

Hydro-Ethanol Cooking Stove Technology: Design, Performance, and Potential for Indian Market



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The Transition to Clean Energy

Kerosene cooking stove



Efficiency: 40 – 55 % (1.5-3 kW)

PM10: 200 – 400 $\mu\text{g}/\text{m}^3$

CO: 600 – 1030 mg/m^3

NOx: 35 – 65 mg/m^3

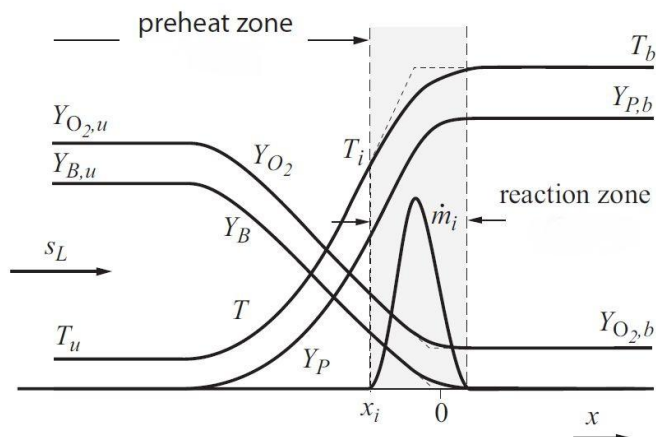
Low thermal efficiency

Longer cooking time

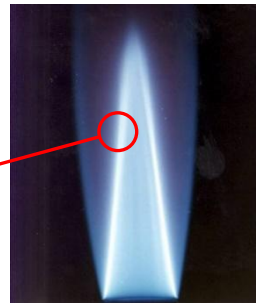
Incompatible for Methanol, Ethanol

Pollutant emissions > WHO limit

Different stove for different liquid fuels



Structure of premixed flames



NOx

< 40
 $\mu\text{g}/\text{m}^3$

PM₁₀

< 25
 $\mu\text{g}/\text{m}^3$

CO

< 30
 mg/m^3

WHO
indoor air pollution
guidelines

The Transition to Clean Energy

Key Challenges with Current Fuels

⚠️ **LPG Price Volatility** – ₹594 → ₹942 within 6 years

⚠️ **High CO Emissions** – LPG combustion: High CO & NO_x
— respiratory damage

⚠️ **Safety Hazards** – Pressurized cylinders risk explosions;
thousands of accidents yearly

⚠️ **Import Dependency** – ₹300B+ annual forex outflow;
vulnerable to global oil price shocks

The shift toward sustainable energy necessitates highly efficient,
low-carbon fuels

Primary alcohols offer significantly cleaner combustion, but pose
challenges: High volatility, low flash point, transportation risks.

Gelation technology addresses this by converting volatile liquids into
a stable, semi-solid state.

This enhances safety, prevents disastrous spills, and improves
transportability while retaining the alcohol's high energy density.



Flash Point
13 °C



The Transition to Clean Energy

What is Hydro-Ethanol Gel Fuel?



Composition

Ethanol (60–80%)

Primary fuel — from sugarcane, molasses, or 2G biomass

Water (10–20%)

Diluent & safety agent — reduces flash hazard

Gelling Agent (2–5%)

Inorganic (Fumed Silica)/Organic Polymers— converts liquid to spill-proof gel

Additives (<2%)

Glycerol (viscosity), Calcium Chloride, HPMC, etc.

Fuel Comparison at a Glance

Parameter	LPG	Ethanol	Gel Ethanol
Calorific Value	46 MJ/kg	26.8 MJ/kg	22–24 MJ/kg
Storage	Pressurized	Liquid tank	Gel (non-pressurized)
Safety	Explosion risk	Flammable	Safest
Renewability	No	Yes	Yes
CO Emissions	> WHO Limit	< WHO limit	< WHO limit
Flash Point	< 60 °C	13 °C	> 35 °C

The Science: How Gelation Works

Polymer chemistry

(MC/HPMC/Carbopol)

The Polymer Network

Hydrogen Bonding

Physical Entrapment

Thermal Gelation

(Methyl Cellulose /Carbopol)

Lower Critical Solution
Temperature

Chemical Neutralization

Rheological

(Non-Newtonian Shift)

Shear-Thinning

Yield Stress Threshold

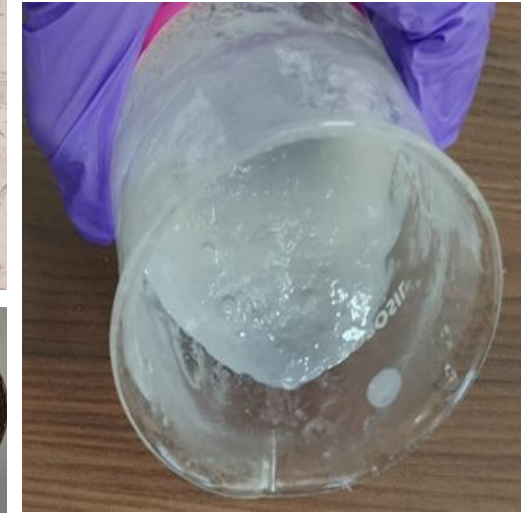
non-Newtonian

Gelation changes how the fuel burns by altering the rate of mass transfer (vaporisation):
Surface Micro-Cavitation + Diffusion-Controlled Release + Linear Burn Rates

