Composition and Outlet Distribution of Pre-combustion Pyrolysis Products

SONG Feilong, WU Yun[*], JIN Di, CHEN Xin, XU Shida
Science and Technology on Plasma Dynamics Laboratory, Air Force Engineering University
Xi'an, Shaanxi Province, China

1   Abstract

Rotary detonation engine (RDE) is a new type of cycle power system. Its thermal cycle efficiency is about 30% higher than that of an aero-turbine engine with isobaric combustion. It can work continuously after ignition and provide stable thrust. It has broad application prospects in the near space high-speed vehicle and so on [1]. At present, the detonation of kerosene-air mixture is faced with such prominent problems as slow evaporation of kerosene atomization, poor mixing effect, high ignition energy and low chemical reaction rate. Auxiliary initiation methods such as hydrogen doping, oxygen supplementation and preheating are not suitable for equipping aircraft in service [2-4]. Enhancing the activity of kerosene-air mixture through fuel pyrolysis is expected to reduce the initiation energy and achieve stable propagation of detonation wave [5]. It is of great significance to solve the problem of kerosene-air detonation.

High temperature pyrolysis environment is generated by partial fuel pre-combustion. Secondary supplementary fuel is pyrolyzed and activated to produce small molecular fuel and active groups. Different temperature environments are provided by controlling the flow rate of pre-combustion fuel in order to obtain different product compositions. The activation of kerosene-air mixture can be achieved to improve detonation performance by searching for the optimum mixture composition.

In the experiment, the method of first-stage pre-combustion heating is used to achieve the required total temperature of incoming flow. At the same time, in order to simplify the system, the process of kerosene pyrolysis is required to be completed in the combustion chamber. When the temperature reaches 1060K, kerosene cracking reaction time is about 50 ms. The pyrolysis reaction rate of kerosene increases exponentially with temperature, and the higher the temperature, the faster the pyrolysis reaction. However, kerosene injected into the gas with too high temperature will be ignited. Therefore, there are several temperature zones in the combustion chamber to study the optimal location of secondary refueling.

In this paper, experiments have been carried out on existing pre-combustion pyrolysis experimental devices to study the effects of different experimental parameters on pyrolysis products. The circumferential distribution of 3 to 5 nozzles at different axial distances is used to study the effect of kerosene filling distance on pyrolysis products. The working pressure range of pre-combustion pyrolysis combustor is 0.1-0.5 MPa, the air flow rate is 0.1-0.4 kg/s, and the total outlet temperature is about 550 K.

The pyrolysis products under each working condition are tested for different positions of kerosene replenishment, and the effects of temperature of kerosene replenishment position and the residence time on the pyrolysis products are studied.
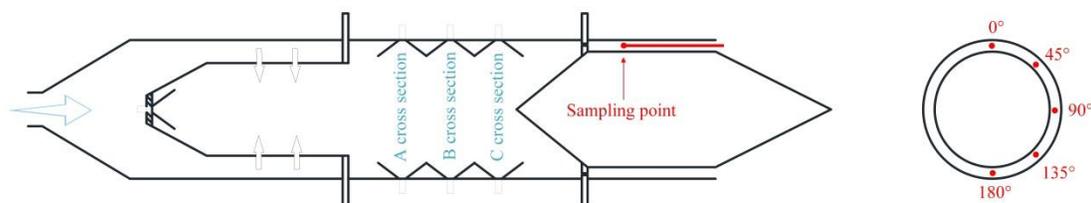
2   Experimental approach

