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To cite this article: A N Shiplyuk *et al* 2019 *J. Phys.: Conf. Ser.* **1404** 012068

Experimental study of the low-melting hydrocarbons regression rate in the inert gas flow

A N Shiplyuk[1], V I Zvegintsev[1], S M Frolov[2], D A Vnuchkov[1], S V Lukashevich[1] and D G Nalivaychenko[1]

[1] Khristianovich Institute of Theoretical and Applied Mechanics SB RAS, 4/1 Institutskaya str., Novosibirsk 630090, Russia
[2] Semenov Federal Research Center of Chemical Physics, Moscow 119991, Russia

vnuchkov@itam.nsc.ru

Abstract. Gasification of organic and inorganic materials in a high-temperature gas flow is a promising technology for various industrial applications like chemical industry, waste processing, rocket and air-breathing propulsion, etc. However, the characteristics of the gasification process of low-melting hydrocarbon materials remain insufficiently studied so far. The present authors propose a methodology for investigating the gasification of combustible materials for ramjets. Experiments on the gasification of cylindrical polypropylene (PP) samples by the high-temperature inert carrier gas (nitrogen) passing through multiple longitudinal channels of 3 mm in diameter and 200 mm long are performed. The flow of the carrier gas is heated by combustion of hydrogen–oxygen mixture. The temperature, pressure, and velocity of the carrier gas in the experiments range from 900 to 1700 K, 0.35 to 1.0 MPa, and 80 to 130 m/s, respectively. The yield of PP gasification products is shown to increase linearly with the carrier gas temperature. At the temperature of 1700 K, the yield of PP gasification products in the test facility attains 8.0 g/s, whereas the ratio of the mass flow rates of the carrier gas and gasification products reaches the value of 4.5.

1. Introduction

The concept of solid-fuel ramjets is currently associated mainly with the scheme of a ducted ramjet engine or a Throttleable Ducted Rocket (TDR) [1-2]. A mandatory element of the TDR is a gas generator (GG) aimed to gasify a solid fuel with a minimum amount (10–20%) of an oxidizer. Such an amount of oxidizer allows gasification of solid fuel due to its partial combustion in the GG and feeding the resulting gaseous products to the main ramjet combustion chamber, where they are completely burned in a high-speed flow of atmospheric air.

In the recent scientific literature, another relevant direction is discussed actively, that is the development of a low-temperature GG for gasification of low-melting fuels (LMF) like polymers (polyethylene, polypropylene, polystyrene, polybutadiene, etc.) with melting point of about 100 °C [3-7]. In the cited references, the design of a two-chamber GG with a sequential arrangement of a conventional solid propellant and LMF is studied numerically. In this design, burning of solid propellant generates a flow of high-temperature combustion products, which passes through the porous layer of LMF and gasifies it.

The objective of this work is to study experimentally the gasification of PP in a flow of heated inert gas (nitrogen). The main issue addressed is the influence of the carrier gas temperature and mass flow rate on the yield of gasification products. These objective and issues are the novel distinctive features of this research.

2. Description of the experimental setup

Figure 1 shows the design of the experimental small-sized GG. At the left end of the GG there is combustion chamber 3 of the fire heater, operating on combustion of the stoichiometric hydrogen–oxygen mixture. In mixing chamber 5, the carrier gas (nitrogen) is heated to the required temperature due to mixing with the combustion products. Thereafter, the heated carrier gas is fed through leveling pre-chamber 6 and profiled nozzle 7 to LMF test sample 8. Polypropylene of the PP H030 GP/1 brand is used as an LMF. Each test sample is assembled from 4 cylindrical elements with diameter of 40 mm and length of 50 mm (figure 2). Each element has 19 evenly spaced longitudinal channels 3 mm in diameter. The total length of the test sample is 200 mm. After passing through the last element of the test sample, the resultant gas flow enters small cylindrical channel 9, which ends with throttling insert 10 with orifice diameter of 6.5 mm. The use of a throttling insert allows maintaining the subsonic flow velocity in the GG. The exhaust gases expel from the GG to a vacuum tank (not shown in figure. 1).

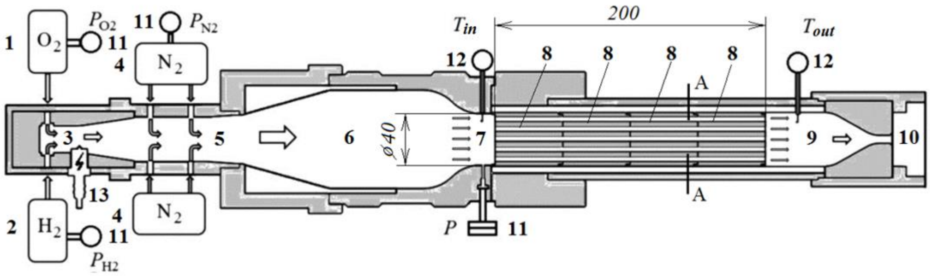


Figure 1. Scheme of a small-sized experimental gas generator.

