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Engineers in Technical and Humanitarian Opportunities of Service

Post Combustion Methods for Emission Reduction in Small Scale Combustion: A Literature Review

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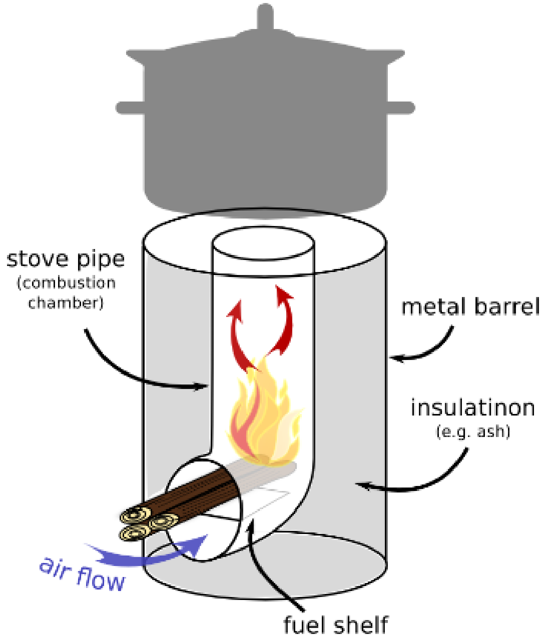
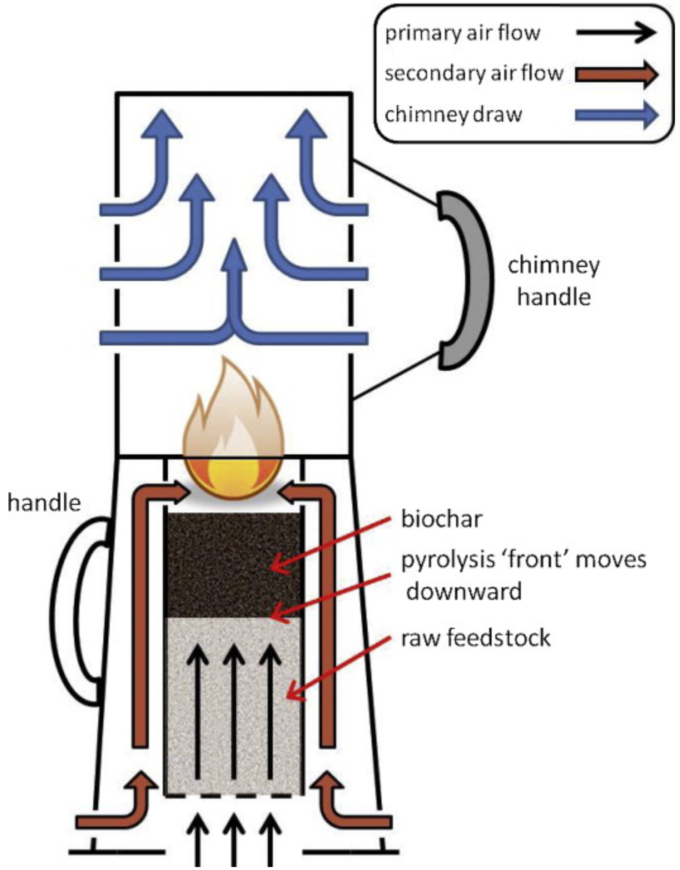
Efficient Cookstoves as a Solution

- Aim of Cookstove Improvements:
  - Increase Efficiency
    - Increase Sustainability of Biomass Fuel Sources … MDG (3) (5) (7)
  - Improve Safety
    - Improve Indoor Air Quality … MDG (4) (5)
    - Reduce Burn Rates … MDG (4) (5)

- Noteworthy Accomplishments:
  - More Efficient than Traditional Cookstoves*
  - Reduced Emissions*
  - Generally Improved Safety

- (*) Noteworthy Struggles:
  - Adoption Rate
  - Developing Tending Practices





If You Can’t Make the Stove Better …
What Can You Do to Reduce Emissions?

