Effects of Turbulence Induction in a Trapped Vortex on Wood Combustion Performance

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Introduction

- Health Issues:

- Deficient mixing leads to incomplete combustion, resulting in the production of toxic emissions such as CO_2, CO, NOx, SOOT, etc.
- UN Foundation approximates 1.6 million premature deaths occur annually due to emissions from inefficient cookstoves.[1]

- Environmental Issues:

- Subsistence and commercial agriculture account for 60% of global deforestation.[2]

- Social Issues:

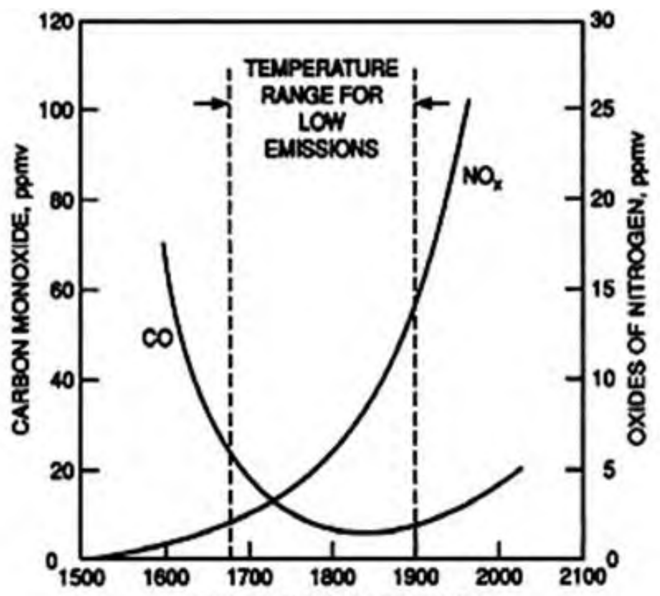
- The IEA Estimates 35% of the global population depends on biomass for energy demand.[3]
- Women spend 4 hours every day cooking when using traditional stoves. They can save 1 hour and 10 minutes when using a clean cookstove.[4]

Current Stoves[5]

3 Stone Cookstove Rocket Stove J-Stove

Chemical Kinetics[6]

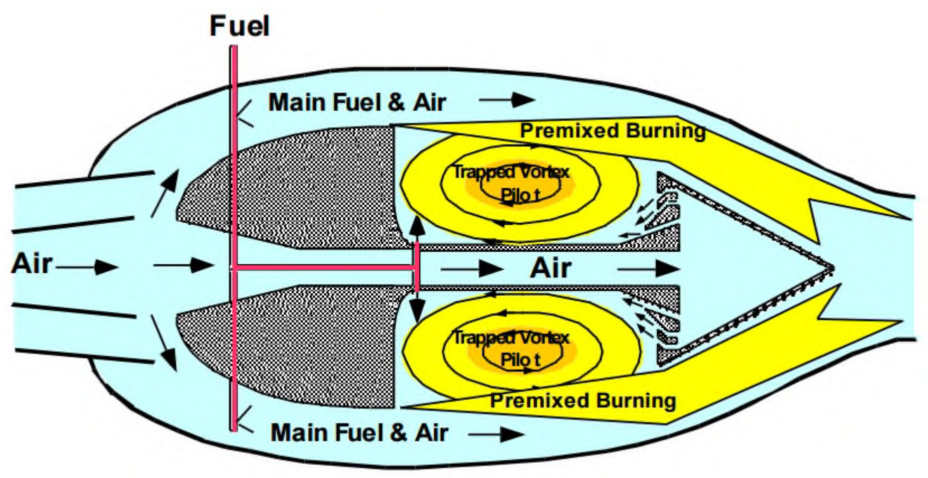
- Temperature changes affect the rate at which reactions occur, which in turn affects the production rates of reaction products.
- Thermal NOx increases with temperature. CO increases with decrease in temperature.



Intermittent vs Steady State

- **Intermittent engines (e.g. Reciprocating engines):**
  - Fuel Sensitive.
  - Cyclic Temperature.
- **Steady State engines (e.g. Gas turbine engines):**
  - Omnivorous.
  - Continuously exposed to higher temperatures.
  - Multiphase (i.e. mass transfer is important.

Trapped Vortex[7]



A trapped vortex configuration is one where premixed fuel and air are forced into a physical cavity via a jet of air creating a region of stable flame with high turbulent mixing due to propagation of kinetic energy into small-scale eddies.