The Science: How Gelation Works

Role of Additives:

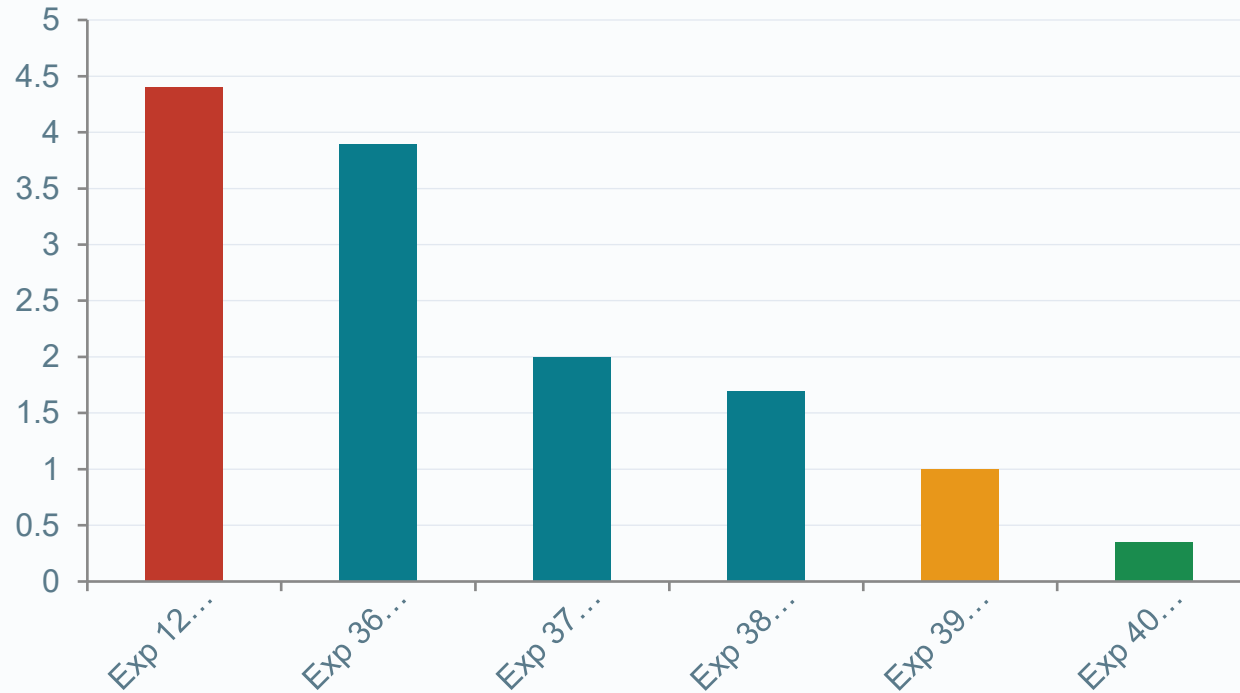
- Calcium Chloride: Improves safety but leaves bubble-layered residue.
- Gelling Agents: Inorganic (Fumed Silica) vs Organic Polymers.
- Organic polymers: Renewable, 3D network via hydrogen bonding.
- Glycerol: Controls viscosity, acts as plasticizer.
- Metal Oxide Nanoparticles: Increase flame temperature and stability.
- HPMC: Provides best homogeneity and lowest residue.



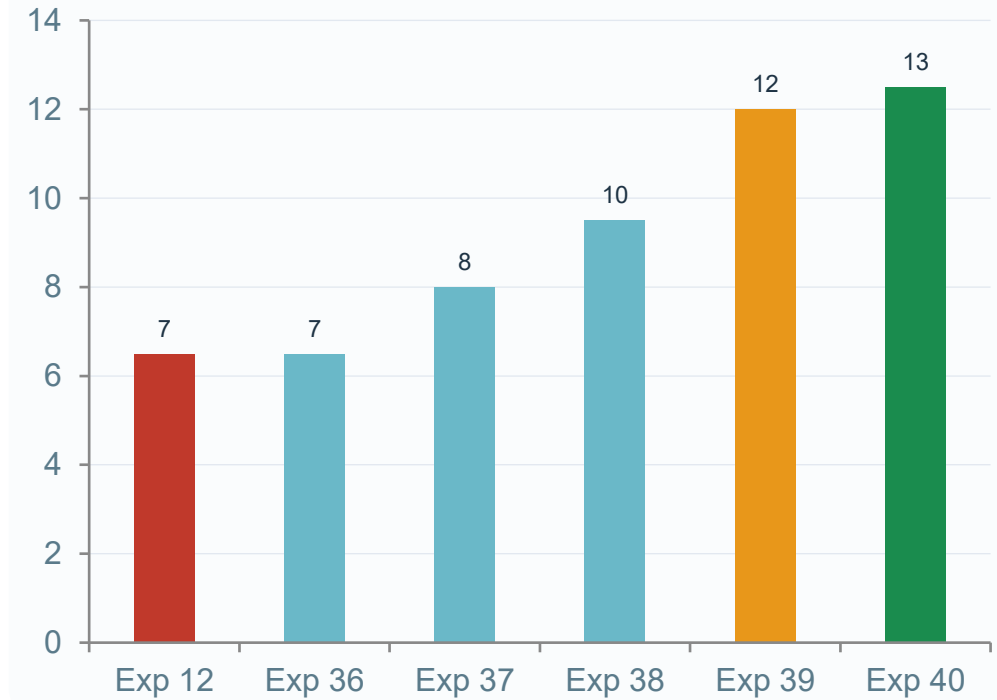
Agent	Mechanism	Pros	Cons
Fumed Silica	Particle Jamming	High stability	High residue; expensive
Agar Agar	Thermo-gelation	Natural/Eco-friendly	Unstable at high alcohol %
HPMC	Organo-gelation	Excellent clarity; low cost	Needs careful hydration
Carbopol	Ionic Crosslinking	Very high yield stress	Requires neutralizer (TEA)

