

CHAPTER 6 EXPERIMENT

Many countries have different in energy resource, energy limitation and industrialized nation. Almost all of burners have been designed for only oil or only gaseous fuel. However, the flexible burners which can be used with both oil and gaseous fuel are only a few.

This chapter presents a new concept of modulating dual fuel porous burner hereafter refers as MDPB. Basically, the MDPB can be operated at any orientation angle with respect to the vertical direction in order to adapt for various industrials. Previous work found that orientation angle does not strongly affect temperature and emissions of CO and NO_x. In this study, a down-flow is considered. The results obtain from the gaseous fuel and liquid kerosene. In case of gaseous fuel are operated both under non-preheated air and preheated air conditions. After that, the liquid kerosene is considered. The measured temperature, emission, i.e. CO and NO_x, and pressure drop are reported to investigate important parameters affect burner performance. The results indicate that the MDPB technology can be one of the future combustion technologies which respond variety countries and various industrials demands.

6.1 Experimental apparatus

Figure 6.1 shows an experimental apparatus of MDPB. Basically, the burner can be operated at any orientation angle with respect to the vertical direction. Previous work (Jugjai and Pongsai, 2007) found that orientation angle does not strongly affect temperature and emissions of CO and NO_x. In this study, only a down-flow direction is considered. The system has two main components, i.e. a fuel-preheated porous medium FP and a porous combustor PC. The FP (Fig.6.2) is a stack of 200 pieces of metallic wire screens with a mesh size of 100 mesh/in, which are installed inside a stainless steel tube of 60 mm in diameter and 75 mm in length. Based on preliminary experiment, it was found that the FP is sufficient to produce efficient evaporation with uniform distribution of the fuel vapor at its exit. The PC (Fig 6.3) consists of inert alumina spheres with an average diameter of 10 mm, which are randomly packed inside the stainless steel tube of 75 mm in diameter and 160 mm in length. Both FP and PC are enclosed by cylindrical steel tubes having internal surfaces lined with high temperature

cement. The two porous media are separated by a mixing chamber of 20 mm in length. Fuel and air supplied are separated for safety reason.

The FP and PC are designed to be coupled with thermal radiation. At steady state condition, in case of using LPG, the radiative heat transfer from PC to FP is used as fuel preheating. In case of using liquid kerosene, heat absorbed within the FP, which is illuminated by an intense radiative heat flux emitted from the PC is utilized sensible heat and latent heat of evaporation of the liquid kerosene. Therefore, when the liquid kerosene is introduced at the upstream end of the FP and flows through it, the liquid kerosene is completely vaporized within the FP. The combustion air (from an air compressor) is supplied into the double-wall air jacket for preheating. After being preheated, the combustion air is then directed to an annular air jacket that surrounds the mixing chamber and the upper part of the PC before being injected into the mixing chamber from four directions through the four small holes being drilled over the side wall of the mixing chamber on the same plane. The holes have a diameter of 5 mm. Each direction of the injected air through each hole tangentially contacts an imaginary circle within the mixing chamber (see section A-A), providing a strong swirling flow motion with very high turbulence intensity, which is very good for mixing. The vaporized fuel meets the preheated air in the mixing chamber in a late mixing fashion such that a homogeneous combustible mixture of fuel and air can be formed followed by combustion within the packed bed of PC. With this late mixing fashion of vaporized fuel and air, an undesirable auto-ignition caused by early mixing of vaporized fuel and air, as is prone to occur in conventional premixed porous burners, can be avoided. In addition, the late mixing can allow for efficient fuel and air preheating with high safety, and thus enhancement in the thermal performance of the porous burner can be expected.

Liquid kerosene in the storage tank is pressurized by nitrogen gas at relatively low pressure (about 1 atm), which is just enough to cause the kerosene to flow to the syringe.