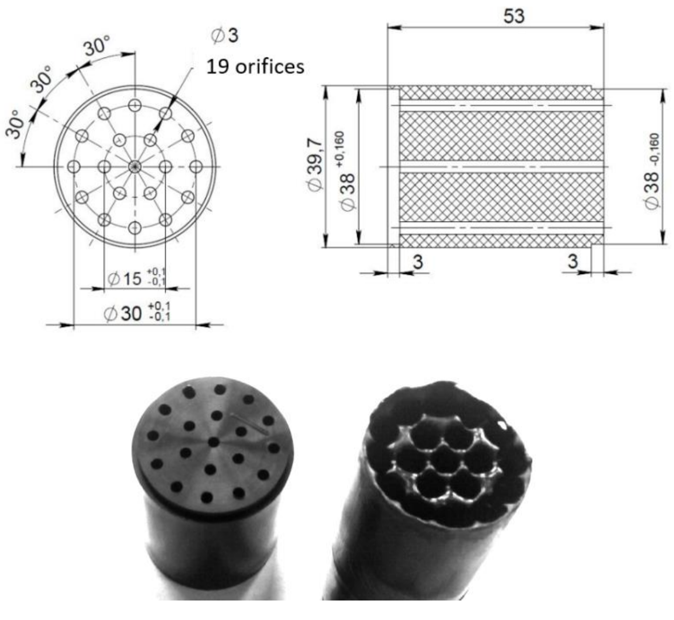


Figure 2. Total view of the test samples. (a) before burning; (b) after burning.

The experiments are performed as follows. The command of a synchronization system triggers the data acquisition system and opens the valves of oxygen and nitrogen supply. In 200 ms, it triggers the spark plug and opens the valve of hydrogen supply. The mass flow rate of hydrogen in experiments ranges from 0.3 g/s to 0.9 g/s depending on the required temperature of the carrier gas. In 300 ms, the spark plug is turned off, implying that the hydrogen–oxygen mixture is ignited, and its combustion is established. The mass flow rates of hydrogen and oxygen are maintained at the stoichiometric ratio. Measurements show that combustion of the hydrogen–oxygen mixture in the fire heater is complete. The carrier gas (nitrogen) is then heated to a preset temperature and directed to the channels in the LMF test sample to heat and gasify the sample material. As a result of experiment, a mixture of nitrogen, steam, and PP gasification products is formed at the outlet of the GG. In 2300 ms, the synchronization system closes the valves of oxygen, nitrogen, and hydrogen supply to terminate the experiment. The data acquisition system is turned off in 3000 ms.

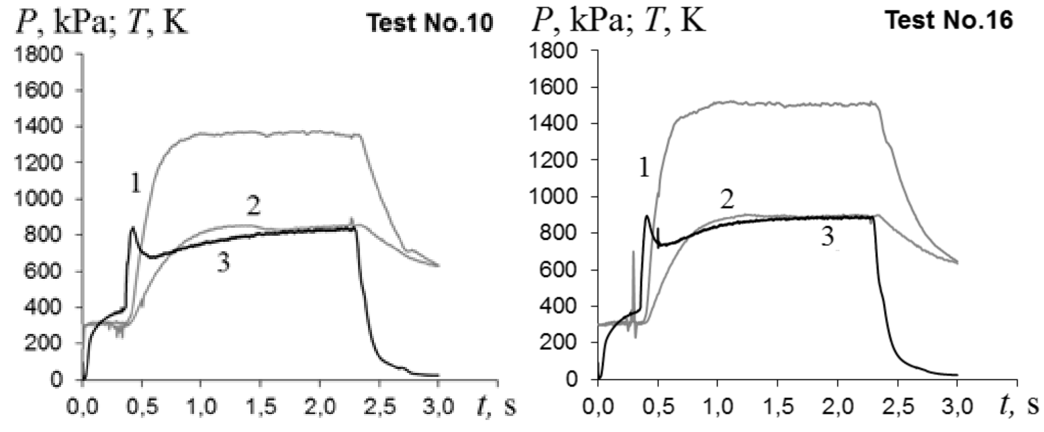
3. Experiment Results

Table 1 shows the measured mass flow rates of hydrogen (G_{H2}), oxygen (G_{O2}), and nitrogen (G_{N2}) supplied to the GG in some representative experiments. In all the experiments, the total mass flow rate of the carrier gas (G_{in}) is seen to remain constant at a level of 35–36 g/s. The gas velocity in the channels of the LMF test sample is 120–130 m/s at the sample inlet and 90 m/s at its outlet.

Table 1. The Initial conditions of experiments on PP gasification by high-temperature nitrogen.

Test No.	G_{H2}, g/s	G_{O2}, g/s	G_{N2}, g/s	$G_{in} = G_{H2} + G_{O2} + G_{N2}$, g/s
14	0.30	2.38	33.20	35.9
8	0.39	3.05	32.20	35.6
12	0.48	3.80	31.00	35.3
10	0.59	4.70	30.50	35.8
16	0.72	5.64	28.60	35.0
20	0.82	6.51	28.20	35.5
18	0.94	7.54	27.50	36.0

Figure 3 shows typical records of pressure and temperature in experiments with PP gasification. Increasing of hydrogen mass flow rate is seen to increase the carrier gas temperature upstream of the LMF test sample (T_{in}) from 900 to 1716 K. The temperature of the gas flow at the outlet of the LMF test sample (T_{out}) is seen to remain relatively low and nearly constant (ranging from 800 to 900 K). During operation of the GG, the pressure in it (P) increases by about 15% ranging from 7 to 10 bar.



