenol from the studied biochar
- Methanol adsorption tests

Materials – food waste

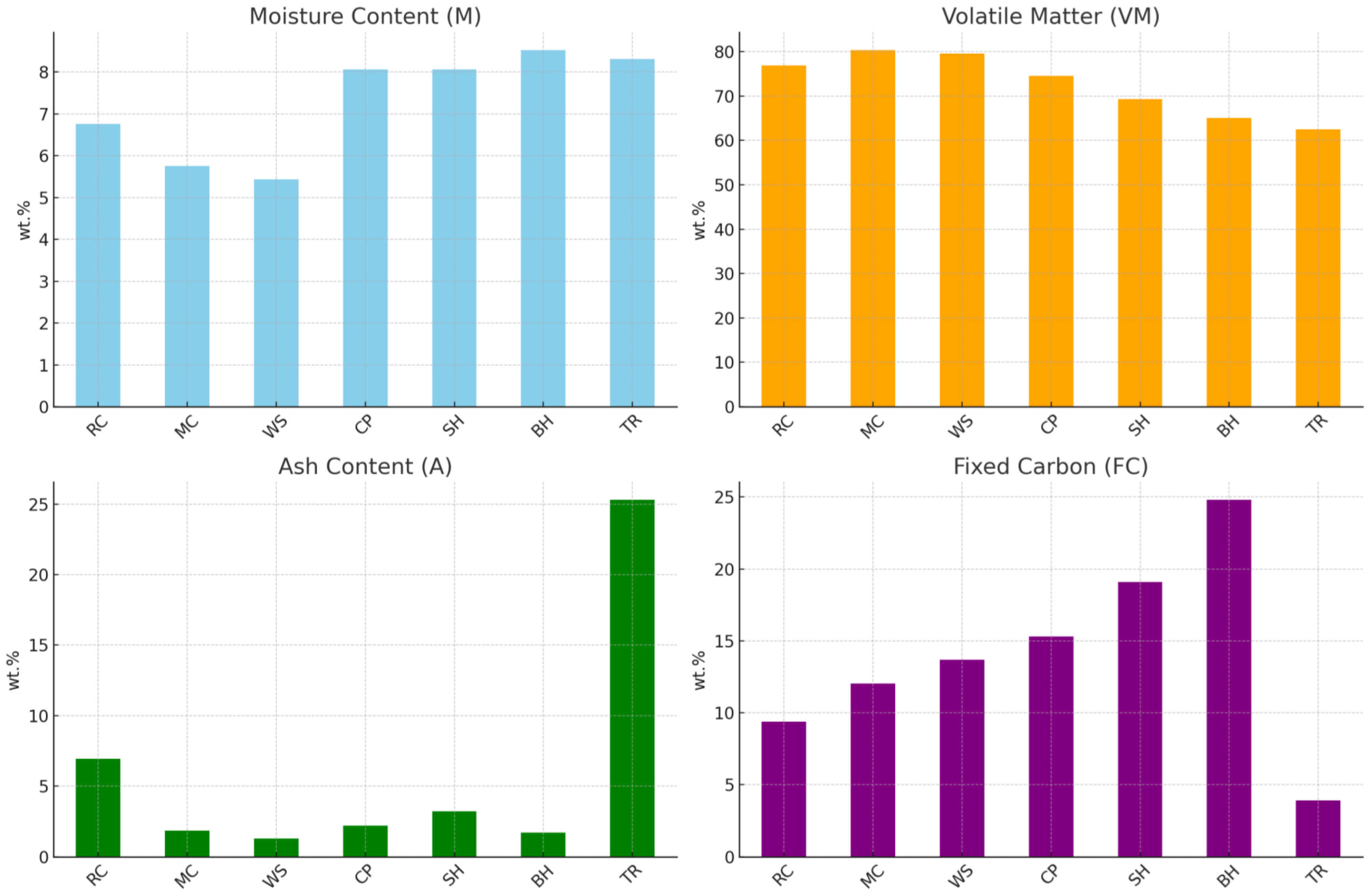
In this study, seven organic by-products were analyzed for thermal valorization: **rape cake (RC)**, **maize cob (MC)**, and **walnut shells (WS), tomato residues (TR), cherry pits (CP), buckwheat husks (BH) and sunflower husks (SH).**