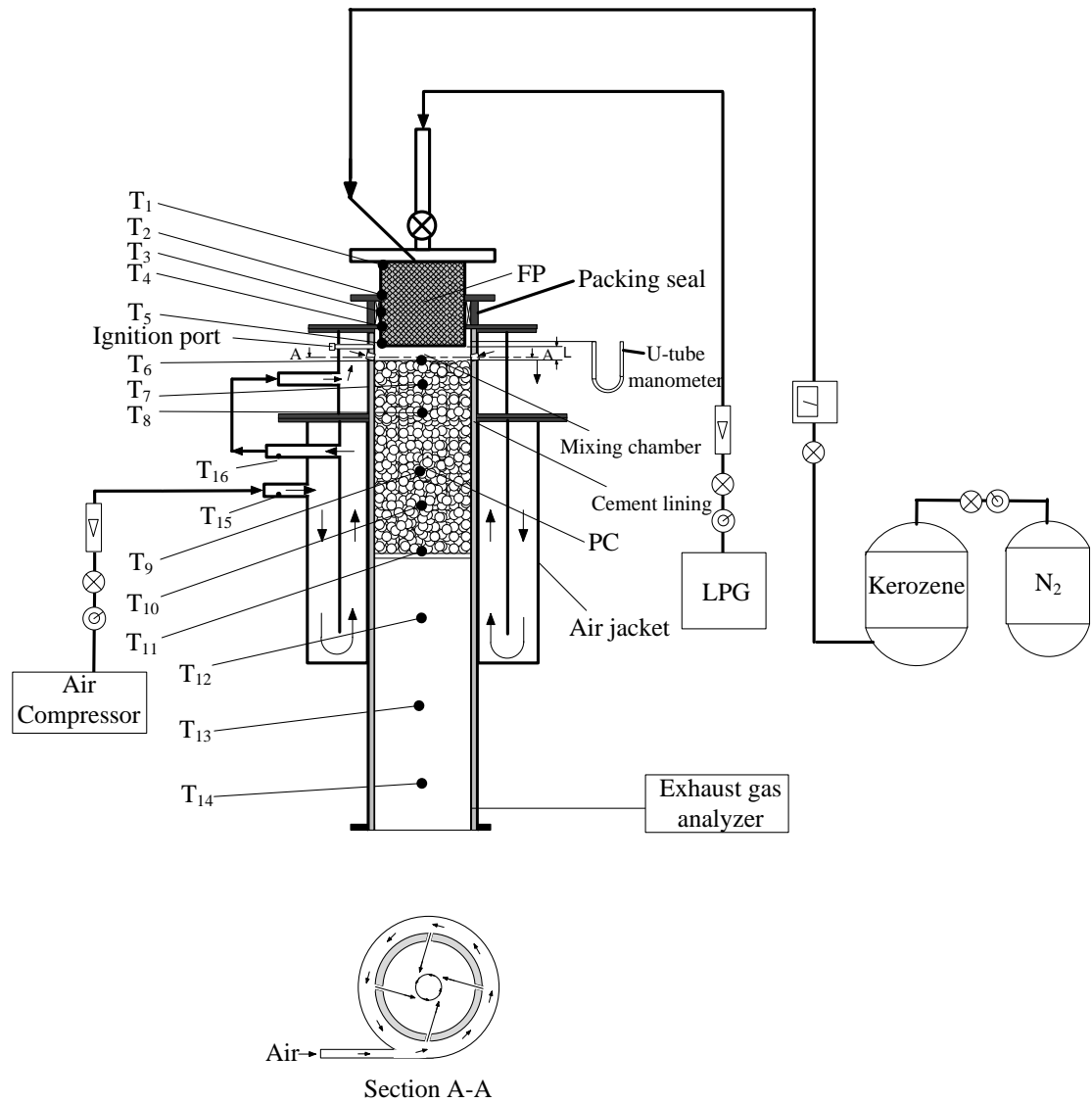


Figure 6.1 Experimental apparatus.

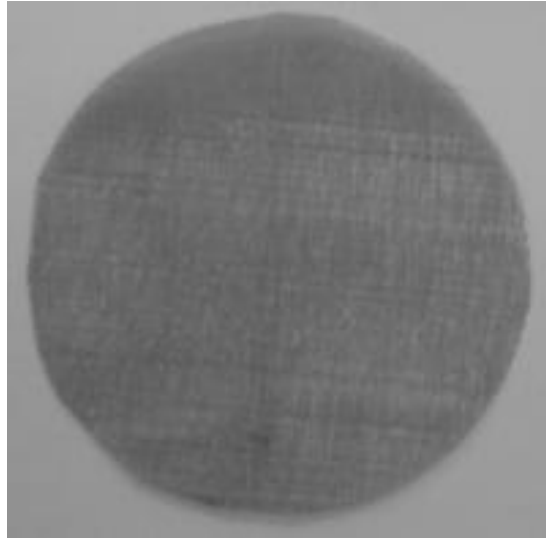


Figure 6.2 Fuel-preheating porous medium FP.