- For Indoor Air Quality … Add a Chimney
- For Overall Air Quality … ???

Figure 7. Integrated honeycomb catalyst.

Catalytic Devices

Fibrous Filters

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aid group Stove

Electrostatic Precipitators

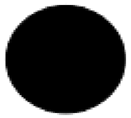
Defining Emissions of Interest

To focus the effort of reducing emissions, primary pollutant emission were identified by observing studies relating combustion emissions to health factors in conjunction with global health policies regarding emission control …

Emissions	Shorthand
Carbon Monoxide	CO
Organic Gaseous Carbons i.e. PAHs, PCCD/Fs, etc	OGC
Nitrous Oxides	NO_x
Sulfur Dioxide	SO_2
Particulate Matter (Catch-all)	PM

Defining PM

- Primary PM types:
  - Organic Carbon Particles [OC]
  - Soot [EC with condensed OC]
  - Ash [Inorganic]

	Spherical organic carbon particles	Soot (elemental carbon aggregates)	Inorganic ash particles
Schematic drawing			
Diameter measured by electron microscopy*	50-600 nm [52, 53]	20-50 nm [52, 73]	50-125 nm [97]
Mobility diameter	100-300 nm [68-70]	50-300 nm [68, 76]	50-125 nm [69, 98, 99]
Internal turbostratic microstructure	No [61]	Yes / No [81-83]	No
Solubility (H_2O)	Depends on ageing [61]	Insoluble	Soluble
Main chemical characteristic	Organic carbon [62, 64, 67] (Most abundant organic compounds: metoxyphenols and monosaccaride anhydrides) [57-60]	Elemental carbon with variable amounts of organics condensed on the surface [12, 62, 81] (Most abundant organic compounds: hydrocarbons and polycyclic aromatic hydrocarbons) [84, 85]	Alkali salts (mainly KCl and K_2SO_4 with small amounts of trace elements (e.g. Zn)) [78, 92]
Combustion conditions	Low-temperature, incomplete combustion [11, 52-56]	High-temperature, incomplete combustion [52]	High-temperature, complete combustion [120]
Possible sources	Air starved combustion or start-up phase of batch wise combustion in conventional stoves, open fireplaces [58,62,64,67]	Combustion in conventional stoves, open fireplaces, boilers for wood, wood chips and pellets [14, 52, 75-79]	Combustion in pellets stoves, boilers for wood, wood chips and pellets [69, 120]

DOI: 10.1186/1743-8977-6-29

Defining PM

- Roughly 40% - 70% of PM has been found to organic or carbonaceous in nature [1] [2]
- Proportion of resultant PM type is more greatly affected by fuel type than stove type / method of operation (manual vs. automatically fired) [1]

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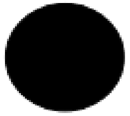
Schematic drawing			
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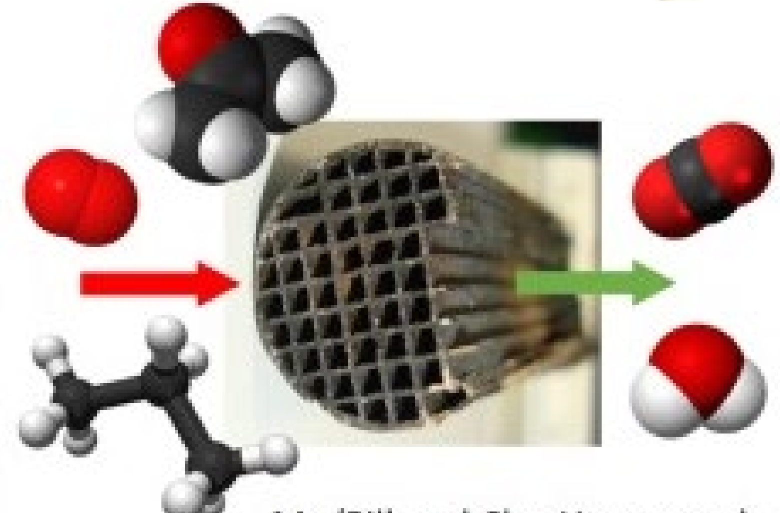
Stove Design / Operation: worse → better