Roquemore et. all (2016) found that a trapped vortex has the following emissions reductions in two different systems:

- 40% reduction in aircraft NOx.
  - Based on typical commercial aircraft engine.
- 50% reduction in aircraft HCs.
- 60% reduction in Navy ship annual NOx.
  - Based on LM2500 marine gas turbine.
- 40% reduction in Navy ship annual HCs.[3]

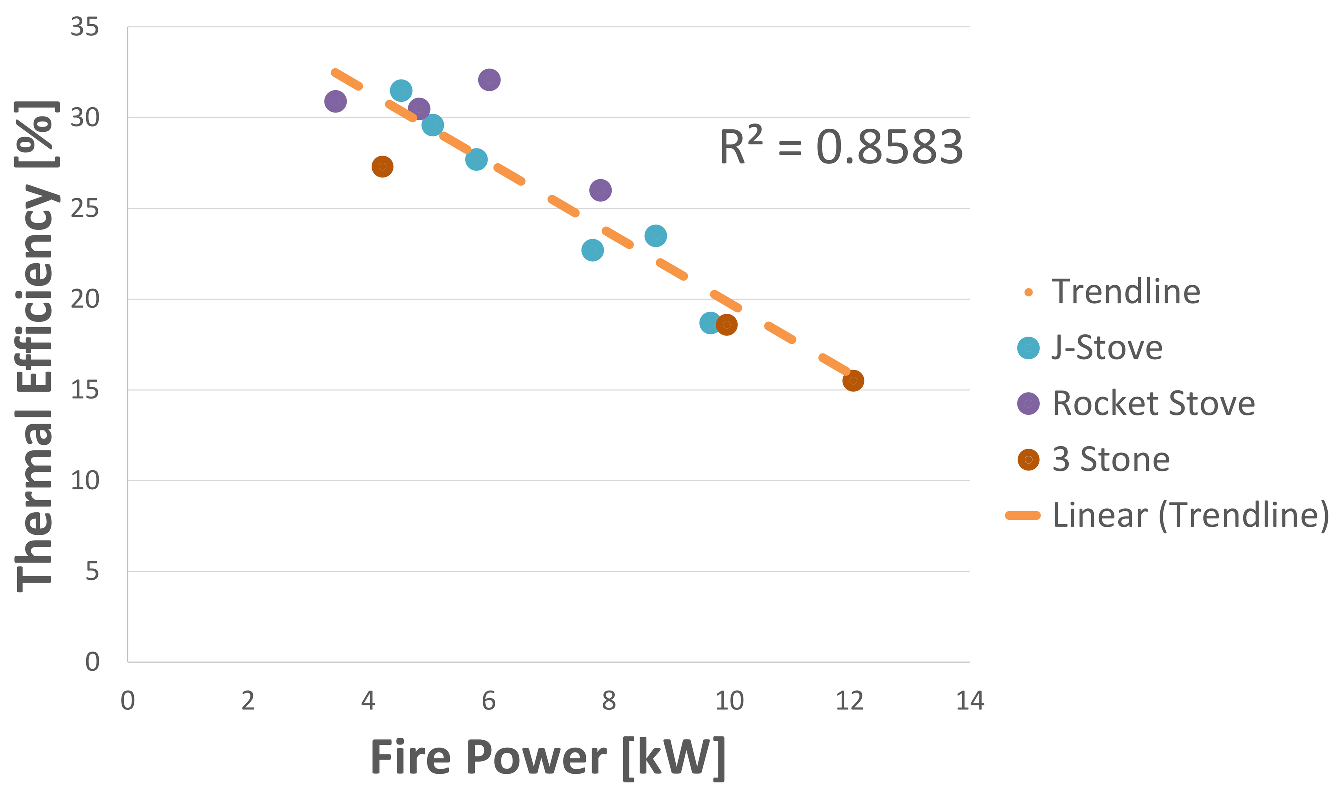
Summary

Wood is one of the most used biomass energy resource in the world. Yet, wood combustion remains highly non-optimized due to the inherent complexity of the process. The wood combustion process is multidimensional and multiphase, leading to large uncertainties. In addition, wood combustion is not a "clean" process; CO, CO2, particulate matter, and other emissions are formed during the wood combustion process as a result of deficient and copious mixing. Thus, a variety of experiments characterizing the performance and speciation of wood combustion using various physical and geometric configurations have been taking place. The goal of these experiments is to study the factors that potentially reduce emissions and increase efficiency.

Previous efforts conducted on Vashon Island, WA, studied the effects of inducing turbulence into a gravity-driven wood stove (a.k.a. J-stove). The results from that study showed extreme flame stretching to the point of quenching, but some configurations showed promising results. Currently, the researchers are reproducing the previous data to ensure consistency before redirecting efforts into inducing turbulence in trapped flame vortex configurations. A previous study by Hsu et al. (Hsu, Goss, Trump, Roquemore, 1998) has shown a positive correlation between induced pressure drop, due to induced turbulence, and primary equivalence ratios in the combustion region.[4] This correlation provides an opportunity to utilize the dynamics of a trapped vortex to manipulate the scale in which chemical kinetics occur to be smaller than the Kolmogrov scale; creating turbulent fuel and oxidizer mixing eddies in the reaction region of the flame.

A Possible future direction of the study includes conducting particle imaging velocimetry (PIV) experiments in order to record the flame speed and turbulent fluctuations to show the effects of a trapped vortex configuration on the flame's position in the infamous combustion regime diagram.