Formulation Performance: Residue & Burn Time

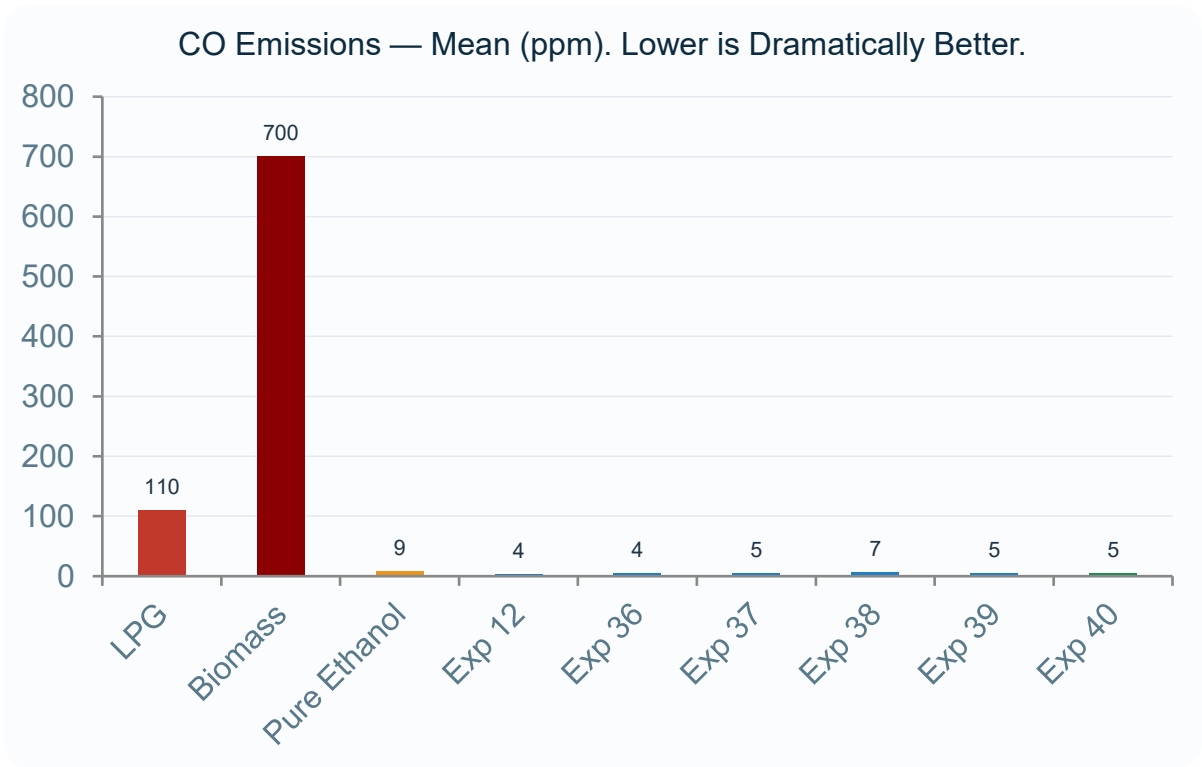
Residue (g) — Lower is Better



Burn Time (min) — Higher is Better



Emission Profile: Cleanest Combustion Fuel

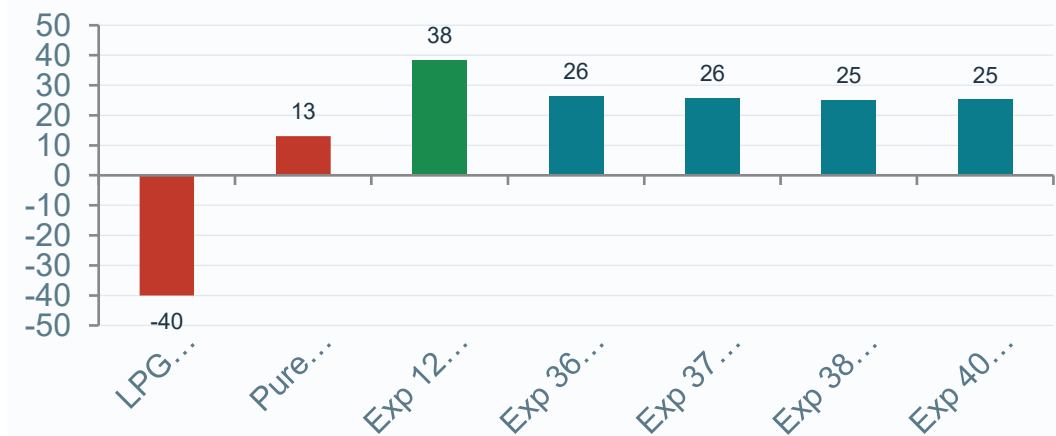


Gel vs LPG Emissions			
CO	~110 ppm	5.13 ppm	↓
NOx	~20 ppm	0.79 ppm	↓
CO ₂	High	0.25%	Lower
SO _x	Present	None	Zero
Soot	Present	None	Zero

