

A Study on the High-luminescence-Flame Thermophotovoltaic Power System

Yueh-Heng Li¹, Chih-Yung Wu², Yei-Chin Chao¹

¹ Department of Aeronautics and Astronautics
National Cheng Kung University, Tainan, 701, Taiwan, ROC

² Advanced Engine Research Center
Kao Yuan University, Kaohsiung County, 1821, Taiwan, ROC

1 Introduction

The recent blooming of research and development of meso-scale power devices is motivated by the increasing need and demand for smaller scale and energy dense power sources. Traditional batteries have failed to satisfy this demand, often causing serious logistical mission constraints and diminishing overall performance of portable devices [1]. Thermophotovoltaic (TPV) devices convert thermal radiant energy directly into electrical power, and TPV cogeneration systems, where the waste heat is also utilized, have found practical applications in the small scale [2-3]. Furthermore, recent investigations have specifically emphasized in the application of improved selective emitters [4] and narrow-band photovoltaic (PV) cells [5] for higher thermal efficiency. In principle, present photovoltaic material has good quantum efficiency in the range of visible wavelength but the emitting spectrum from the emitter of the combustion-driven TPV system locates in the near-infrared wavelength. This spectrum mismatch leads to recent intensive research and development of the narrow-band photovoltaic cells and selective emitters in the TPV community all over the world. However, flame emission spectrum mainly locates in the visible wavelength range. Therefore, a new concept of a high-luminescence-flame TPV system is proposed to enhance the overall efficiency while using the less expensive conventional broadband photovoltaic cell. This high-luminescence-flame TPV system has a broad emitting spectrum due to combining the visible wavelength range from the flame and the near-infrared wavelength range from the emitter. It helps to reduce the manufacture expense and increase the material flexibility of PV cells.

Creating high-luminescence flame is a prior consideration for the fueling system of the proposed TPV system. General methane and hydrocarbon gaseous fuels have faint yet high-temperature flames. However, blending CO/CH₄ fuel composition may lead to different flame luminescence [6]. Depending upon the concentration ratio of CO in the CO/CH₄ blended fuel mixture, flame luminescence becomes brighter, and its corresponding color turns to silver-white as the CO percentage is increased. Nonetheless, the emissivity of flames is certainly low compared to that of solid materials. It is impossible to solely utilize the flame luminescence to achieve high efficiency. To ameliorate this

disadvantage, a new strategy in combustor design should be comprehensively considered. Concept, design and preliminary results of the proposed new TPV combustor are addressed in the following sections.

2 Concept and Design

Figure 1 indicates the flame features in different CO/CH₄ fuel composition conditions. Flame luminescence changes from faint-blue to bright-white as CO concentration percentage in the blended fuel mixture is increased. However, flame emissions in all fuel composition conditions congregate within the visible wavelength range as shown in Fig. 2. In a high CO blended concentration percentage case (80%CO+20%CH₄), the flame emission spectrum has higher broadband intensity base and peaks as compared to high methane concentration percentage case (20%CO+80%CH₄). Therefore, the flame of high carbon-monoxide concentration percentage blended-fuel can effectively provide high intensity emission in visible-wavelength for a combustion-driven TPV power system.

Collecting both the high luminescence from high CO concentration blended flame and the thermal radiance from an emitter simultaneously in the TPV system is an efficient manner to amend the drawback of inherently low flame emissivity. Based upon this concept, a novel annular combustor design is proposed. Figure 3 sketches the diagram of the annular combustor. This combustor has dual cylindrical tubes in the main chamber. One is a thermo-infrared tube acting as an emitter, and the other is a transparent tube for visualization and allowing emission transporting to PV cells. The thermo-infrared tube made by SiC is 5 mm in inner diameter and 8 mm in outer diameter. The diameter of a main combustion chamber made by quartz is 14 mm. Air is supplied from a compressor system, whereas methane and carbon monoxide are supplied from gas cylinders. Fuel and air are mixed before entering the combustor. Premixed fuel/air mixture is injected through the central outlet and secondary air flow goes through a swirler. Swirling air flow mainly acts to stabilize the flame in the bottom of the chamber.

3 Preliminary Results

In order to examine the feasibility of generating stable flame luminescence and radiant emission, combustion of CO/CH₄ blended fuel of stoichiometric and different fuel-compositions in a dual-annular combustor is performed and shown in Fig. 4. Figure 4 shows the combustion phenomena inside the combustor in different fuel blending conditions and each image has the same exposure time (1/25 sec). In high methane percentage fuel, it shows low flame luminescence but high emitter incandescence as shown in Fig. 4(a). On a contrary, in high carbon monoxide concentration percentage, high sliver-blue light exists around the emitter at the bottom of the chamber and its overall emitting intensity is stronger than that of high methane percentage fuel as shown in Fig. 4(c). Flames successfully anchor at the bottom end of the emitter and burn along the emitter stick. Utilizing a powermeter to examine the overall emitting intensity of the present system is also performed. Table 1 indicates the emitting intensity in different fuel blending conditions. It is prominent that emitting intensity increases depending upon an increase of CO concentration percentage. It reveals that accumulation of both flame luminescence and emitter incandescence turns out an increase of the total emission.