RC

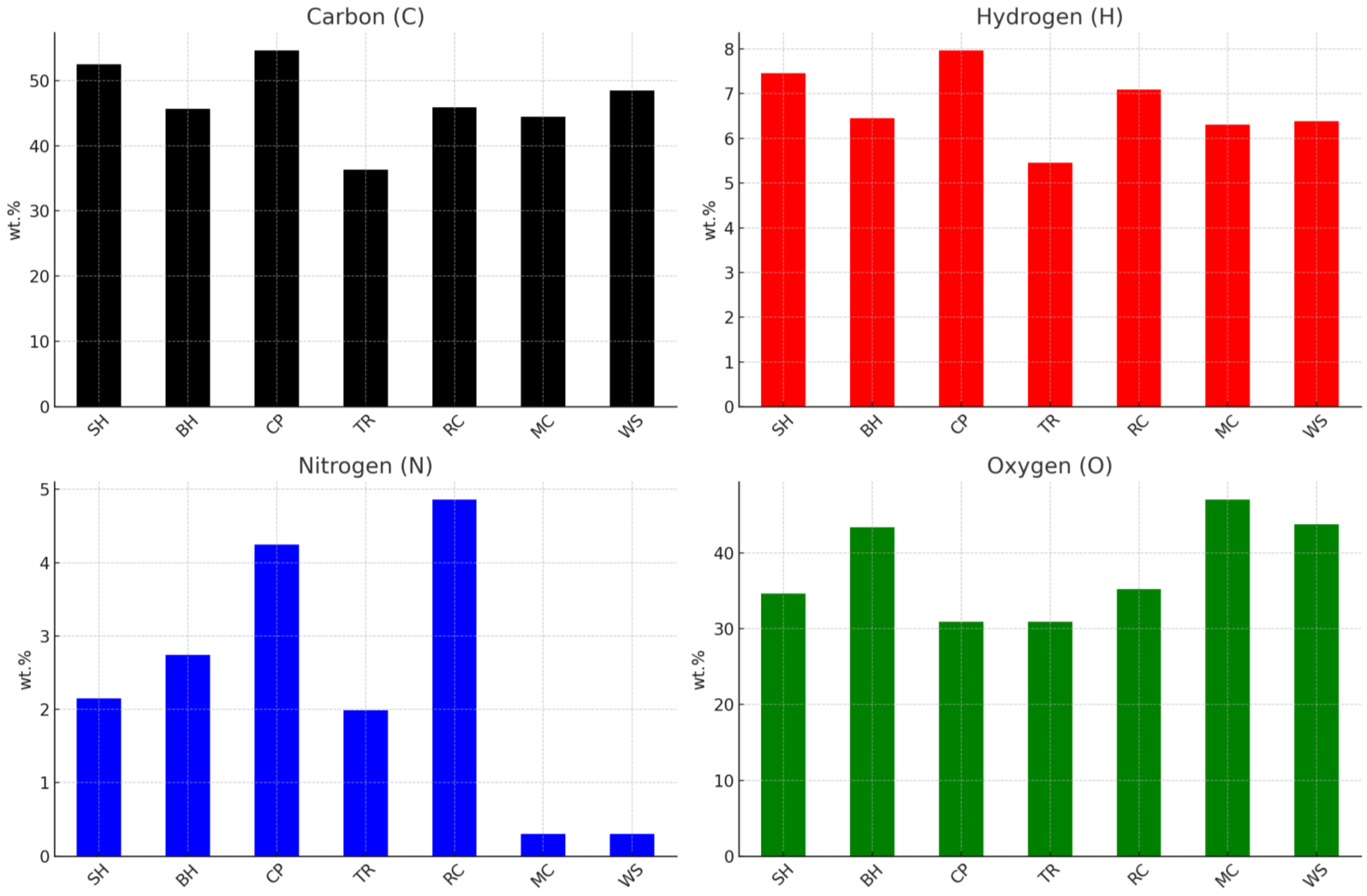
MC

WS

Proximate and ultimate analyses of the studied materials



Proximate and ultimate analyses of the studied materials



Fibre analysis of the studied materials

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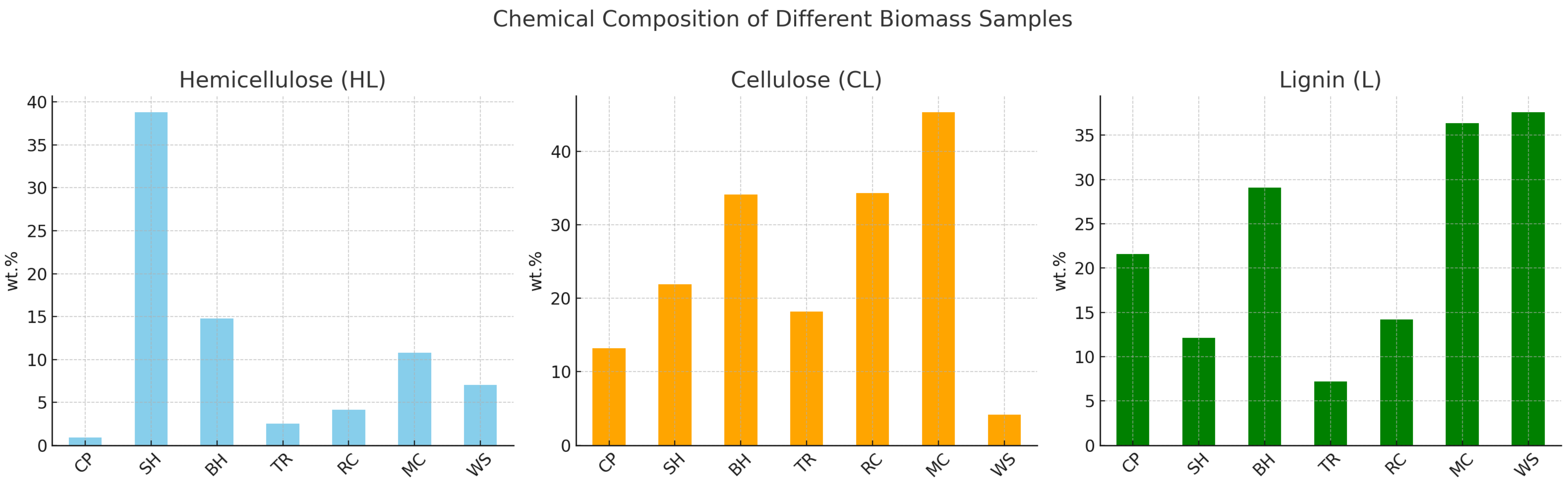
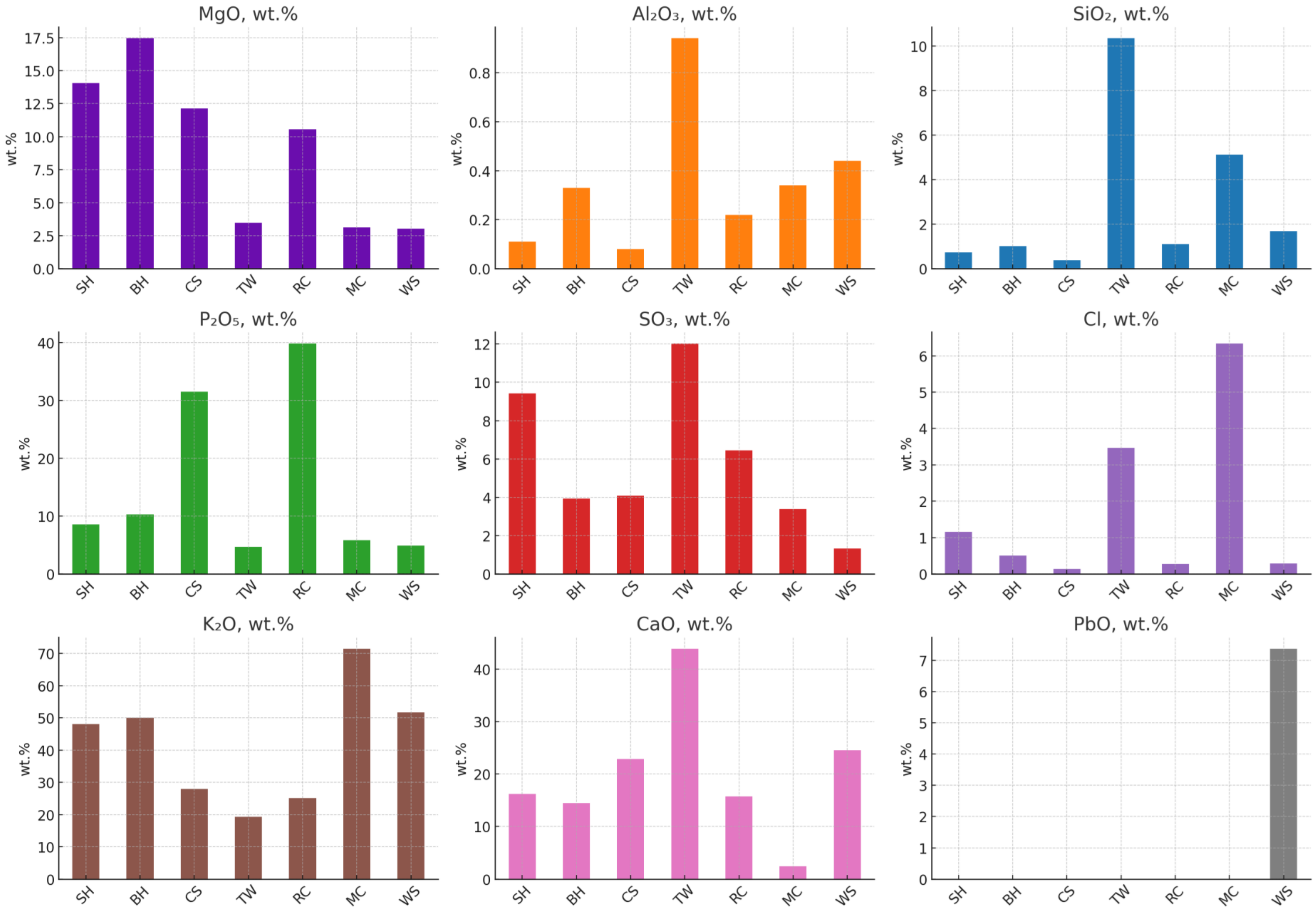