EC/TC [total C] Ratio: 0.01 to 0.11 | 0.5 to 0.75 | NaN (total C ~1%)

Sources:
[1] DOI: 10.1016/j.atmosenv.2011.05.006
[2] DOI: 10.1080/00032719.2015.1052970

Catalytic Devices: Overview

- Catalytic Converter [CC]
  - Used to encourage oxidization of harmful gases to more inert alternatives
  - Applications: gas engine exhaust systems, diesel engine exhaust systems, energy generation systems, industrial size factories, and wood-stove applications
  - Common Catalysts: platinum, palladium, and rhodium
  - Common Substrates: metallic or ceramic



Mn/Pillared Clay Honeycomb

Catalytic Devices: Experimental Performance

DOI #	10.1021/acs.energyfuels.7b00803	10.1016/j.atmosenv.2012.01.016	10.1016/j.renene.2017.10.065
maxCR for CO	32 / 73 %	21 % (80 % during burnout)	95 %
maxCR for OGC	61 / 58 %	14 %	60 %
maxCR for PM	41 / 33 %	30 %	~30 %
Findings:	Claimed clear proof of concept for catalysts, and claimed honeycomb design to be superior to others. **Indirectly noted importance of placement of catalyst.**	**Demonstrated the catalytic measures could have an effect on particle size distribution.** Suggested that efficiency of operation could be based on phase of combustion.	Established relationship between space velocity / coated area and conversion rate. **No trend between these parameters and PM though.**

Catalytic Devices: Considerations & Limitations

- Considerations:
  - Catalyst and Substrate Type
  - Placement of Catalytic Device
- Limitations:
  - Evidence suggests CC will never fully eliminate PM, only mitigate it (up to 70%, as only carbonaceous PM will be effected) [2] [3]
    - It appears that the more efficient the stove, the less impactful the CC
    - Evidence suggests reduction of soot (specifically PAHs) can result in increases in PCDD/Fs which might have equally bad health effects [1]
  - Gaseous byproducts can make CCs be prone to clogging and chemical “wear,” and/or actively inhibit CC function (i.e. methane, water, etc.)
  - The pressure drop exerted on a natural draft stove by a CC may inhibit primary combustion dynamics enough to discourage implementation

Sources:

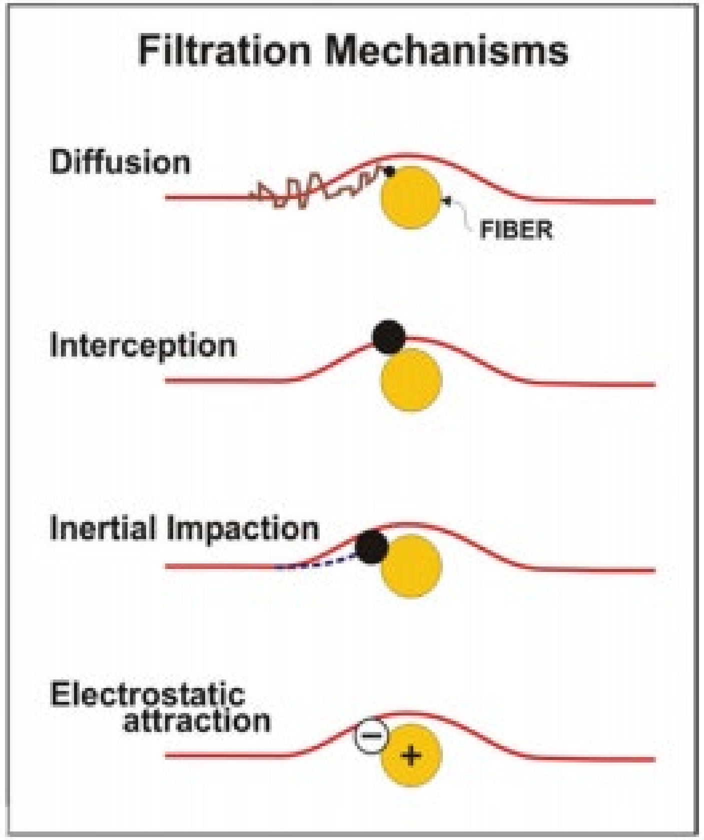
[1] DOI: 10.1016/j.chemosphere.2012.02.027