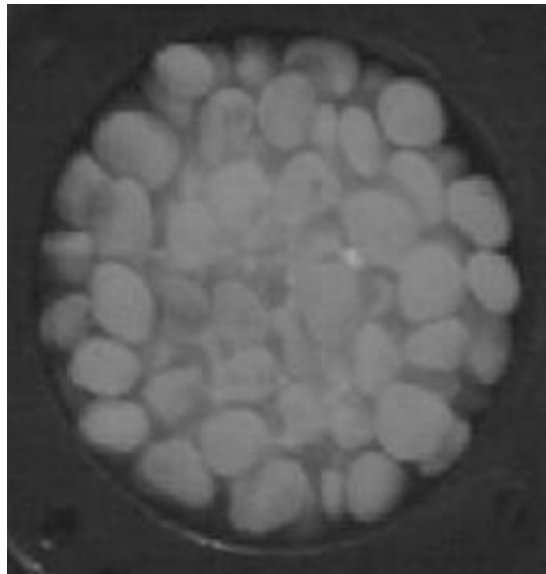


Figure 6.3 Porous combustor PC.

6.2 Measurement

The measured temperature along the burner length and the composition of exhaust gases at the burner exit are used to investigate combustion characteristic. N-type sheath thermocouples (1.5-mm diameter) of $T_1 - T_5$ are inserted from above along a lateral direction of the FP for observing fuel preheating and evaporation. These sheathed thermocouples are inserted through a small gap at the interface between the cement lining and the FP to prevent the liquid fuel flow pattern within the FP from being

disturbed by protrusion of the thermocouple junctions. B-type thermocouples (0.25- mm diameter) of T_6 - T_{11} are inserted from the side wall and installed at the centerline of the PC for observing combustion characteristics. Additional N-type thermocouples of T_{12} - T_{14} are installed at the tail pipe of the PC for measuring combustion gas temperature at the exit. Moreover, the N-type thermocouples of T_{15} and T_{16} are installed at the inlet and the exit of the air jacket, respectively for measuring inlet temperature and preheated temperature of combustion air. The thermocouple signals are digitized by a general-purpose DT 650 Data Logger, and then transmitted to a personal computer. The steady state condition is considered in the experiment. The reading temperatures of thermocouples for all locations were almost flat. The thermocouples are solid, thus their readings represent the solid phase (or porous medium) temperature.

Emission of the dry combustion products at the PC exit is monitored by using Messtechnik Eheim model Visit01L, which is a portable emission analyzer designed especially for quasi-continuous measurement. A gas processing system of NO_x and CO is especially tuned for electrochemical sensors, ensuring long-time stability and accuracy of measurement. The measuring range of the analyzer is 0-4,000 ppm for the NO_x and 0-10,000 ppm for the CO with a measuring accuracy of about ± 5 ppm and resolution of 1 ppm for both NO_x and CO. In the experiment, all measured emission data are corrected to 0% excess oxygen and dry-basis. Fuel and air flow rate are measured by calibrated rotameters. The pressure difference ΔP is also recorded using standard manometers. Repeated measurement shows an uncertainty of about 10% for temperature and the species concentration.

6.3 Procedures

The liquefied petroleum gas (LPG) is first supplied into the FP from its upstream end and mixed with the swirling air in the mixing chamber followed by combustion within the PC for preheating the system before switching to the liquid kerosene. Ignition is initiated by inserting a pilot flame through a small ignition port, which is located at the side wall of the mixing chamber. A relatively rich mixture of LPG and air is used at the initial ignition to allow for stable free flame combustion to occur inside the mixing chamber. Upon successful ignition, the pilot flame is removed and the ignition port is closed. Then, an operating condition at a relatively lean combustion is adjusted by

increasing air flow rate at a fixed fuel flow rate. When the main flame is moved to stabilize within the PC and the temperature at the exit of FP (T_5) increases up to a continuous evaporation and auto-ignition temperature (500-700 °C) of the liquid kerosene, then the fuel is switched from LPG to liquid kerosene. The liquid kerosene is directly supplied into the FP by pressurizing the kerosene by using high pressure nitrogen gas. Then, a parametric study is performed to understand the effect of equivalence ratio Φ on temperature profiles within the NSPB.