Although the total emission of the combustor effectively increases based on this concept, there is uneven distribution of radiant emission from the emitter due to the short flames. Therefore, optimizing total emission outcome through combustor design and operation on an optimized CO/CH₄ blending condition will be the next-step research scheme. Fluid structure and flame configuration may influence the total emission intensity of the system.

4 Conclusions

The new concept of a meso-scale high-luminescence-flame TPV system is proposed and a novel dual-annular combustor based upon this concept is designed and tested. High CO concentration percentage blended fuel generates a high luminescence flame. Superposing flame luminescence and emitter incandescence is expected to enhance the emission ranging from visible to near-infrared wavelength. Preliminary results prove the feasibility of the proposed dual-annular combustor and verify that high CO concentration percentage in the CO/CH₄ blended fuel can apparently increase the overall emission intensity of the dual-annular combustor compared to high CH₄ concentration percentage flame.

References

- [1] Dunn-Rankin D. et al. (2005) Personal Power Systems. *Prog. Energy Combust. Sci.* **31**: 422.
- [2] Chia L. C., Feng B. (2007) The development of a micropower device. *J. Power Sources* **165**: 455-480.
- [3] Durisch W. et al. (2003) Small self-powered grid-connected thermophotovoltaic prototype system. *Appl. Energy* **74**: 149.
- [4] Nakagawa N. et al. (2005) Thermal emission properties of Al₂O₃/Er₃Al₅O₁₂ eutectic ceramics. *J. Eur. Ceram. Soc.* 25:1285.
- [5] Qiu K., Hayden A. C. S. (2003) Performance of low bandgap thermophotovoltaic cells in a small cogeneration system. *Sol. Energy* 74: 489.
- [6] Wu CY et al. (2009) Effects of CO addition on the characteristics of laminar premixed CH₄/air opposed-jet flames. *Combust. Flame* 156:362.

Table 1. Emission intensities in varied fuel compositions.

CH ₄ percentage (%)	CO percentage (%)	Emission intensity (mW)
90	10	870
70	30	903
50	50	940
30	70	955
10	90	975

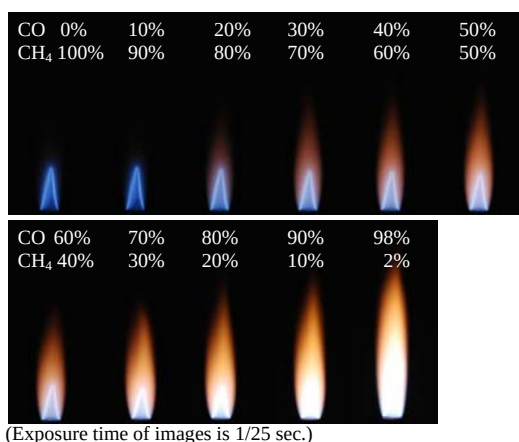


Figure 1. Flame images in different CO/ CH₄ blended fuel mixtures and fixed exit velocity of 2 m/sec, ER of 1.

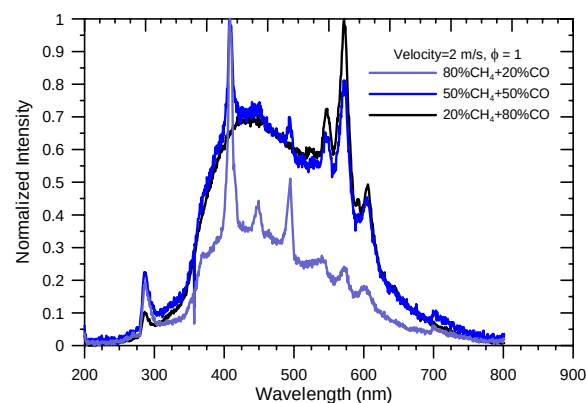


Figure 2. Flame emission spectra in different fuel blended conditions.

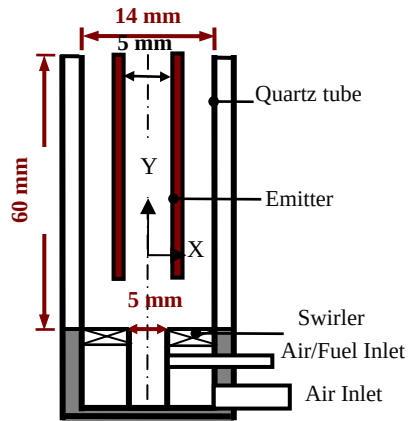


Figure 3. Sketched diagram of the annular combustor.

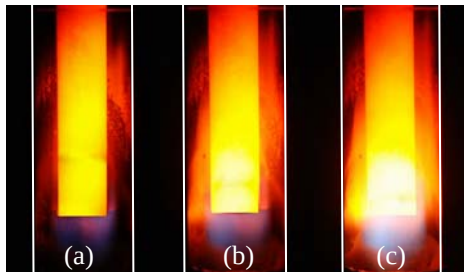


Figure 4. Combustion phenomena inside the annular combustor in (a) 80%CH₄ 20%CO, (b) 50%CH₄ 50%CO, and (c) 20%CH₄ 80%CO conditions.