Studied materials chemical composition of ash



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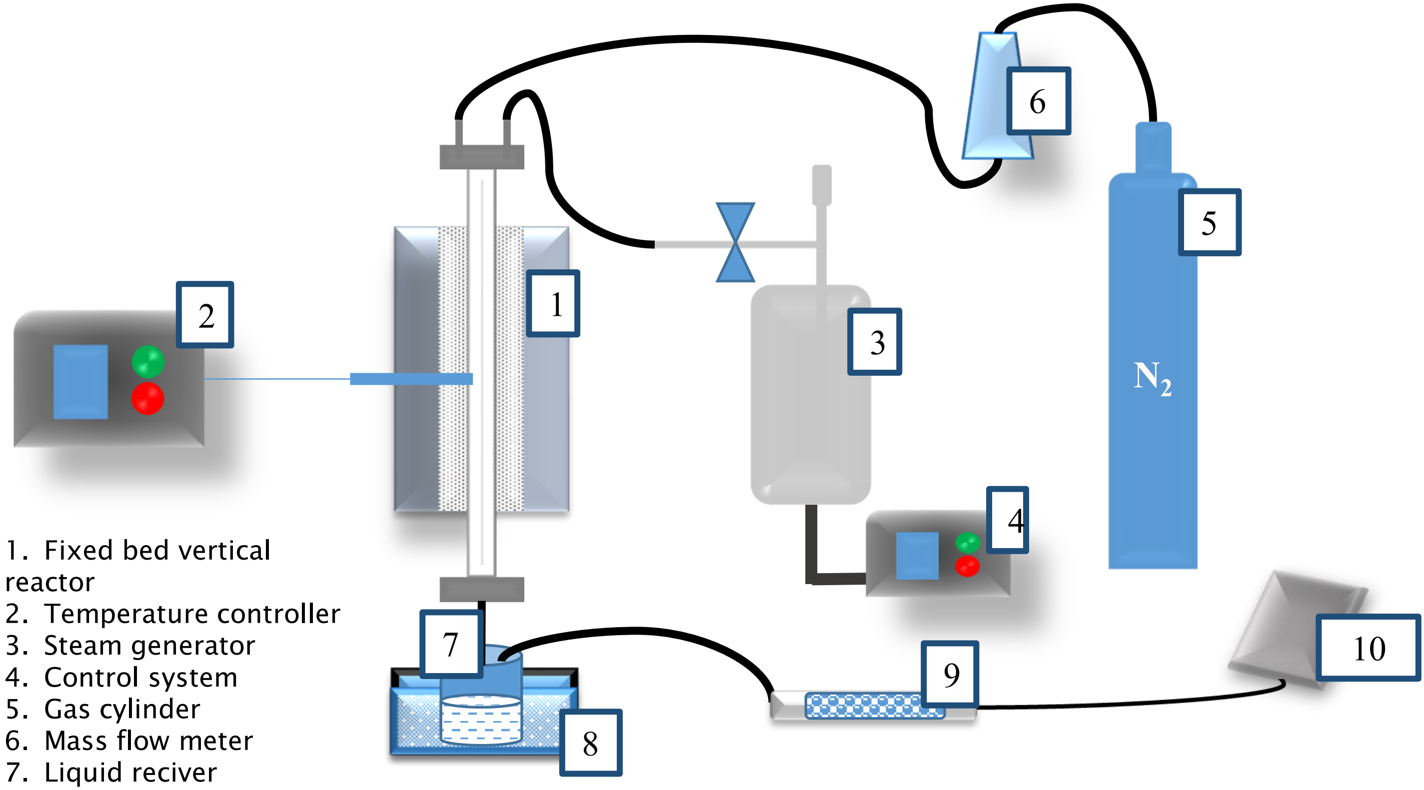
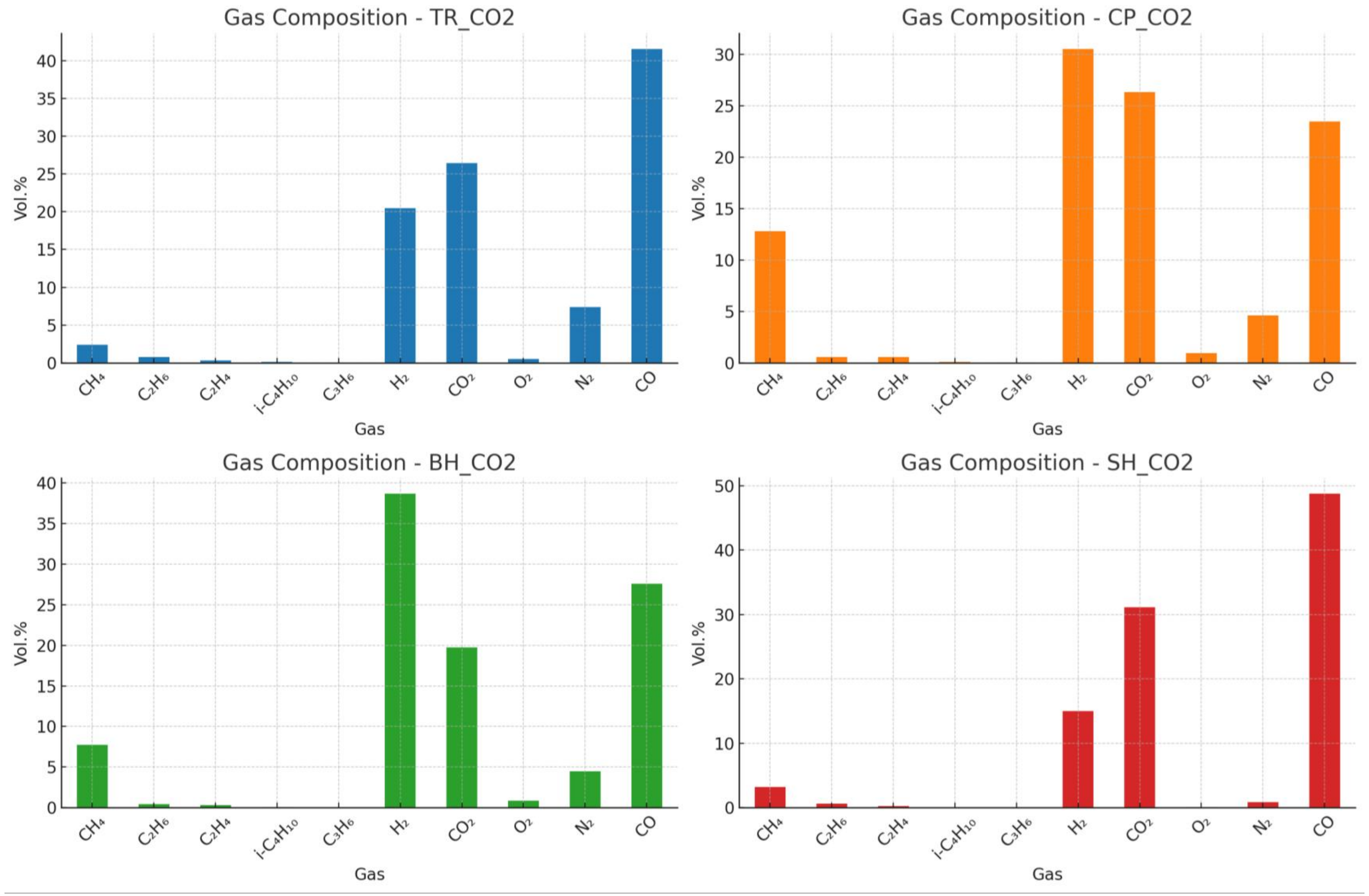
Thermochemical conversion