Preliminary Results



Observed negative linear relationship between thermal efficiency and fire power independent of stove type.

Turbulent Regime Shift[8]

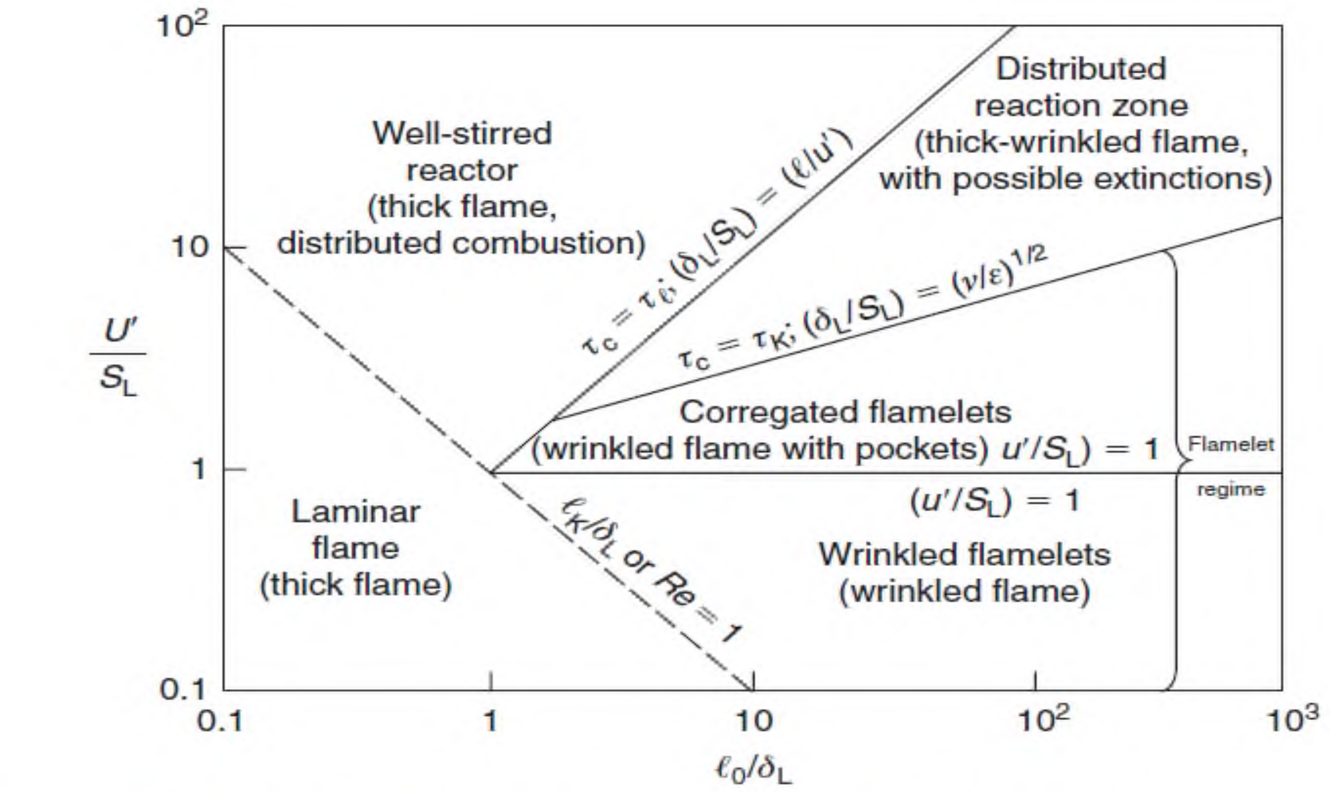


FIGURE 4.48 Turbulent combustion regimes (from Abdel-Gayed *et al.* [61])

- Inducing enough turbulence ideally shifts the flame from the wrinkled flamelet regime to the well-stirred reactor (WSR) regime.
- In the WSR, Turbulent eddies are smaller than the reaction scale, leading to better mixing of the fuel and oxidizer.

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1: United Nations Foundation. September 2010.
2: Agyei, Y. "*Deforestation in Sub-Saharan Africa.*" Tufts University.
3: IEA Energy for Cooking in Developing Countries.
4: Alliance News. "*Women Spend 374 Hours Each Year Collecting Firewood in India, Study Finds.*" Global Alliance for Clean Cookstoves. 2015.
5: Three types of stoves on which current testing is being done. Photo Credit: Erin Peiffer.
6: CO and NOx response to temperature variation. Christos Samaras.
7: A graphical representation of a trapped vortex and NOx production in a trapped vortex setting compared to other gas turbine engine configurations. Mel Roquemore et. All. "*Nuclear Powered Rocket Concept.*" Wright-Patterson Airforce Base. 2016.
8: Turbulent combustion regimes. Glassman, I., R. A. Yetter. "*Combustion – 4th Edition.*" Princeton University – Combustion Research Laboratory. 2008.