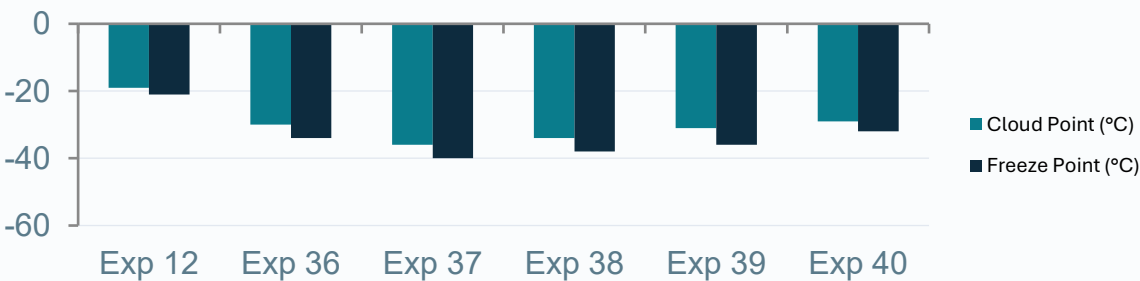


Efficiency and Safety Properties: Flash Points

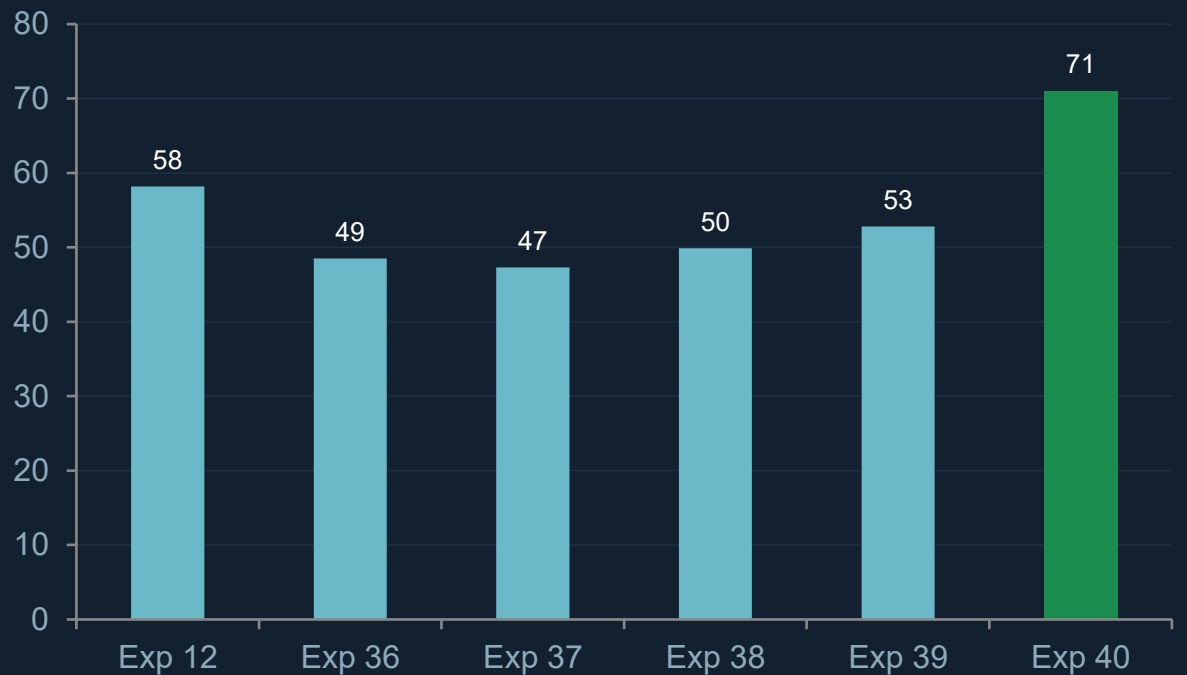
Flash Point (°C) — Higher = Safer



Cloud & Freezing Points (°C) — Lower = More Cold-Resistant



Thermal Efficiency (%) by Formulation



Flash Points: 38.46°C (highest, safest), all well above standard handling temperature
Cloud points: -19°C to -36°C for sub-zero operability