- **Reactor**: Fixed-bed vertical quartz reactor with quartz wool support.
- **Carrier Gas**: Nitrogen used to purge air and maintain inert conditions.
- **Drying Phase**: Heated to **200 °C** over **20 minutes** to remove moisture.
- **Activation Phase**: Steam, CO_2 or mix introduced.
- Temperature ramped to **800-900 °C** and held for **15-30 minutes**.
- **Cooling Phase**: Steam stopped; cooling under nitrogen to ambient temperature.

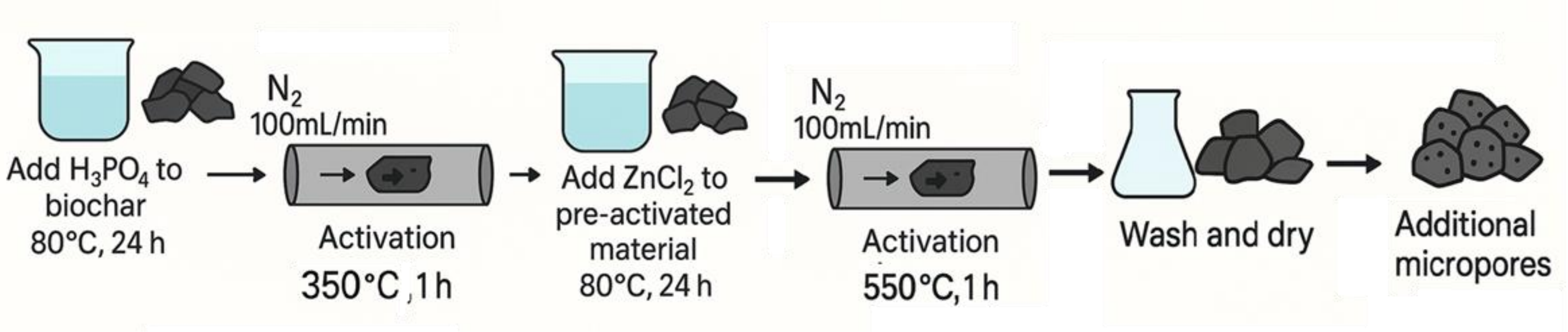


1. Fixed bed vertical reactor
2. Temperature controller
3. Steam generator
4. Control system
5. Gas cylinder
6. Mass flow meter
7. Liquid reciver
8. Ice-water bath
9. Dryer
10. Tedlar bag