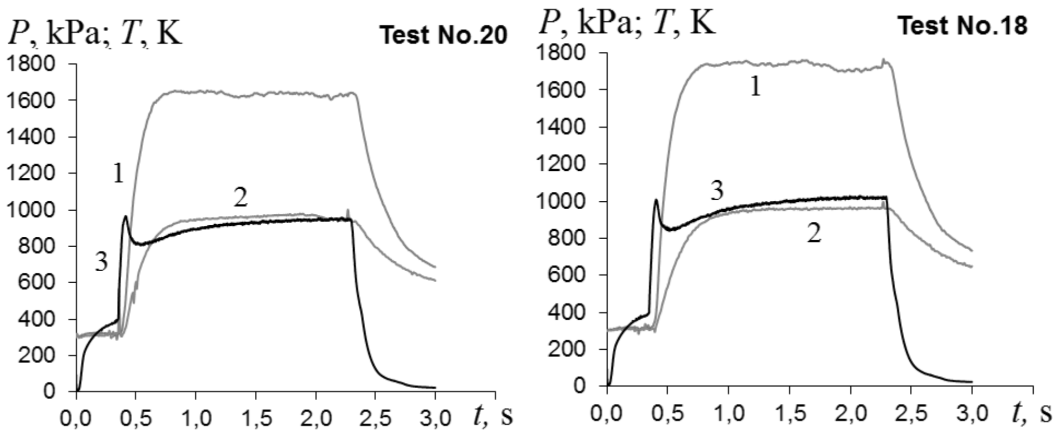


Figure 3. Typical temperature and pressure records in experiments with PP gasification. (1 - T_{in}, 2 - T_{out}, 3 – P)

Table 2 shows the time-averaged (over $t_g \approx 1.7$ s) characteristics of the gasification process. In particular, table 2 shows the yields of gasification products (G_{PP}) and the ratios of the mass flow rates of the carrier gas to those of PP gasification products (G_{in}/G_{PP}) in different experiments. The maximum yield of gasification products is 8 g/s at the carrier gas temperature of 1716 K. The minimum value of G_{in} / G_{PP} is 4.5 at the carrier gas temperature of 1716 K.

Table 2. Time-averaged test results of PP gasification with a high-temperature nitrogen.

TestNo.	t_g, s	T_{in}, K	T_{out}, K	P_{in}, kPa	G_{PP}, g/s	G_{in} / G_{PP}
4	1.059	909	650	622	0.13	271.41
8	1.507	1050	729	666	1.27	27.97
12	1.678	1183	825	709	2.42	14.58
10	1.666	1348	816	786	4.08	8.77
16	1.712	1494	865	855	5.64	6.20
20	1.788	1620	935	910	6.49	5.48
18	1.772	1716	925	976	8.00	4.50

Figure 4 shows the dependence of the mass flow rate of PP gasification products on the temperature of the carrier gas at the LMF test sample (T_{in}). The yield of gasification products is seen to increase linearly with the temperature of the carrier gas.

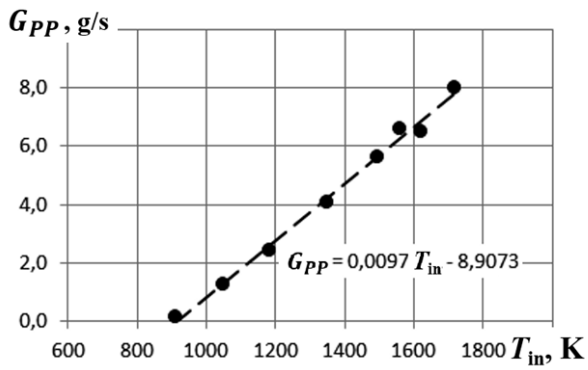


Figure 4. Yield of PP gasification products vs. the carrier gas temperature.

4. Conclusion

An experimental facility is developed and experiments are performed to study the gasification of low-melting fuel (polypropylene) by a flow of high-temperature inert carrier gas (nitrogen) through a test sample with 19 longitudinal channels 3 mm in diameter and 200 mm long. The carrier gas temperature, pressure, and velocity in the experiments range from 900 to 1700 K, 0.35 to 1.0 MPa, and 80 to 130 m/s, respectively. The yield of gasification products is shown to increase linearly with the temperature of the carrier gas. At the carrier gas temperature of ~1700 K, the yield of gasification products in the facility attains 8.0 g/s, and the ratio of mass flow rates of the carrier gas and gasification products reaches the value of 4.5.

Acknowledgements

The research was carried out within the framework of the Program of Fundamental Scientific Research for the state academies of sciences in 2013-2020 (project No. AAAA-A17-117030610121-9), (project No. AAAA-A17-117030610121-9) and was partly supported by the Russian Foundation for Basic Research (grant 18-08-00076a).

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