Optimization of burning process of hydrocarbon fuels with varying specific heat of combustion

E R Saifullin¹, Yu V Vankov²

¹Kazan Federal University, 18 Kremlyovskaya str., Kazan 420008, Russian Federation
²Kazan State Power Engineering University, 51 Krasnoselskaya str., Kazan 420066, Russian Federation

E-mail: techphys@kpfu.ru

Abstract. This article explores the combustion of gaseous fuel in the case of an abrupt change of the specific heat of combustion. Analyzes the changes in the rate of heat when the fuel and air flows are constant. Defines the conditions for which retained the initial rate of heat release and optimal fuel-air ratio.

1. Introduction

Optimization of the combustion of gaseous fuels - an urgent task [1], [2], [3]. At present, the associated petroleum gas and waste of refinery plants are often used as a fuel in thermal power plants. These gases are unstable composition and calorific value. During the combustion of such fuels heat release rate will be variable. As a result, the thermal regime of the power plant will be unstable.

In this article it is considered the case of abrupt change of the specific heat of combustion. It is defined as the need to change the fuel and air supply, the heat release rate by the combustion of the fuel remained constant.

2. Initial relations

Use the well-known relations from the theory of combustion processes [4]:

\[ q = 7050n + 2500, \quad [q] = \text{kcal/m}^3. \]  
\[ g^* = 7.13n + 2.28, \quad [g^*] = \text{m}^3/\text{m}^3, \]  

(1)

(2)

q – heat of combustion per unit volume of fuel, \( g^* \) – the volume of air required for complete combustion of fuel per unit volume, \( n \) – carbon number.

Let the fuel has constant over time the heat of combustion \( q_0 \). When the complete combustion of the fuel at a rate of \( G_{f,0} \) heat release rate is equal:

\[ Q_{f,0} = q_0 G_{f,0}, \]  

(3)

the necessary amount of air flow, according to (2) is equal:

\[ G_{a,0} = g_0^* G_{f,0}. \]  

(4)

Heat flux obtained heat transfer agent related to the rate of heat release by ratio

\[ Q_0 = \eta_0 Q_{f,0}, \]  

(5)

where \( \eta_0 \) – the efficiency of the heat exchanger.
3. Theoretical analysis

Suppose that at some point in time the heat of combustion abruptly changed by a small amount \( \Delta q \), and then remains constant over time, i.e.:

\[
q = q_0 \pm \Delta q, \quad \Delta q / q_0 = \theta_q \pm 1.
\]  

(6)

From the relations (1), (2):

\[
g^* = k_5 q + k_6, \quad k_5 = k_3 / k_1, \quad k_6 = k_4 - k_2 / k_1.
\]  

(7)

Given the relations (6), (7):

\[
G^*_a = G^*_{t,0} = G^*_{a,0} \pm k_5 \Delta q G^*_{t,0}.
\]  

(8)

The (-) sign in (6), (8) corresponds to a reduction of fuel combustion heat. In this case, a complete combustion needed less air than the first. As a result, the complete combustion of the fuel appears surplus of air, which reduces the combustion temperature [5], [6], [7]. Furthermore, according to formula (3) decreases the rate of heat. Therefore, according to (5) reduced the heat flux obtained by heat transfer agent from the products of combustion.

In order to restore the initial thermal conditions in the complete combustion of fuel, it is necessary to change the fuel and air flows.

\[
G_t = G_{t,0} + \Delta G_t = G_{t,0} (1 + \theta_t), \quad G_a = G_{a,0} + \Delta G_a = G_{a,0} (1 + \theta_a).
\]  

(9)

It is necessary to restore the initial rate of heat, i.e.:

\[
q G_t = Q_0 = q G_{t,0}.
\]  

(10)

Terms complete combustion has the form:

\[
G_a = g^* G_t.
\]  

(11)

After substitution of (9) into equation (10), (11) and neglecting terms of the 2nd-order terms, obtain:

\[
\theta_t = \theta_q, \quad \theta_a = \theta_t - \theta_q.
\]  

(12)

In view of (6), (7) have:

\[
\theta_q = \frac{\Delta g^*}{g^*_0} = \frac{k_5 \Delta q}{k_5 q_0 + k_6}.
\]  

(13)

Calculations made on the basis of formulas (1) and (2) showed that \( k_5 = 10^{-3}, k_6 \approx 0,25 \). I.e. \( q_0 \) - quantity of the order \( 10^4 \) kcal/m\(^3\) and above, the value \( k_5 q_0 \) much more than \( k_6 \). Therefore:

\[
\theta_q = \theta_q.
\]  

(14)

The (+) sign in (6), (8) corresponds to an increase of heat of combustion.

In this case, for the complete combustion of fuel unit requires more volume of air. Because air flow rate remains the same, the increase of the specific heat of combustion of fuel leads to its incomplete combustion.

To restore the initial thermal regime without incomplete burning of fuel changes the fuel and air flows according to the equations (9).

The condition of conservation of heat release rate (10) and the condition of complete combustion of fuel (11) - are the same.

Substituting expressions (6), (8) and (9) into (10), (11), taking into account the linearization of equation (13) gives the following results:

\[
\theta_t = -\theta_q, \quad \theta_a = 0.
\]  

(15)
4. Conclusions

So, after the reduction of the specific heat of combustion of fuel at a small relative value, to restore the initial thermal conditions can increase fuel flow by the same relative value without changing the air flow.

After raising the specific heat of combustion at a relative small value, reducing the fuel flow to the same relative value without changing the air flow can provide complete combustion and a predetermined value of the heat flow imparted to the heat transfer agent.

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References
[1] Amr I and Saiful B 2007 Fuel 87 1824
[2] Snow D A 2001 Great Britan B. Plant engineer’s reference book 864
[3] Iovleva O V and Larionov V M 2007 Russian Aeronautics 50(3) 303-308
[4] G. F. Knorre, K. M. Aref’ev, A G Blokh 1966 Russia B. Theory of combustor processes 1042
[5] Larionov V M and Nazarenko T I 2000 Izvestiya Vysshikh Uchebnikh Zavedenij. Aviatsionnaya Tekhnika (4) 69
[6] Larionov V M and Beloded O V 2003 Izvestiya Vysshikh Uchebnikh Zavedenij. Aviatsionnaya Tekhnika (4) 48-52
[7] Beloded O V and Larionov V M 2006 Russian Aeronautics 49(1) 44-48