Synthesis gas composition – CO_2 gasification



Chemical activation procedure

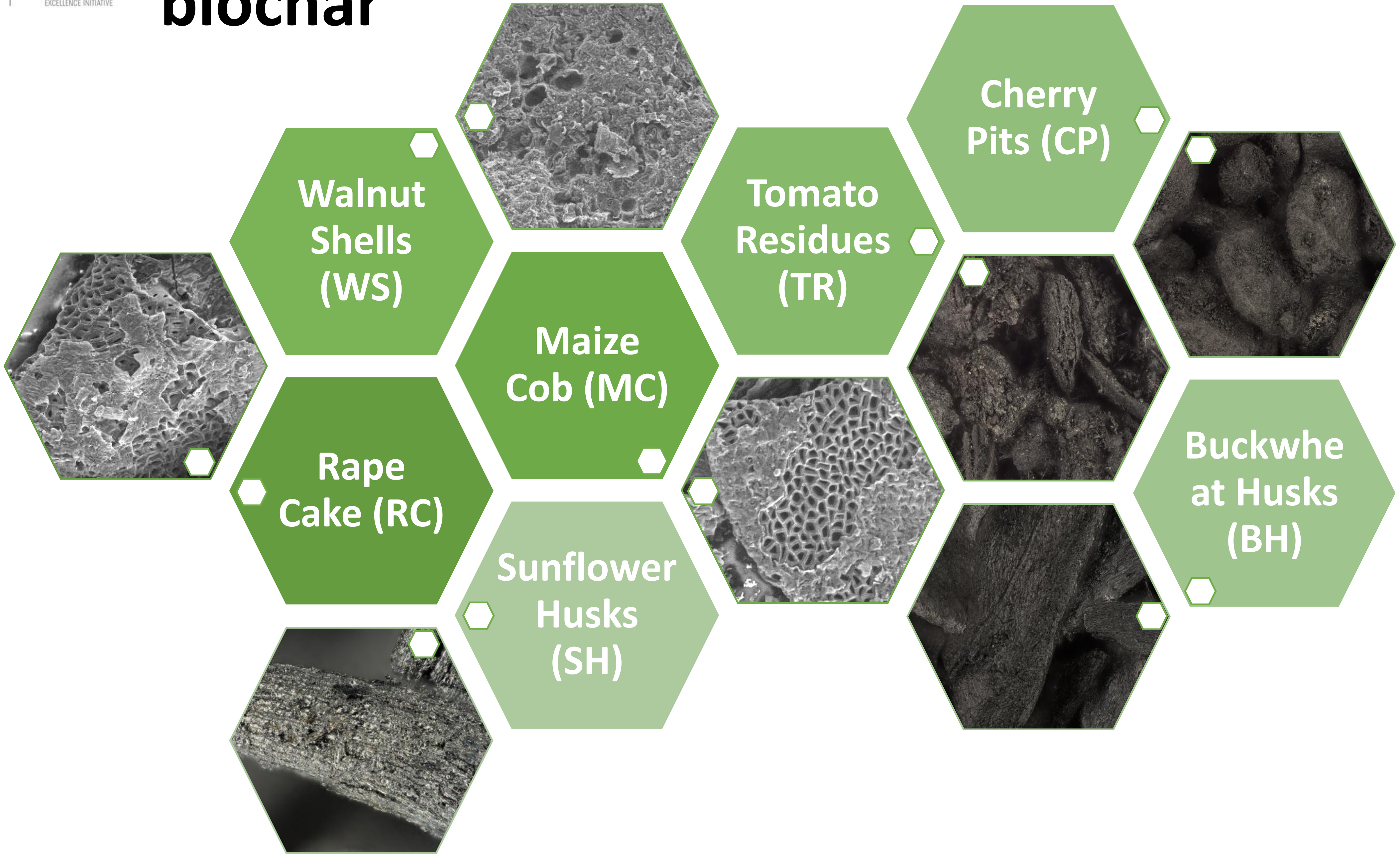


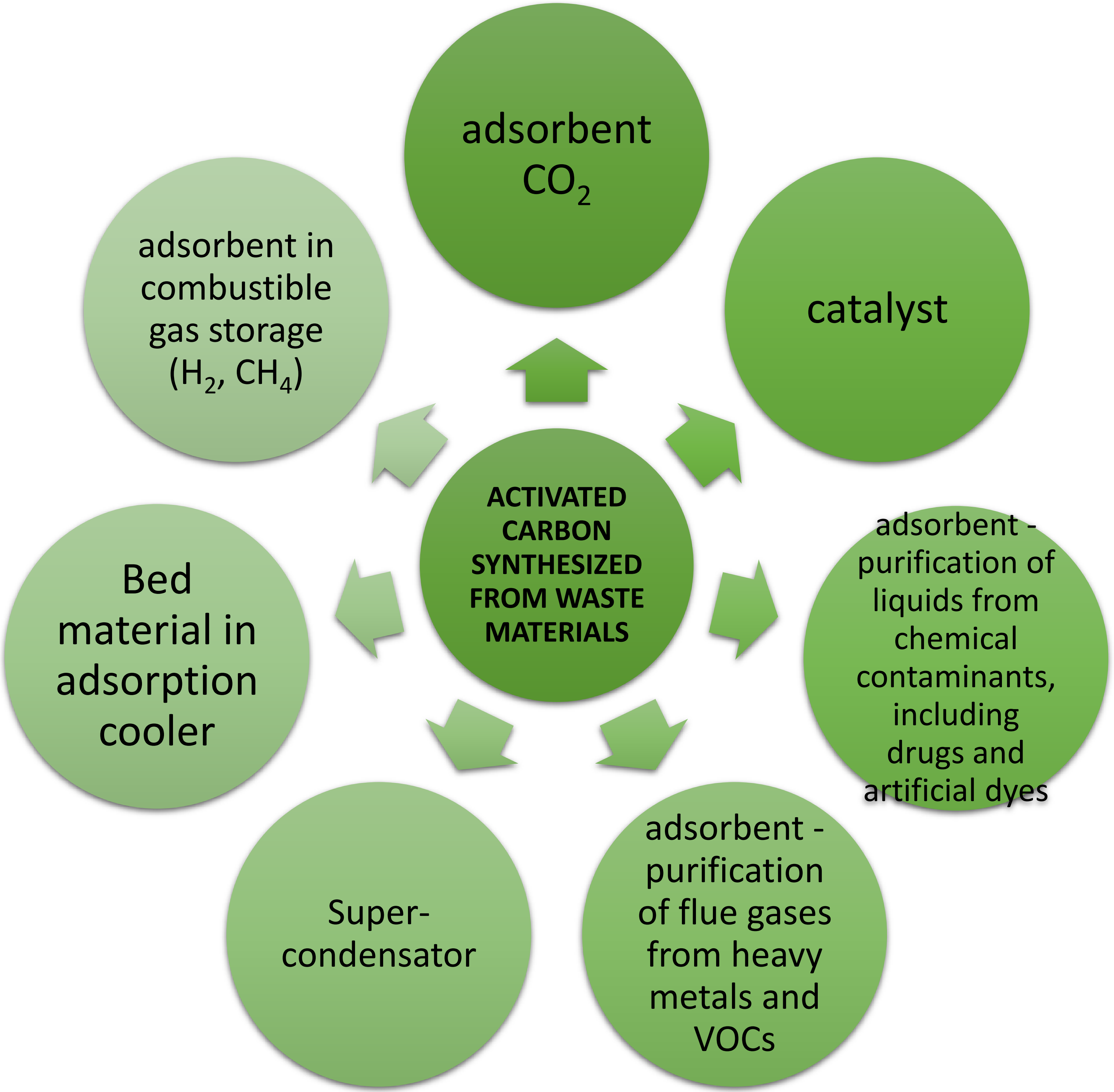
A sequential chemical activation process using H_3PO_4 and $ZnCl_2$ was conducted to improve the specific surface area and microporosity of the resulting biochar. Activating with H_3PO_4 first, followed by $ZnCl_2$, led to the breakdown of P-O-C bonds and the formation of additional micropores.

