Steam plasma gasification of polyvinyl chloride

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Abstract: The paper deals with steam plasma gasification of polyvinyl chloride. In this process, carbon monoxide, hydrogen and hydrogen chloride are formed. The main parameters of the plasma process were determined: steam plasma/polyvinyl chloride mass ratio is 0.66 kg/kg; plasma enthalpy is 6.2 MJ/kg. The resulting hydrogen chloride can be used to obtain anhydrous hydrogen chloride.

Keywords: steam thermal plasma, polyvinyl chloride, synthesis gas, hydrogen chloride.

1. Introduction

The problem of processing chlorine-containing plastics is very significant in the modern world. This is due to the formation of dioxins as a result of thermal processing of such materials. For this there are a number of methods: high temperature pyrolysis [1], traditional combustion [2], reduction by hydrogen [3], oxidation with supercritical water [4], plasma methods and others. Various types of plasma are used to process organochlorine compounds. Nonequilibrium plasma shows significant efficiency only with the additional use of the catalyst [5]. However, the main disadvantage of this method is low productivity, which does not allow to apply these methods in industry. There is a large amount of research related to the processing of organochlorine compounds using the thermal plasma [6]. The main plasma gas in most of these works is air [7]. However, when using air, the reaction products contain a large amount of nitrogen oxides, which have a high toxic effect. With the development of plasma technology, it became possible to process such substances using the steam thermal plasma, which provides a high depth of organic matter conversion. Currently, steam plasma torches operate on a mixture of steam and other (protective) gas, providing a longer life of the electrode node. Argon is most often used as a protective gas [8, 9]. Alternatively, carbon dioxide can be used [10]. Such the plasma torch was tested with steam-carbon dioxide [11] and carbon dioxide reforming [12] of natural gas and carbon tetrachloride [13].

2. The main part

To assess the performance of the high voltage AC plasma torch [12], a thermodynamic calculation of plasma steam gasification of polyvinyl chloride was carried out. Most often, polyvinyl chloride is used in a mixture of other substances, so its composition and lower heating value are determined according to literature data [14]. The composition of the plastic obtained on the basis of this substance is follow: C—45.2; H—5.6; O—1.6; Cl—47.6% wt. The process temperature was constant (1500 K). This temperature is necessary in order to reliably decompose all organochlorine compounds. To reduce the concentration of solids in the process, the pressure was chosen to be 1 atm. In this case, the probability of formation of complex aromatic compounds that are actively formed at elevated pressure is significantly reduced. The main variable parameter was the specific flow rate of steam plasma. The material and heat balances were used to determine the enthalpy of the steam plasma. For this, the heat of combustion of polyvinyl chloride (22,690 kJ/kg), the heat of combustion of synthesis gas and the thermal energy of the reaction products were used. The calculation does not take into account the heat of evaporation of water. The equation for the gasification reaction of polyvinyl chloride is as follows:

$$(C_2H_3Cl)_n + 2nH_2O = 2nCO + 3nH_2 + nHCl \quad (1)$$

Since the main quantity of dioxins is contained in soot, its formation is the most important marker for the detection of a large number of hazardous substances. The dependence of the composition of the reaction products on the specific flow rate of steam plasma is shown in Figure 1. As can be seen from the figure, at low specific flow rate of steam plasma, the products of the reaction contain a lot of graphite. At specific flow rate of 0.66 kg/kg of polyvinyl chloride, only gaseous products remain. This area is optimal for obtaining high calorific synthesis gas.

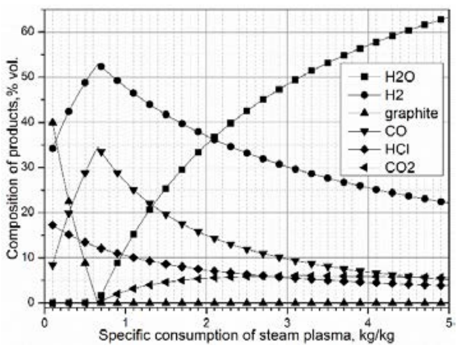

Fig. 1. Dependence of the composition of the reaction products on the specific flow rate of the steam plasma

The dependence of plasma enthalpy on the specific flow rate of steam plasma is shown in Figure 2.

As can be seen from the figure, the maximum value of plasma enthalpy is achieved under stoichiometric conditions. At the same time, this value (8.12 MJ/kg) is easily achieved in most plasma torches, even taking into account the heat losses in the plasma-chemical reactor.

However, in industrial conditions, some excess oxidant is required. It usually ranges from 1.2 to 2. To determine the process conditions, the minimum excess oxidizer was selected, at which the oxidant specific flow rate was 0.92 kg/kg of polyvinyl chloride.

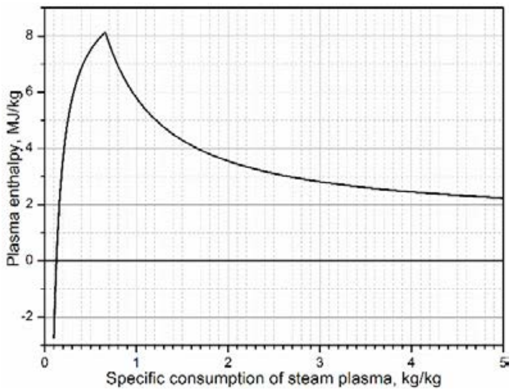

Fig. 2. The dependence of plasma enthalpy on the specific flow rate of steam plasma

The composition of the products will be as follows: H_2 - 48.98; CO - 28.41; HCl - 10.90; H_2O - 9.58. Plasma enthalpy is 6.2 MJ/kg. After cooling, the mixture will form two phases: gaseous, consisting of hydrogen and carbon monoxide and a liquid phase consisting of water and hydrogen chloride. The azeotropic point of a mixture of water and hydrogen chloride corresponds to a concentration of hydrogen chloride equal to 20.24%wt. From this it follows that pure hydrogen chloride can be separated from the liquid phase using rectification. Similar initial studies were carried out to obtain hydrogen halides using thermal plasma [15]. Raw materials may not contain carbon. Compounds that can be processed include uranium hexafluoride [16], carbon tetrafluoride [17]. This allows to use most of the products of processing of polyvinyl chloride: synthesis gas to produce thermal energy due to its combustion and hydrogen chloride, which is a valuable chemical product.

When using a high-voltage plasma torch with steam capacity of 3 g/s [12], it is possible to determine the unit productivity of the plasma-chemical plant for the processing of polyvinyl chloride. The power of the plasma torch is 110 kW. Carbon dioxide is used as a protective gas, which also partially reacts with polyvinyl chloride at high temperatures. Carbon dioxide is fed into the near-electrode zone to increase the lifetime of the electrode unit.

The capacity of raw materials and main products per plasma torch is presented in table 1.

Table 1. Capacity for raw materials and main products.

Substance		Capacity	
		g/s	kg/h
Input	Polyvinyl chloride	4.55	16.38
	Steam	3.00	10.80
Output	Hydrogen	0.50	1.82
	Carbon monoxide	4.10	14.76
	Hydrogen chloride	2.05	7.38
	Steam	0.89	3.20

3. Conclusions

The plasma torch under study can be used to process polyvinyl chloride to produce combustible synthesis gas and an aqueous solution of hydrogen chloride with a high concentration. In this case, the polyvinyl chloride capacity will be 4.55 g/s (16.38 kg/h). At the same time, a liquid mixture (0.99 g / s) of hydrogen chloride (69.76%wt — 0.69 g/s) and water (30.24%wt — 0.30 g/s) will be formed.

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5. References

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