Economic Analysis & Comparison

Why Gel Fuel is Safer



Non-Pressurized

No cylinders, no explosion risk — can be stored in any container



Spill-Proof Gel

Gel structure prevents leakage even if container overturns



Controlled Evaporation

Lower vapor pressure than liquid ethanol → reduced fire hazard



Higher Flash Point

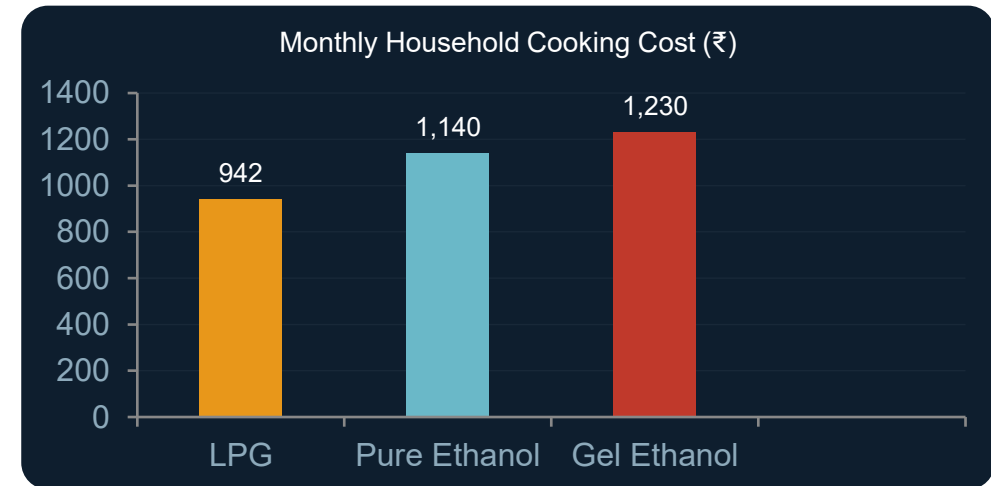
38.46°C vs liquid ethanol: 13°C — much harder to ignite accidentally



Cold Climate Ready

freezes at -40°C → suitable for Himalayan households

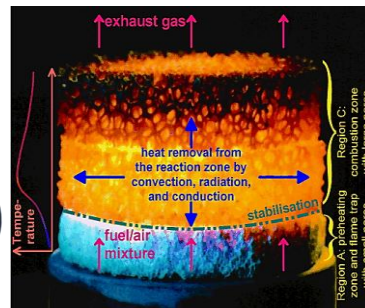
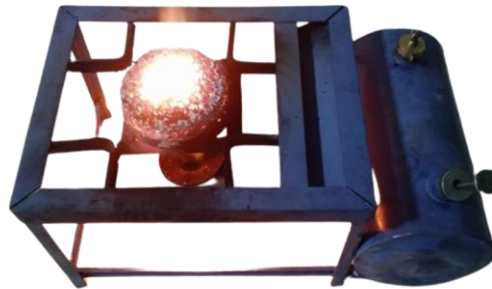
Component	CV (MJ/kg)	Required Mass / Month	Stove Efficiency
LPG	46.4	14.20 kg	68%
Gel Ethanol	23.0	28.65 kg	68%



30% price premium over LPG, making the technology highly competitive when factoring in zero explosion risks, localized agricultural economic growth, and drastically reduced indoor carbon monoxide emissions

High Efficiency Stove Design

Infrared Cook Stove (ICS) is a novel cooking device that improves burner efficiency while reducing fuel consumption, cooking time, as well as hazardous pollutants like CO, NO_x, and smoke.



Infrared Cook Stove

15% higher efficiency than the existing counterparts

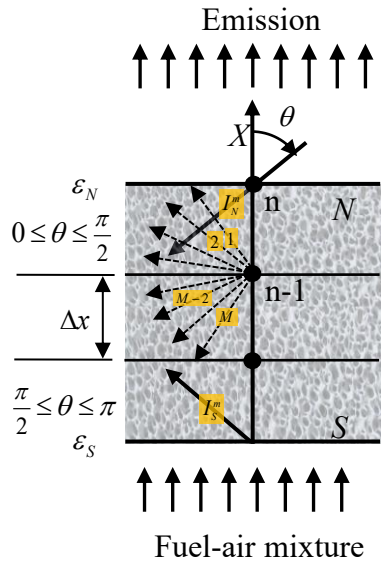
Uses heat recirculation technology

Cook faster, Fuel saving with less emissions

Compatible for both methanol and ethanol and other low calorific value fuels)

CO: 1-10 ppm, NO_x: <1 ppm (Well below the WHO permitted limit)

PM Integrated Burner Formulation



Continuity equation

$$\frac{\partial(\xi\rho_g)}{\partial t} + \frac{\partial(\xi\rho_g u)}{\partial x} = 0$$

Ideal gas law

$$\rho_g = \frac{P\bar{W}}{RT_g}$$

Solid-phase energy equation

$$(1-\xi)\rho_s C_s \frac{\partial T_s}{\partial t} - h_V(T_g - T_s) - (1-\xi)\lambda_s \frac{\partial^2 T_s}{\partial x^2} + \frac{\partial q_R}{\partial x} = 0$$

Gas-phase energy equation

$$\xi\rho_g C_g \left(\frac{\partial T_g}{\partial t} + u \frac{\partial T_g}{\partial x} \right) + \xi \sum_{k=1}^K \rho_g Y_k C_{g,k} V_k \frac{\partial T_g}{\partial x} + \xi \sum_{k=1}^K \dot{\omega}_k h_k W_k + h_V(T_g - T_s) = \xi \frac{\partial}{\partial x} \left(\lambda_g \frac{\partial T_g}{\partial x} \right)$$

Labels for the gas-phase energy equation terms: Convective, Species diffusion contribution, Heat generation, Heat exchange, Gas conduction.

Species mass conservation equation

$$\xi\rho_g \left(\frac{\partial Y_k}{\partial t} + u \frac{\partial Y_k}{\partial x} \right) = - \frac{\partial}{\partial x} (\xi\rho_g V_k Y_k) + \xi \dot{\omega}_k W_k$$

Labels for the species mass conservation equation terms: Mass flow of species k due to convection, Mass flow of species k due to molecular diffusion, Net mass production of species by chemical reaction.