Surface area and pore structure of the studied biochar

Studied material	Specific surface area (BET), m^2/g	Micropore Vol., cm^3/g	Mean pore diameter (adsorp. BJH), nm	Mean pore diameter (desorp. BJH), nm
RC_H2O	302.8	0.1027	6.05	3.86
RC_chem	441.18	0.1466	9.06	5.07
MC_H2O	315.72	0.1150	5.58	2.65
MC_chem	537.59	0.1873	4.33	2.69
WS_H2O	544.96	0.1813	5.02	3.51
WS_chem	557.09	0.1922	4.37	2.71
TR_CO2	90.12	0.03	8.43	5.05
CP_CO2	509.11	0.19	4.41	2.99
BH_CO2	410.59	0.16	4.49	2.65
SH_CO2	223.71	0.10	4.64	2.62

Morphology of the studied biochar



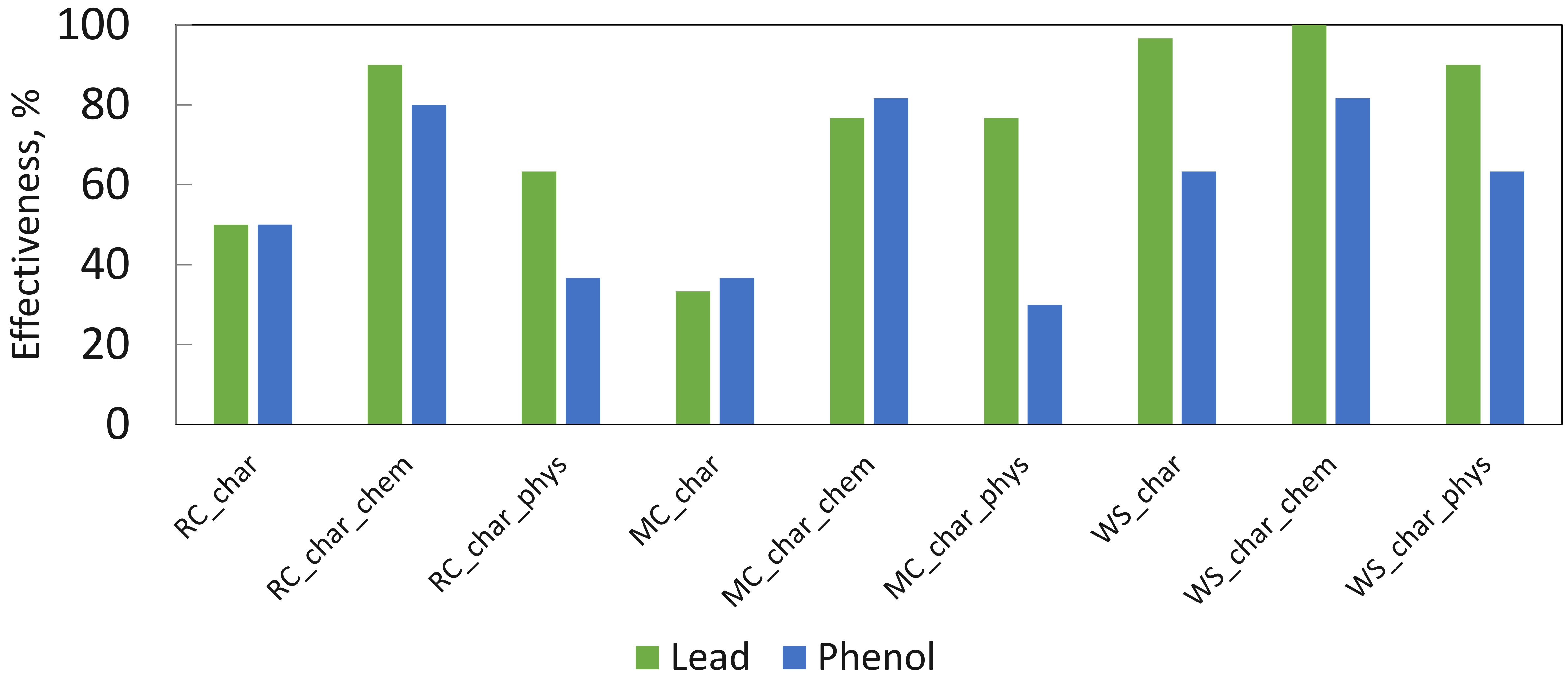

ACTIVATED CARBON SYNTHESIZED FROM WASTE MATERIALS
adsorbent CO_2
catalyst
adsorbent - purification of liquids from chemical contaminants, including drugs and artificial dyes
adsorbent - purification of flue gases from heavy metals and VOCs
Super-condensator
Bed material in adsorption cooler
adsorbent in combustible gas storage (H_2, CH_4)