[2] DOI: 10.1016/j.atmosenv.2011.05.006

[3] DOI: 10.1080/00032719.2015.1052970

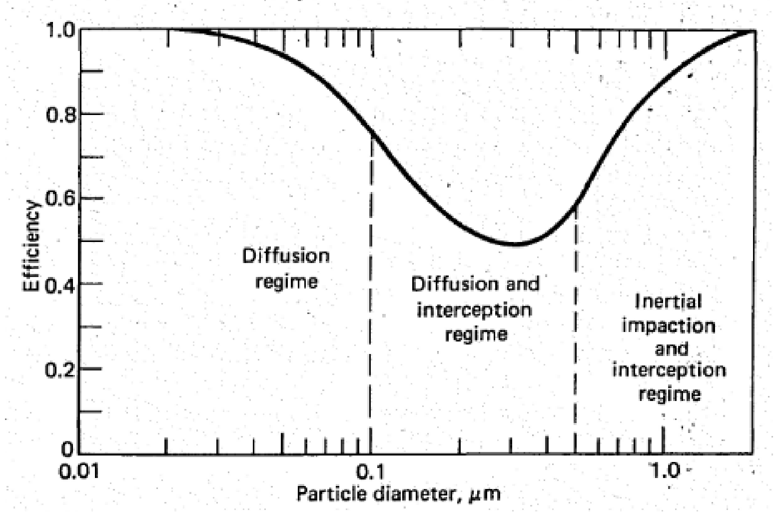
Fibrous Filters: Overview

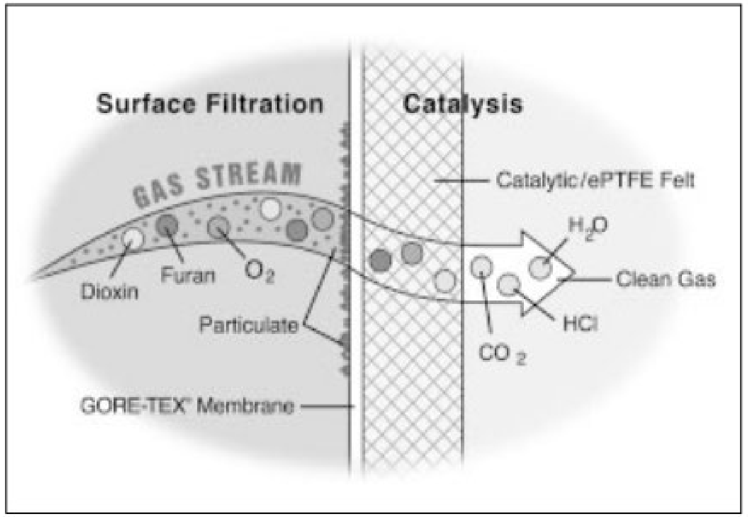
- Fibrous Filter
  - Interwoven fibers of specific size used to mechanically and electrostatically entrap moving particles
  - Applications: residential, commercial, industrial, and automotive air filtration
  - Common Filter Types: base fibrous filters, high efficiency particulate air (HEPA) filters, high efficiency air filters (HEAFs), electrostatic air filters and induction air filters
  - Common Materials: plastic, organic, or metallic