Modified Arrhenius expression

$$k_{f_i} = A_i T_g^{\beta_i} \exp\left(-\frac{E_i}{RT_g}\right)$$

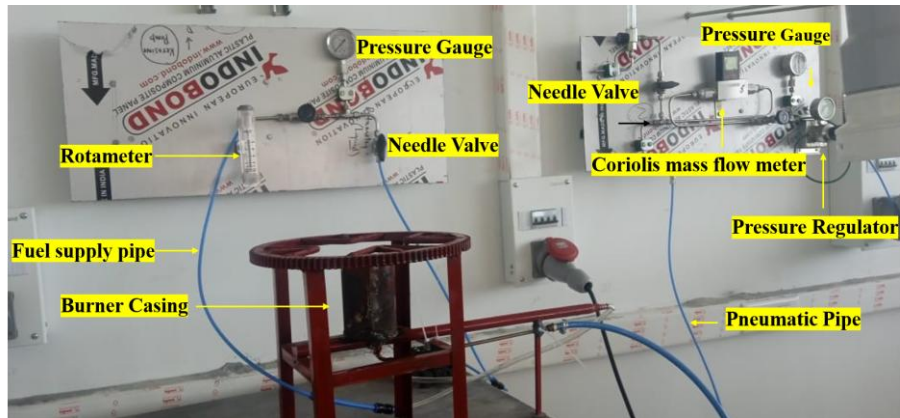
Radiative transfer equation

$$\cos\theta \frac{dI^m}{dx} = -\Gamma I^m + \Gamma(1-\omega) \frac{\sigma T_s^4}{2} + \frac{\Gamma\omega}{4\pi} G = -\Gamma I^m + S$$

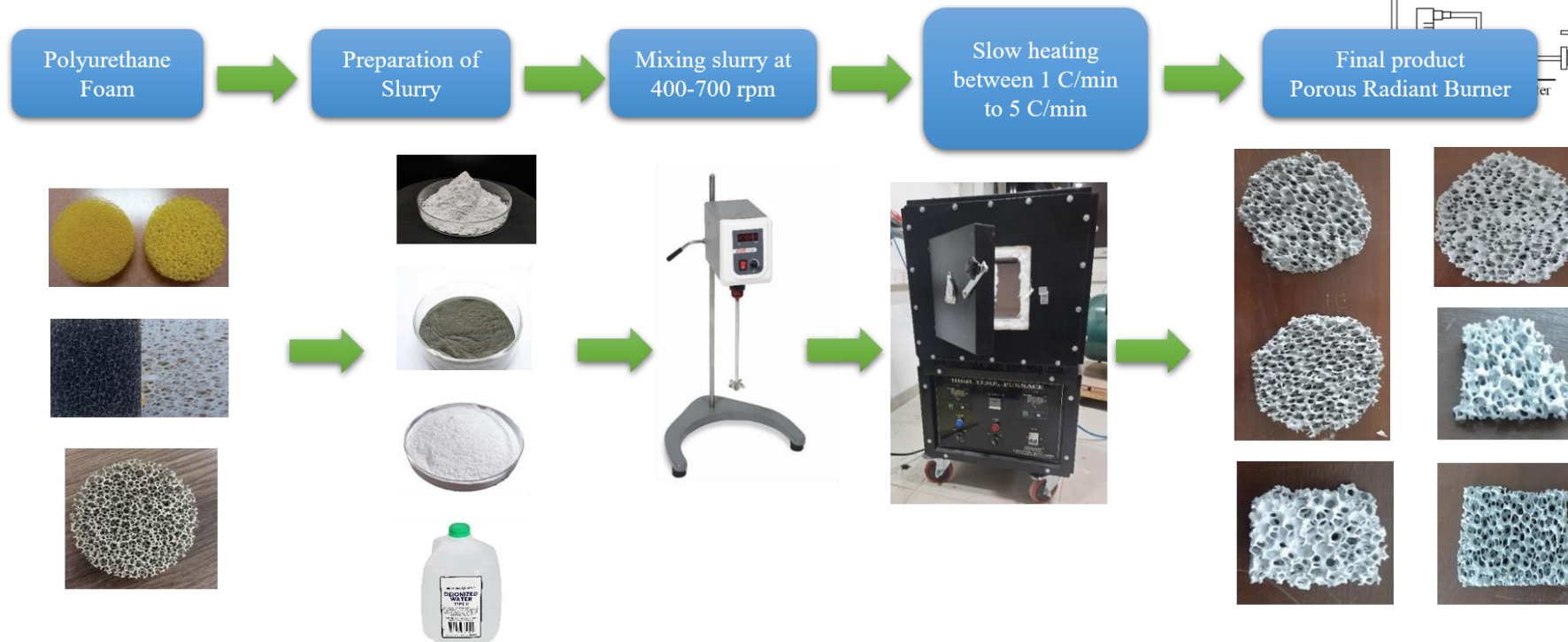
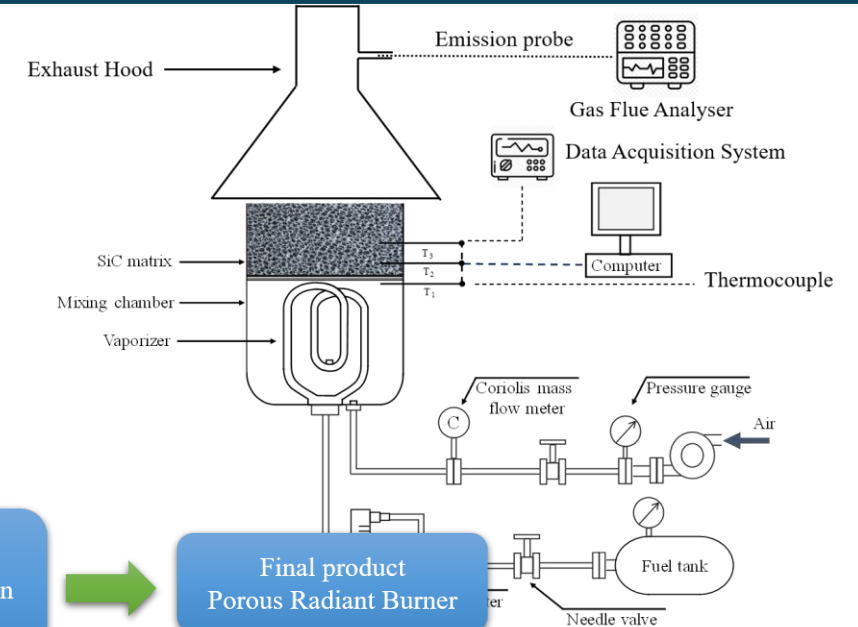
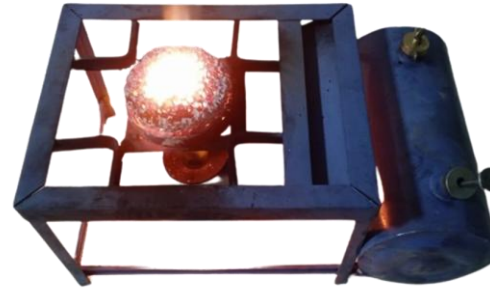
Radiative heat flux