Figure 1. Pre-combustion pyrolysis unit sketch

In the experiment, three fuel supply sections are arranged in the pre-combustion cracking chamber, and the sections A, B and C are arranged from the exit of the pre-combustion chamber to the far direction. The average test parameters are: pre-combustion fuel 2.74 g/s; air flow 48.9 g/s; refueling flow 6.60 g/s; pre-combustion chamber pressure 0.37 MPa. The cracking gas enters the annular slit through a circular uniformly distributed orifice through the diversion cone. At the downstream position of 75 mm from the pore, five sampling points are arranged circumferentially to collect gas samples. The pyrolysis products are analyzed by Agilent 7890B gas chromatograph. The gas chromatograph is configured as a three-channel refinery gas scheme, which can quantitatively analyze hydrogen, alkanes, olefins and alkynes below C_3 and C_3, alkanes and olefins of C_4, n-pentane and iso-pentane. Among them, hydrogen is analyzed by thermal conductivity detector (TCD) with a detection limit of 200 ppm, and the remaining hydrocarbon gases are analyzed by flame ionization detector (FID) with a detection limit of 2 ppm.
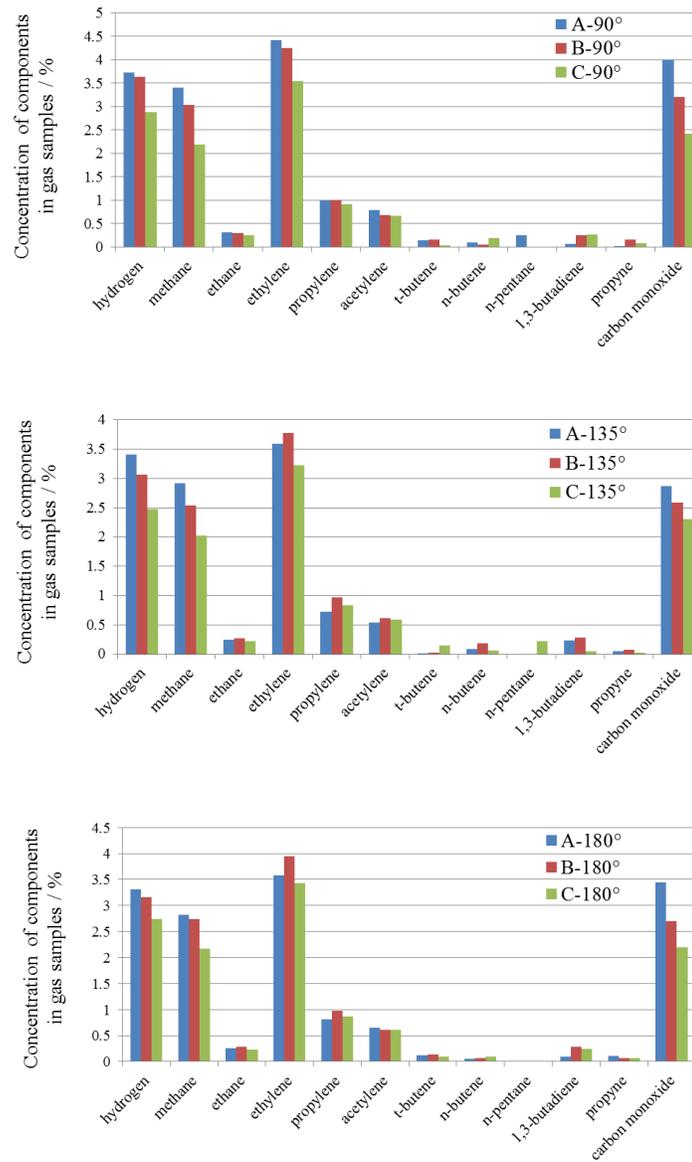
3   Results and discussions
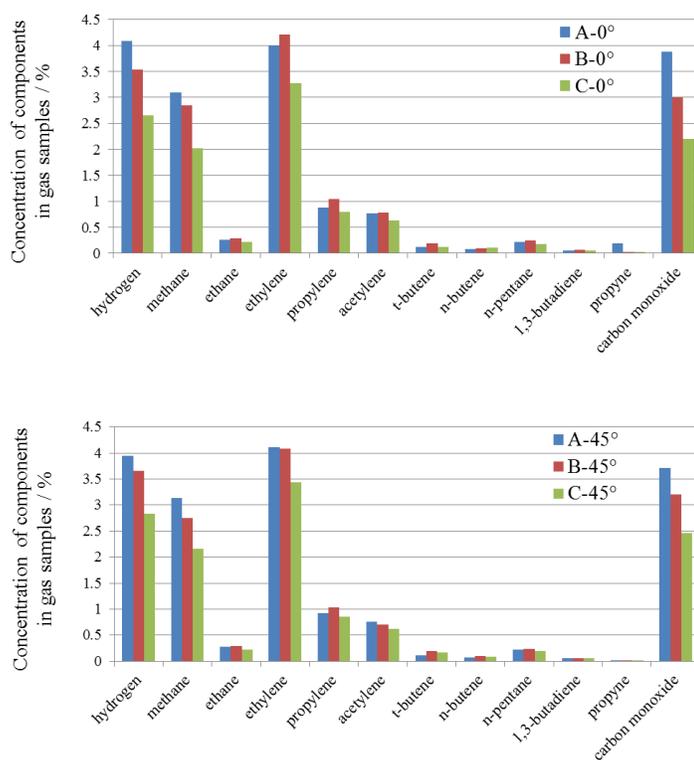
Figure 2. The influence of kerosene filling position on pyrolysis products.

Figure 2 shows the product comparison diagrams of three cross-sections of kerosene-supplement at different angles. Pre-combustion pyrolysis products are very rich, up to 20 components, of which hydrogen, methane, ethylene and carbon monoxide concentrations are the largest, each of which is more than 2% of the volume fraction of the gas sample. Secondly, propylene, acetylene and methane all exceed 0.1%. As can be seen from the figure, the concentration of hydrogen, methane and carbon monoxide gradually decreases at all angles of the annular slot outlet as the kerosene replenishment position moves backwards upward. On the one hand, the closer the refueling position is to the outlet, the lower the local temperature of the fuel injection position, which reduces the cracking rate; on the other hand, the closer the refueling position is to the outlet, the less residence time of the fuel injected into the cracking chamber

in the high temperature zone. However, ethylene, propylene and ethane show similar concentration at cross-section A and B, and even higher concentration at cross-section B.