Adsorption efficiency of lead and phenol from the studied biochar

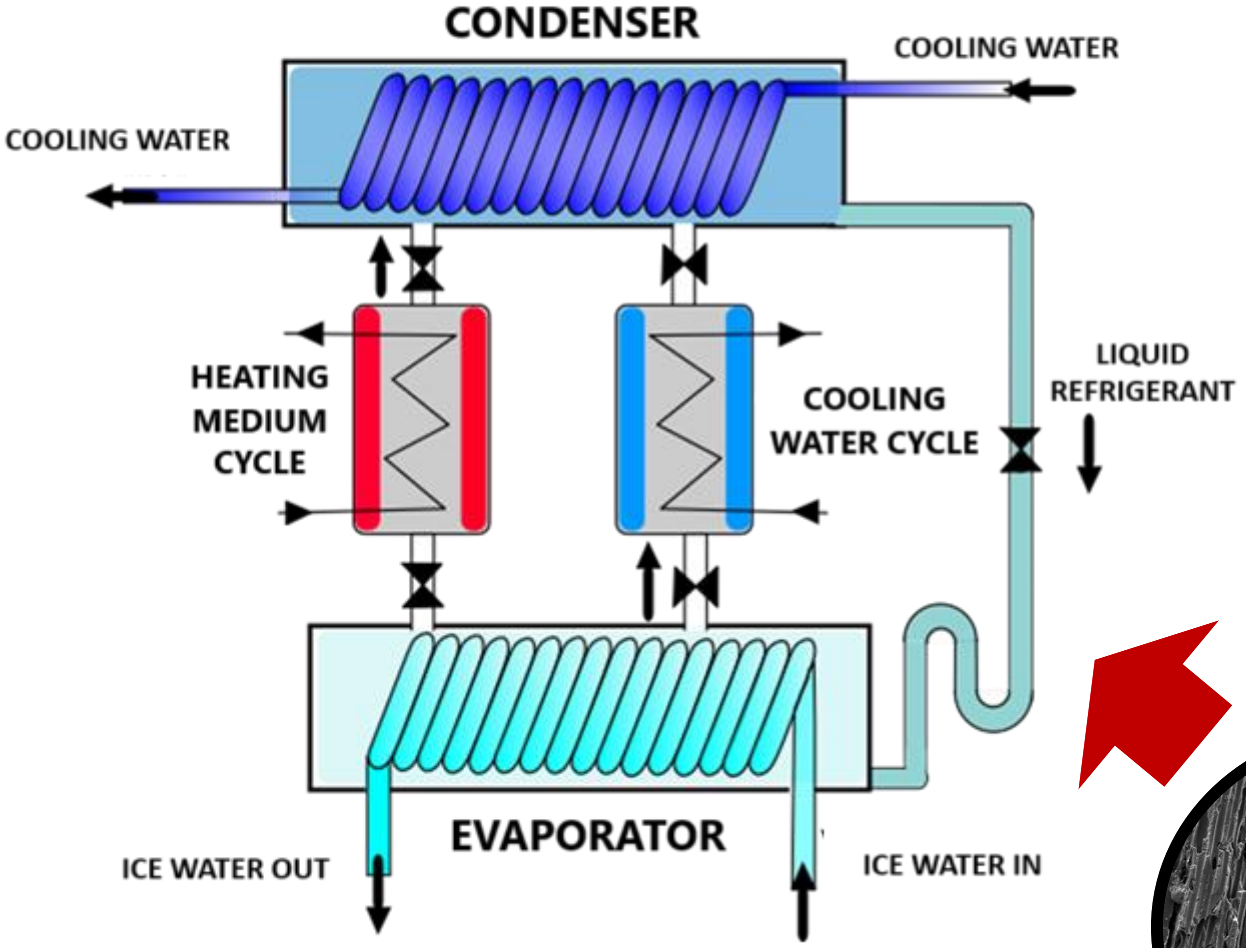
- **Chemical Reagents**
  - Phenol: Sigma Aldrich (Poznań, Poland)
  - $PbCl_2$ Standard Solution: Merck (Poland)
  - Concentrations monitored via spectrophotometry (Merck test kits).
- **Sorption Study**
  - Model water with deionized water.
  - Inorganic: Pb^{2+}, 300 mg/L, pH 7.0
  - Organic: Phenol, 600 mg/L, pH 7.0
  - Adsorption in 100 mL bottles:
    - 50 mL solution, 2 g/L adsorbent.
    - Shaker: 320 rpm, 60 min, room temp.
- **Toxicity Test**
  - Aqueous extracts per PN-EN 12457-4:2006.
  - Test organism: Lemna minor (freshwater plant).
  - Conditions:
    - 25 ± 1 °C, 6000 lux, 7 days.

Toxic Effect (%)	Toxicity Class
≤ 25.00	No toxicity
25.01 – 50.00	Low toxicity
50.01 – 75.00	Toxicity
> 75.00	High toxicity

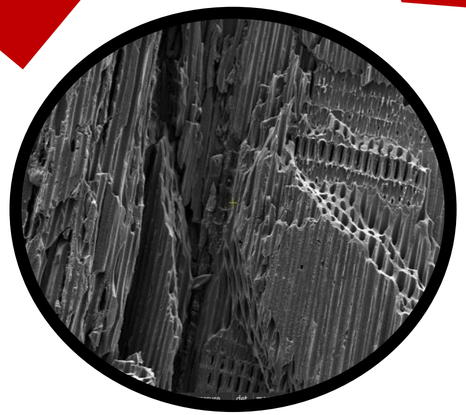
Adsorption efficiency of lead and phenol from the studied biochar