6.4 Experimental results in case of using LPG

Experimental results consist of two-parts: in case of using LPG and liquid kerosene. Fig. 6.4 shows the effect of Φ on measured solid temperature profiles for FR = 5 kW. With an increasing Φ from 0.5 to 0.7, the temperature in PC is increased and the reaction zone is located at the same position; the same trend as obtained by the model (refer chapter 4). However, at a higher equivalence ratio ($\Phi > 0.7$), increasing Φ results in a decrease in the temperature in PC, and the flame is moved to the downstream zone of PC. This may be attributed to a poor mixing between the combustion air and the fuel, as Φ increased. Thus, the mixture of air and fuel may be decreased when Φ is increased more than 0.7.

Fig.6.5 shows the corresponding measured CO and NO_x emissions at the same experimental conditions. It is found that Φ has no significant influence on CO emission for all experimented Φ value. Until Φ is more than 0.93, CO emission abruptly increases (not shown). This may be attributed to poor mixing followed by incomplete combustion and lowering in temperature in PC. Within the range of Φ studied in the present work, the reported CO emission is as small as that of the conventional premixed porous burner. However, the burner emits relatively high NO_x emission because of its relatively strong preheating effect of the combustion air. In addition, ΔP slightly decreases with increasing Φ because of decreasing of air flow rate (see Fig. 6.6).

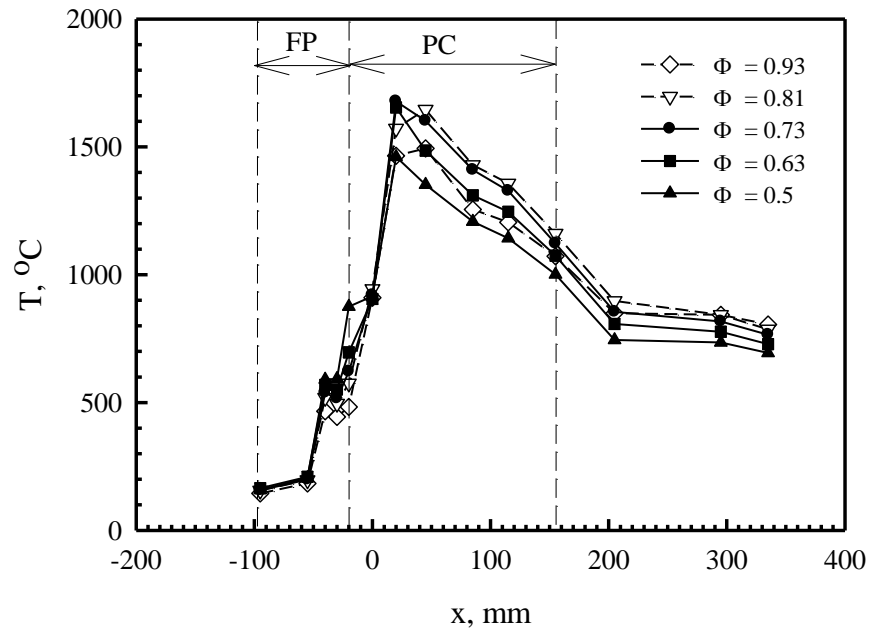


Figure 6.4 Effect of Φ on temperature in case of using LPG.

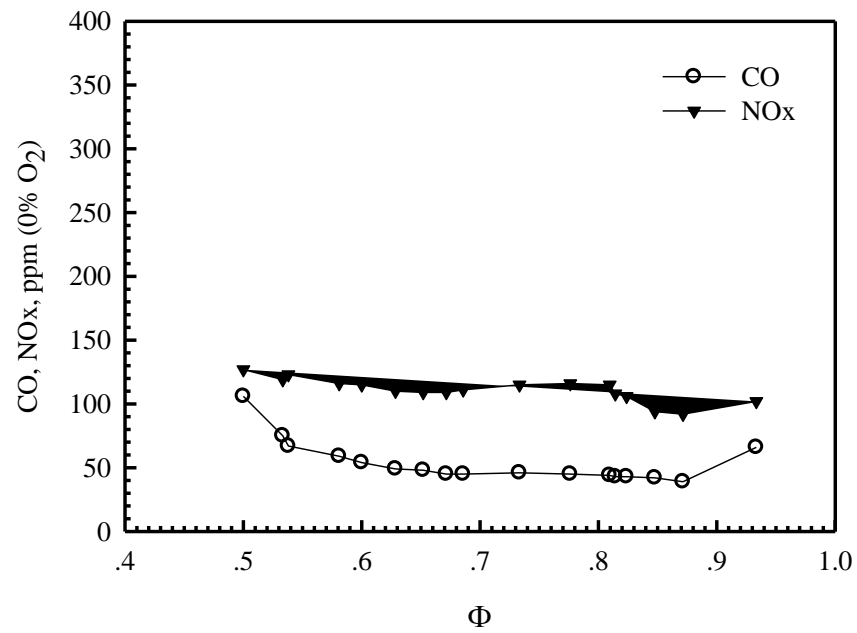


Figure 6.5 Effect of Φ on CO and NO_x emission in case of using LPG.