In addition, an average of about 2.6% oxygen was detected in the product. This is because the fuel used for pre-combustion is located in the center of the head of the pre-combustion chamber, so the part near the center will be rich oil burning, while the edge will be lean, resulting in the remaining part of O_2. Although some of the fuel will continue to burn and release heat after refueling, which is conducive to the further increase of local temperature, it can't consume oxygen completely.
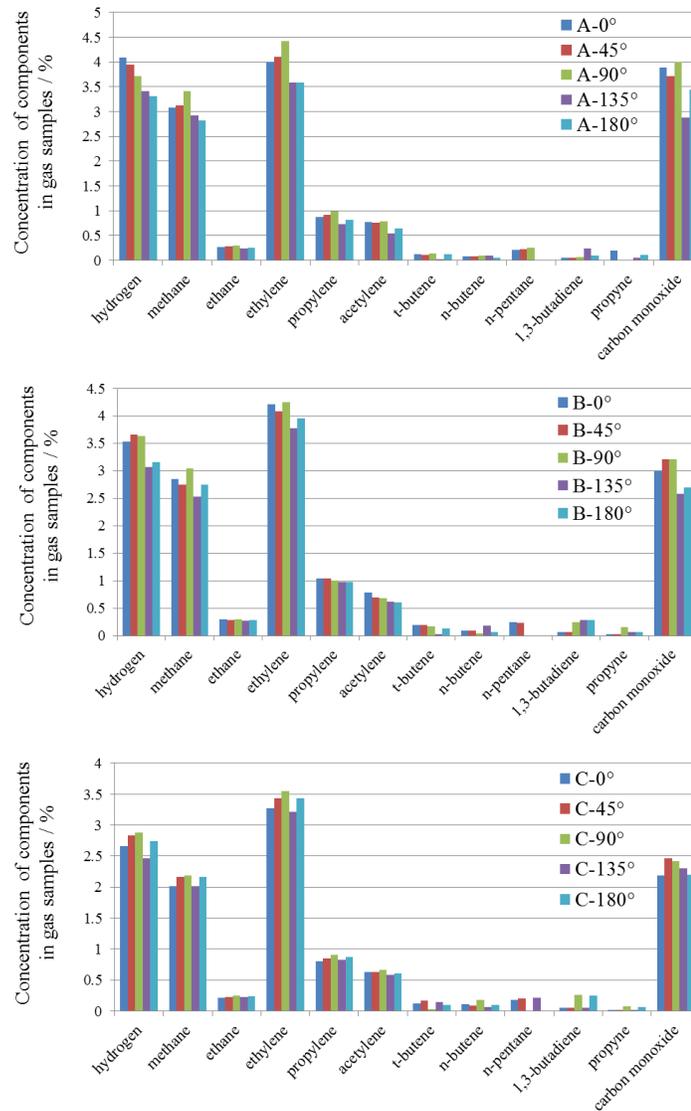
Figure 3. Product distribution in different angular positions of export section

The product composition at different circumferential positions of the annular outlet is compared and analyzed when filling kerosene at each section, as shown in Figure 3. It can be seen from the figure that the circumferential distribution of products is basically uniform after rectification by diversion cone, and it

is not obviously different with the change of the position of kerosene replenishment. However, it is worth pointing out that there is an obvious law of hydrogen concentration in the five sampling positions around the outlet when the kerosene is injected into the cracking chamber at section A, that is, the concentration of hydrogen decreases gradually during the transition from the top to the bottom of the outlet. The possible reason is that the cracking product is far away from the outlet when the kerosene is supplied at A section. When the product moves downstream along the direction of flow, because hydrogen is the lightest gas, it may float upward, which results in the circumferential distribution of hydrogen at the outlet.

4   Conclusions

The position of kerosene filled affects the formation of products mainly by affecting the residence time of reactants in high temperature zone. The shorter the residence time is, the lower the main pyrolysis gas content is. The change of hydrogen, methane and carbon monoxide is obvious. The nearer the position of kerosene replenishment is to the outlet, the lower the concentration of kerosene in all angles is.

The distribution of cracking gas in the annular chamber is relatively uniform when the kerosene is filled at the same section of the pre-combustion cracking chamber. When injecting kerosene at section A, the cracking gas is redistributed circumferentially over a relatively long distance due to the large distance between the generating location of cracking gas and the outlet. The most obvious is hydrogen, which is the lightest gas. After entering the annular chamber for a certain distance, the concentration of hydrogen decreases gradually from 0 to 180 degrees, which is from the top to the bottom of the annular outlet.

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