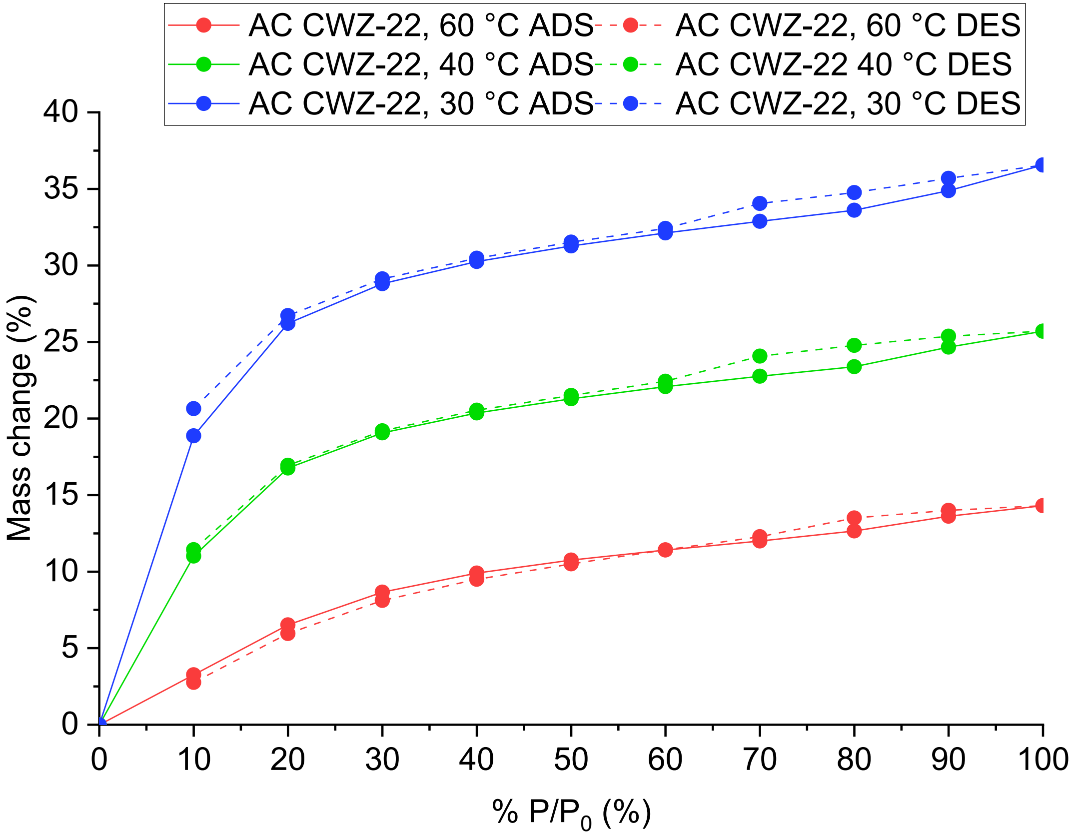
Bed material in adsorption cooler

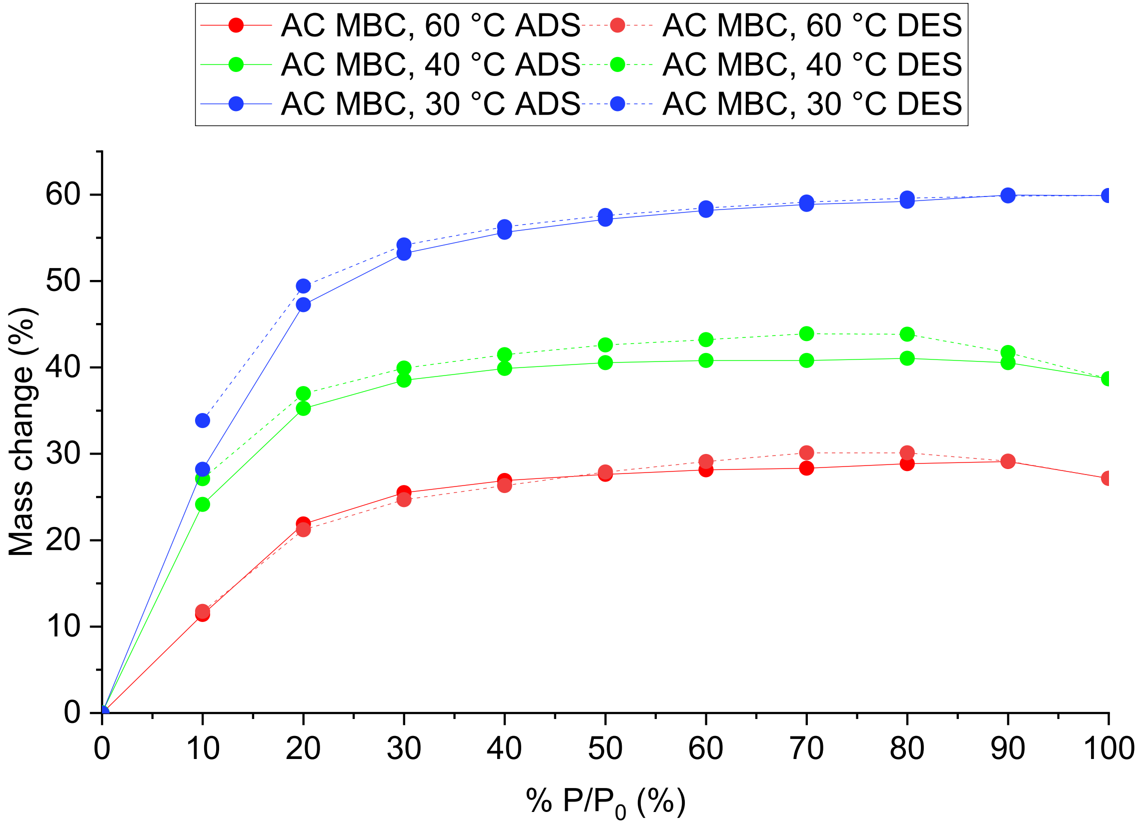


Operation diagram of a two-bed adsorption chiller



Adsorption and desorption isotherms for the AC





Summary of the SCP and COP ratios of an adsorption chiller operating with different operating working pairs

Working pair	T_{ads}, T_{cond} [°C]	T_{des} [°C]	T_{evap} [°C]	SCP_{max} [W/kg]	COP for SCP_{max} [-]
CWZ-22/methanol	30	60	7	71.2	0.575
CWZ-22P/methanol				57.2	0.476
Norit GL 50/methanol				30.7	0.380
AC MBC/methanol				111.9	0.639
AC EWC/methanol				1.1	0.019
CWH-22/methanol				95.5	0.615
AKPA-22/methanol				68.4	0.604
RDF_IW_H2O/methanol				53.5	0.631
RDF_IW_KOH/methanol				88.9	0.673
RDF_MW_H2O/methanol				30.4	0.528
TDF_H2O/methanol				16.6	0.411
TDF_KOH/methanol				31.4	0.498

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Conclusions

- ✓ The selected food waste materials, rich in lignocellulosic components, were successfully converted into biochar with char yields of approximately 25%. Carbon-rich biochar (up to 80% by weight) was obtained, particularly from maize cobs and walnut shells.
- ✓ Single-step CO_2 gasification enhanced the porosity and specific surface area of the food waste used in this study, yielding results comparable to those of commercial activated carbons.
- ✓ Both physical (steam at 900 °C) and chemical (H_3PO_4 + $ZnCl_2$) activation significantly improved the surface properties of biochar, increasing its porosity and specific surface area (above 500 m^2/g).
- ✓ The chemically activated biochar exhibited the highest adsorption capacity, effectively removing both organic (phenol) and inorganic (lead) pollutants from aqueous solutions.
- ✓ The ecotoxicity test showed that none of the biochar samples tested proved toxic to aquatic plants. These results indicate its safe potential for environmental applications, particularly in wastewater treatment and pollutant removal.

Published work regarding porous carbon materials

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Research Paper

Waste-Derived carbon porous materials for enhanced performance in adsorption chillers: A Step toward a circular economy

Agata Mlonka-Mędrala [a,*], Katarzyna Jagodzińska [b], Tomasz Bujok [a], Wojciech Kalawa [a], Tong Han [b], Karol Sztekler [a], Wojciech Nowak [a], Łukasz Mika [a]

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Fuel 324 (2022) 124435

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Thermal upgrading of hydrochar from anaerobic digestion of municipal solid waste organic fraction

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Thank you for your attention!

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