Fibrous Filters: Experimental Performance

- Efficiency defined by most penetrating particle size …
  - A region of most penetrating particle size exists, where the efficiency of mechanisms filtration [2]
- Proven effective up to 99-99.9% at catching PM when properly implemented [1] [2] [3] [4]
  - 97.5% MERV at 90 nm particle size [3]
- Catalytic filtration systems found to reduce OGC by up to 98.4% and PM up to 99.95% [4]
  - Captured most OGC with PM (70%), catalytic reduced remaining OGC





Sources:
[1] DOI: EPA/452/B-02-001
[2] DOI: 10.1080/00022470.1980.10464592
[3] DOI: 10.1007/s12649-017-9858-4
[4] DOI: 10.1080/10473289.2001.10464391

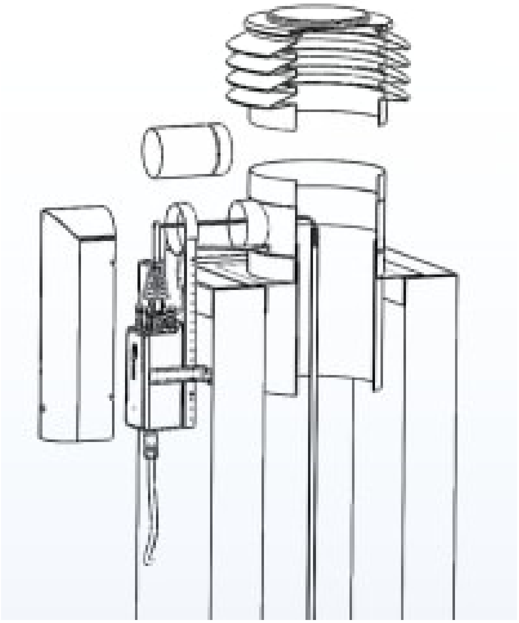
Fibrous Filters: Considerations & Limitations

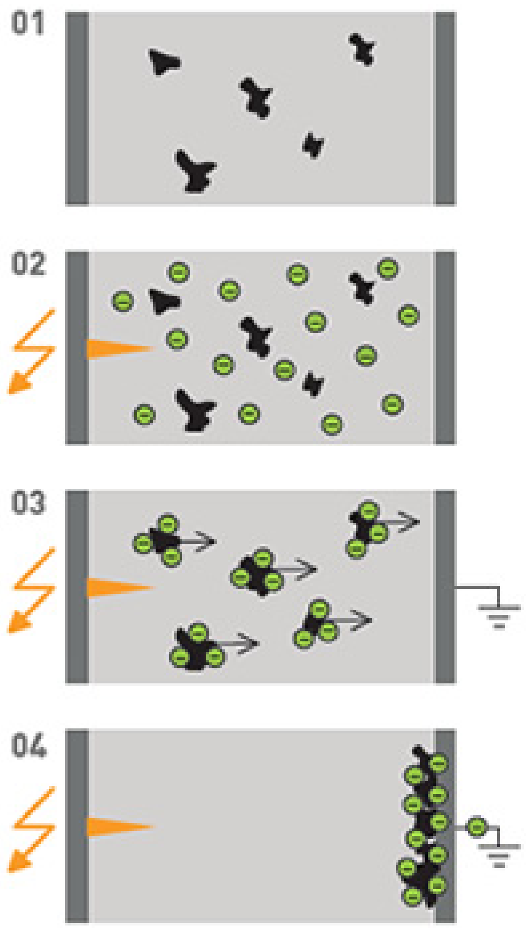
- Considerations:
  - Sizing of Filter
  - Reuse-ability / Wash-ability
    - Filters require periodic cleaning depending upon build up of dust [1]
  - Durability of Filter
  - Additional Emission Reduction
- Limitations:
  - The pressure drop exerted on a natural draft stove by a fibrous filter may inhibit primary combustion dynamics enough to discourage implementation [1] [2]

Sources:
[1] DOI: 10.1007/s12649-017-9858-4
[2] DOI: 10.1080/10473289.2001.10464391