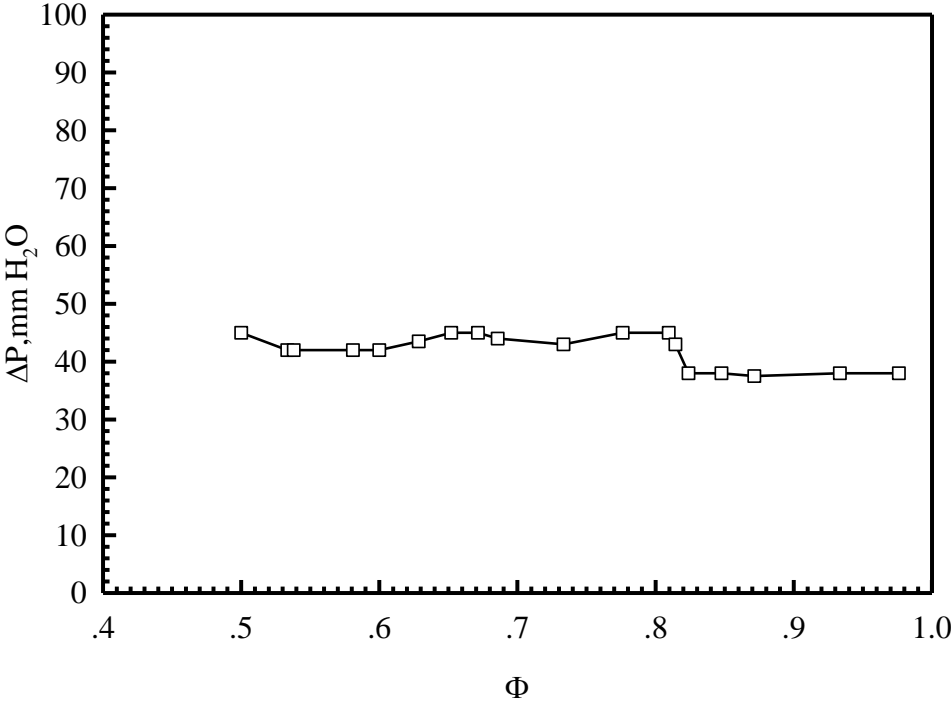


Figure 6.6 Effect of Φ on ΔP in case of using LPG.