$$\frac{\partial q_R}{\partial x} = \Gamma(1-\omega)(4\pi I_b - G)$$

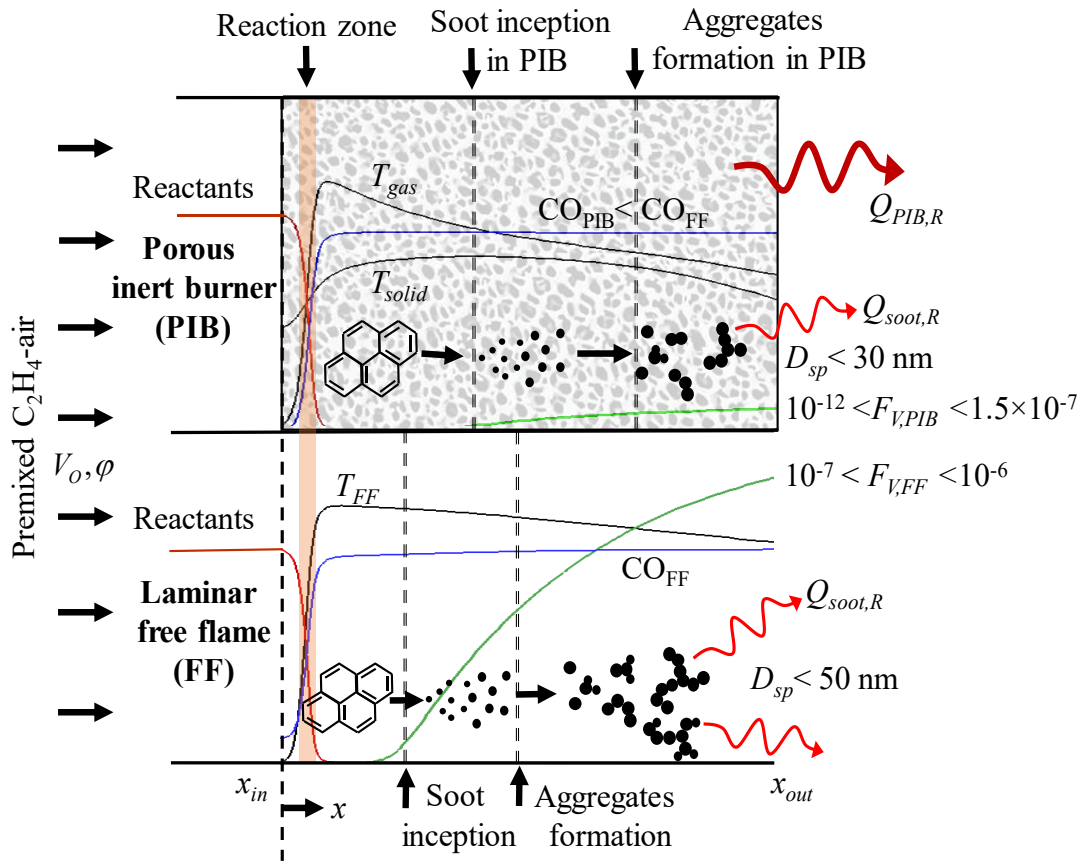
High Efficiency Stove Design



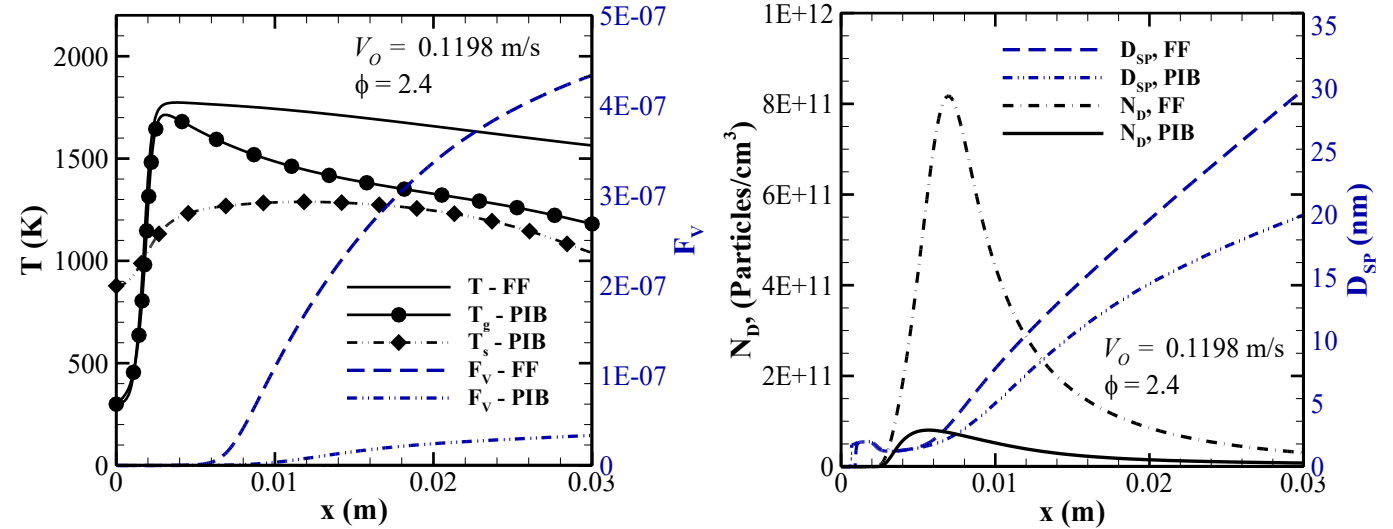
ICS Setup



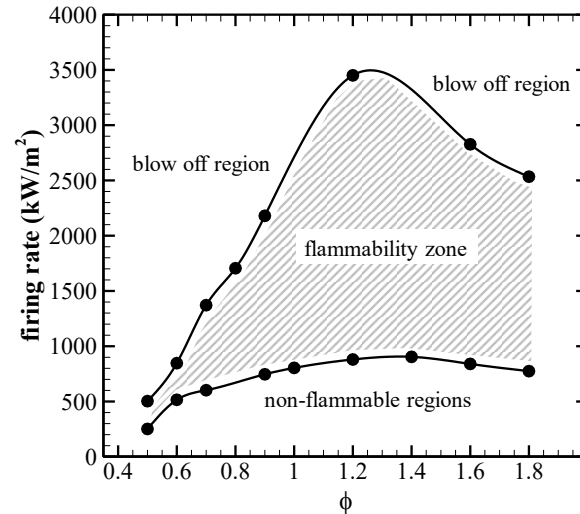
Suppression of Soot Formation in ICS



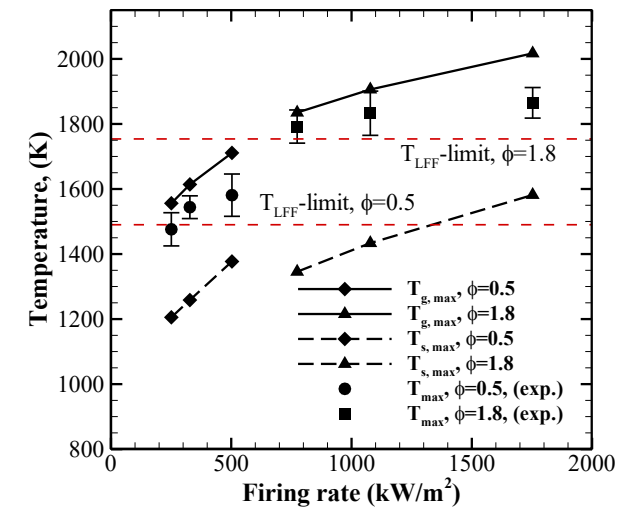
Conceptual illustration of the comparisons of soot growth process within ICS and FF combustion.



Comparisons of axial gas and solid-phase temperature profiles, soot volume fractions, particle number densities and soot diameters



Stable flammability ranges of the burner



Model validation

Conclusion & Key Takeaways

Conclusion:

- Alcohol-based gel fuels were successfully developed and characterised.
- Gel ethanol retains ~85% of pure ethanol's calorific value (~23 MJ/kg).
- Nanoparticle-enhanced formulations improved thermal performance.
- ICS is 15% higher efficient than conventional counterparts.

The Value Proposition:

- Monthly Cost: ₹1,230 (vs ₹942 for LPG).
- High flash point compared to liquid ethanol.

Key Takeaways:

- Gel ethanol is safer, cleaner, and renewable.
- It solves the LPG problems: import dependency, price volatility, safety hazards.
- It improves upon pure ethanol: spill-proof, controlled evaporation, easier handling.
- Cost can be reduced by implementing ICS technology for ethanol gel.

Thank you



HSBC