Electrostatic Precipitators: Overview

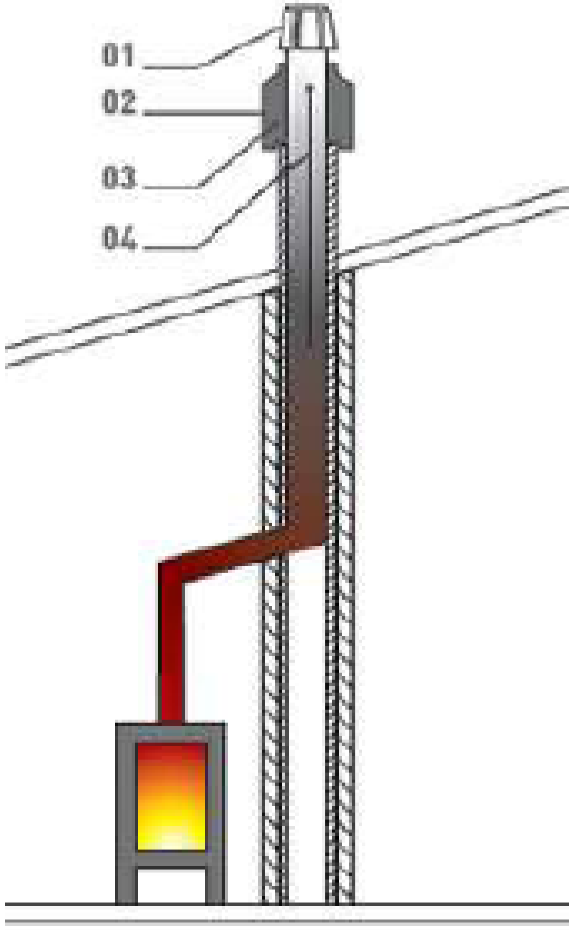
- Electrostatic Precipitators [ESPs]
  - Features charged plates, wires, or surfaces which create a strong electrical field capable of entrapping and collecting PM on a surface
  - Applications: residential, commercial, and industrial air filtration and dust treatment
  - Common ESP Types: chimney-top, boiler attached, integrated (plate-wire precipitators, flat plate precipitators, tube precipitators, two-stage precipitator)





ESPs: Experimental Performance

- Similar most penetrating particle …
  - Electrostatic Charging
  - Electrostatic Collection
- Various ESP designs tested year round in real-life conditions consistently reduced PM
  - 30-93% reduction in total PM
  - 50-97% reduction in PM_1
- ESPs placed farther downstream were found to reduce OGC along with and PM [1]



Sources:
[1] http://task32.ieabioenergy.com/wp-content/uploads/2017/03/06_Hartmann.pdf
[2] DOI: 10.1016/J.BIOMBIOE.2017.01.025

ESPs: Considerations & Limitations

- Considerations:
  - Sizing of power supply and electrode
    - Limit sneakage and rapping reentrainment [1] [2]
    - Limit arcing or other sparking [1]
  - Frequency of cleaning of collection surface
    - ESPs require periodic cleaning of the entrapment surface to ensure proper entrapment and lack of re-entrainment of clumps of particles [1] [2] [3]
- Limitations:
  - An ESP requires a steady and reliable power source in order to operate effectively [3]

Sources:
[1] DOI: EPA/452/B-02-001
[2] http://task32.ieabioenergy.com/wp-content/uploads/2017/03/06_Hartmann.pdf
[2] DOI: 10.1016/J.BIOMBIOE.2017.01.025

Effect of Post Combustion Methods on Emission Reduction

Assuming access to power, ESPs are most effective.

However, each methods has distinct advantages which could be leveraged to reduce emission in small-scale combustion of wood or biomass.

Emission	CCs	Fibrous Filters	ESPs
CO	30-95%	-	-
OGC	30-60%	Up to 70% (Up to 98.4% with CC)	Up to 70%
NO_x	-	-	-
SO_2	-	-	-
PM	30-40%	99-99.9%	50-97%

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Questions?

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