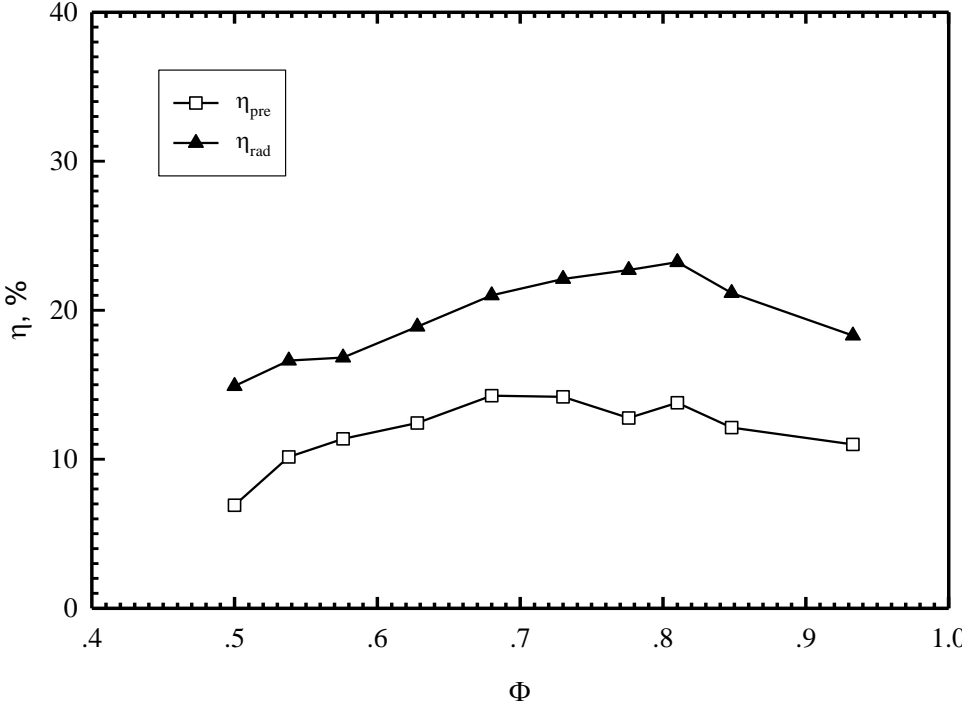


Figure 6.7 Effect of Φ on η_{rad} , η_{pre} in case of using LPG.

Fig.6.7 shows the effect of Φ on η_{rad} and η_{pre} . The η_{rad} , and η_{pre} are calculated from the corresponding measured temperature profile using equations 6.1 and 6.2. A radiant output efficiency is an important thermal performance parameter, which indicates the useful energy for heating the product at downstream. The radiant output efficiency is already defined in previous chapter 4.

As the equivalence ratio Φ is less than 0.8, the η_{rad} , and η_{pre} almost linearly increased with Φ because of an increase in the combustion temperature in the PC (see Fig.6.4). A further increase in Φ beyond $\Phi > 0.8$ leads to a decrease in the η_{rad} , and η_{pre} . This may be attributed to the lowering of the combustion temperature caused by the aforementioned poor mixing followed by an incomplete combustion within the PC.

6.5 Experimental results in case of using liquid kerosene

Fig.6.8 shows measured solid temperature profiles with varying Φ at FR= 5 kW. With an increasing Φ , the temperature in PC is increased because of increasing in quality of mixture. Nevertheless, the temperature in FP does not significantly changed with Φ because varying Φ dose not effect on fuel mass flow rate.

Fig.6.9 shows the corresponding measured CO and NO_x emissions. The emission of CO is not significantly changed with Φ . CO emission abruptly increases as $\Phi = 0.93$ (not shown). This may be attributed to poor mixing followed by incomplete combustion and lowering in temperature in PC. Within the range of Φ studied, CO emission is as small as that of the conventional premixed porous burner. However, this burner emits relatively high NO_x emission of about 180 ppm because of its relatively strong preheating effect of the combustion air. In addition, ΔP decrease with increasing Φ which is reasonable with decreasing in air mass flow rate (see Fig.6.10).

Fig.6.11 shows effect of Φ on η_{rad} and η_{pre} at FR= 5 kW. With increasing Φ , η_{rad} is increased cause to increasing temperature in PC. Moreover, flme movement to the upstream zone (see Fig.6.8)of PC is also reasonable for and increasing in η_{pre} .

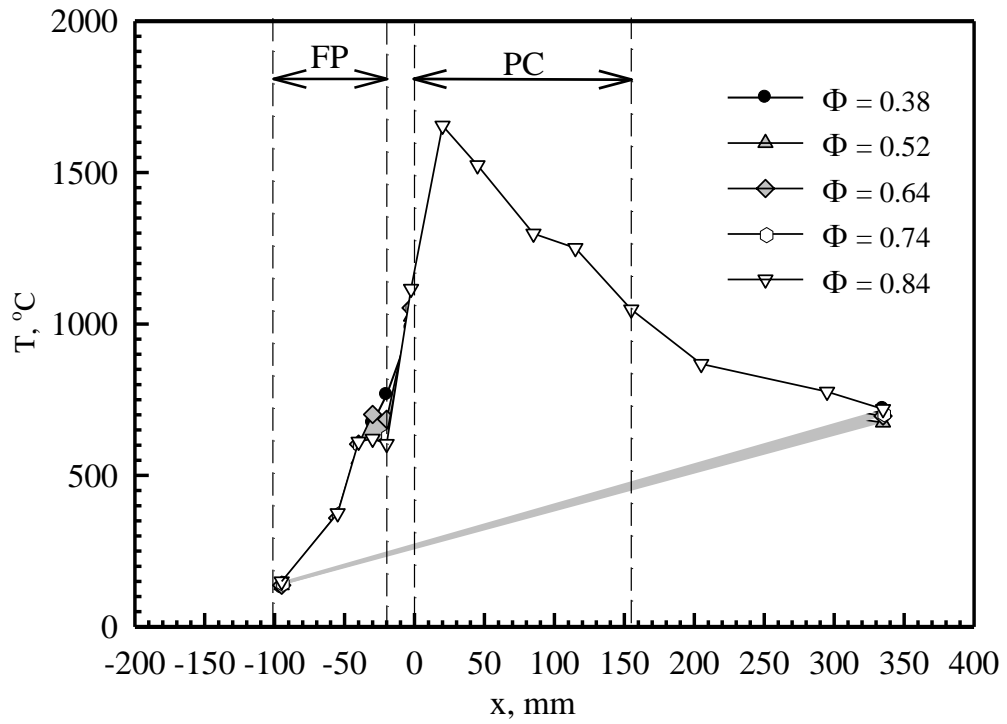


Figure 6.8 Effect of Φ on temperature in case of using liquid kerosene.

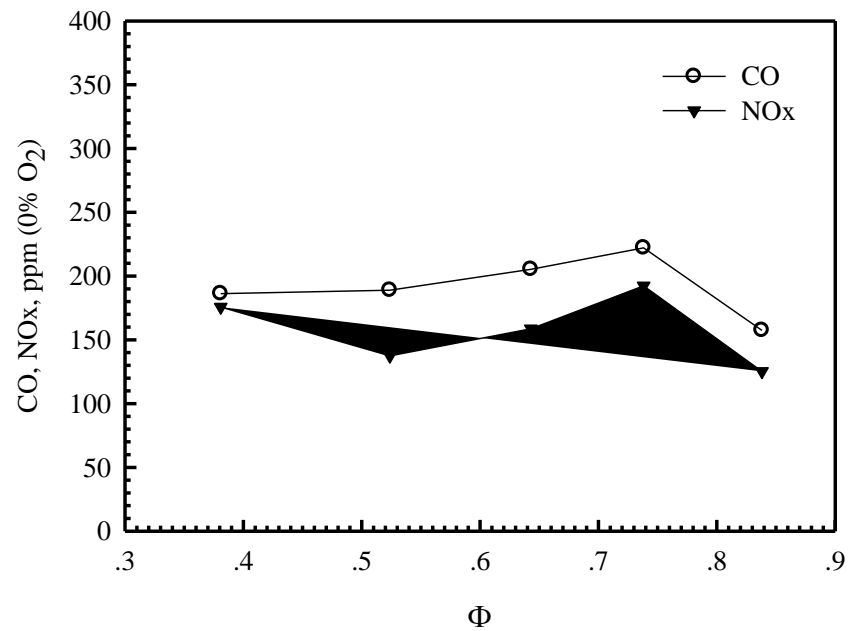


Figure 6.9 Effect of Φ on CO and NO_x emission in case of using liquid kerosene.

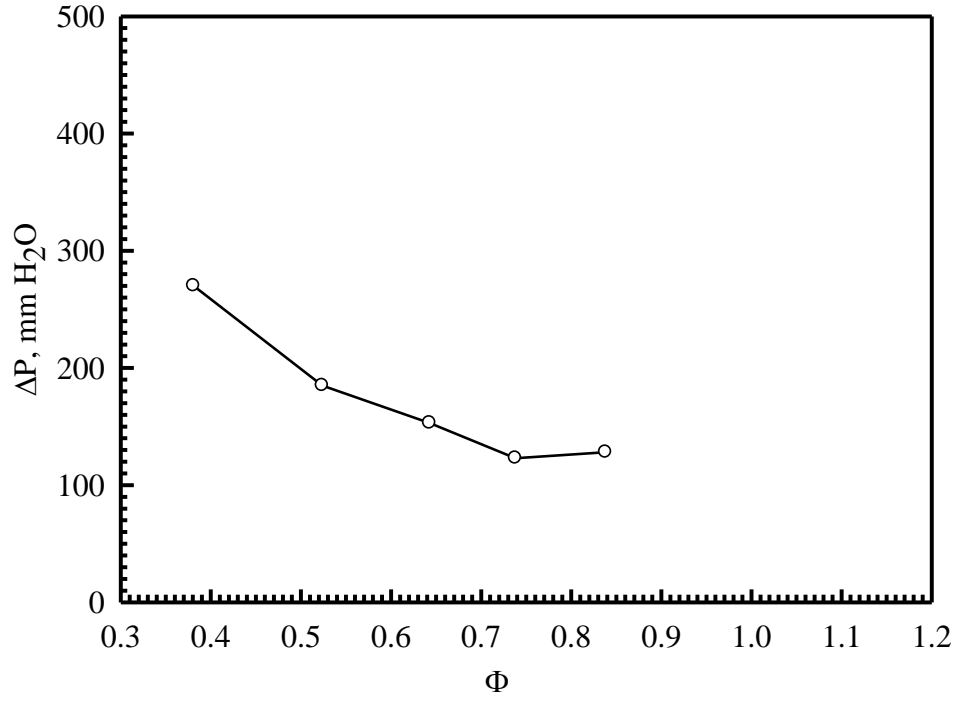


Figure 6.10 Effect of Φ on ΔP in case of using liquid kerosene.

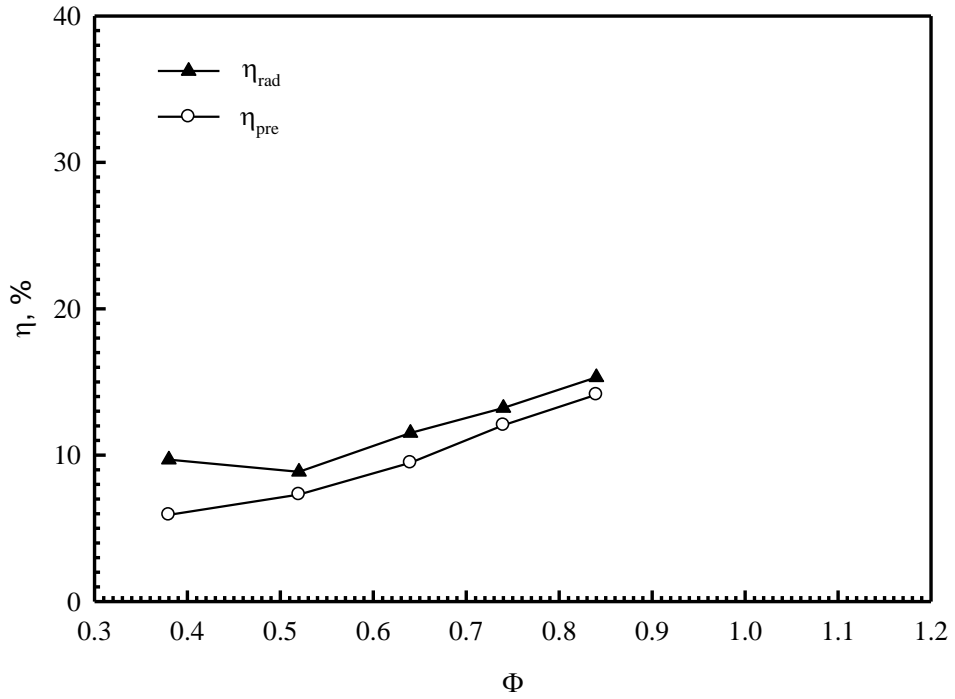


Figure 6.11 Effect of Φ on η_{rad} and η_{pre} in case of using liquid kerosene.

6.6 Conclusions

This chapter presents a new concept of modulating dual fuel porous burner (MDPB). Liquefied petroleum gas or liquid kerosene is used as fuel. The MDPB has two main components, i.e. a fuel-preheated porous medium FP and a porous combustor PC. The FP and PC are designed to be coupled with thermal radiation. For using LPG, the radiative heat transfer from PC to FP is used as fuel preheating. In case of using liquid kerosene, heat absorbed within the FP, which is illuminated by an intense radiative heat flux emitted from the PC is utilized sensible heat and latent heat of evaporation of the liquid kerosene. Then the liquid kerosene is introduced at the upstream end of the FP and flows through it, the liquid kerosene is completely vaporized within the FP. After being vaporized, the vaporized kerosene and the preheated air from the air jacket are mixed in the mixing chamber and are burned in the PC. The conclusions are as follows:

1. MDPB can be operated by using for liquefied petroleum gas or liquid kerosene.
2. In case of using LPG, within the range of Φ studied in the present work, the MDPB provide high radiant output efficiency with low emission CO which is as small as that of the conventional premixed porous burner.
3. In case of using liquid kerosene, the MDPB provide high radiant output efficiency in the same range normal porous burner for gaseous with low emission i.e., CO and NO_x, which is small than that of the conventional sprayed burner. Because the heterogeneous combustion in a free space of conventional sprayed burner is replaced for a homogeneous combustion within a porous combustor (PC).
4. The MDPB is future burners because it is flexible using for gaseous fuel or oil that responds variety countries and various industrials demands.