Thermal incineration of lean mixtures

Introduction

Waste gases, which are composed mainly of air and trace combustible gases, are produced in many industrial processes. Mixtures of such gases are called lean mixtures due to low concentration of combustible fraction. An example of a sector in which lean mixtures are produced in large amounts is coal mining where large ventilation air flow rates occur containing trace amounts of methane. Although the concentrations of methane are much lower than the lower flammability limit of air-methane mixture, the chemical energy lost in these large streams is frequently high enough to cover the energy needs of the coal mines.

Thermal incineration of lean mixtures is not possible using conventional combustion systems and burners. The easiest way of utilizing these kinds of waste gases is to use them as oxidizers in combustion of standard value fuels. Such a solution is however frequently economically or technically unjustifiable. It is also possible to use catalytic combustion techniques, however they are frequently either too expensive or too complicated to operate. In many situations the most favorable way of utilizing these gases is to use autothermal incineration technologies. In Fig. 1 a schematic diagram presenting such a technology is shown. The fresh mixture before entering the combustion chamber is heated up by flue gases. This causes widening of its flammability limits and allows obtaining a stable flame in the combustion chamber even for relatively low calorific value of the mixture [1]. The effect of widening the flammability limits (lower L_d and upper L_g) with temperature for methane/air mixture is presented in Fig. 2.

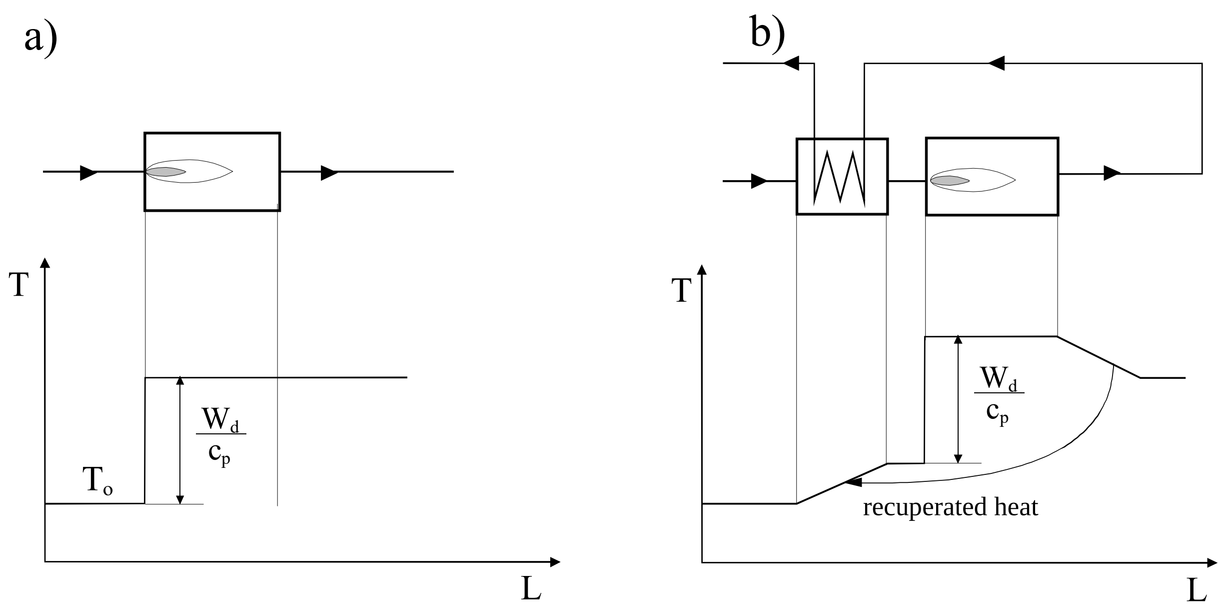

Fig. 1. Temperature distribution during classical combustion (a), and autothermal incineration (b)

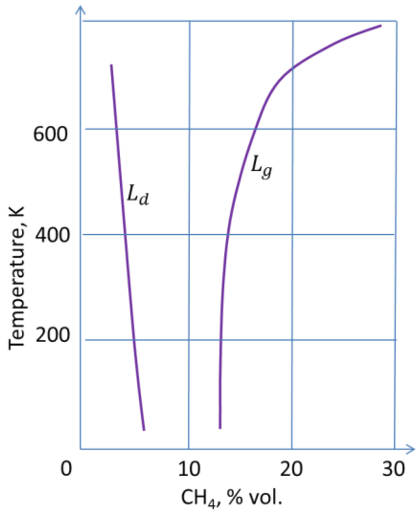

Fig. 2. Influence of temperature on the lower L_d and upper L_g flammability limits of methane/air mixture (based on [2])

Another example of a device exploiting the idea of heat recuperation from flue gases is presented in Fig. 3. The fresh mixture flows in the central tube and is heated up by the flue gases formed during its combustion. The temperature of the fresh mixture at the burner inlet depends (among others) on the heat transfer area of the heat exchanger. Materials durability plays an important role in construction of such devices.

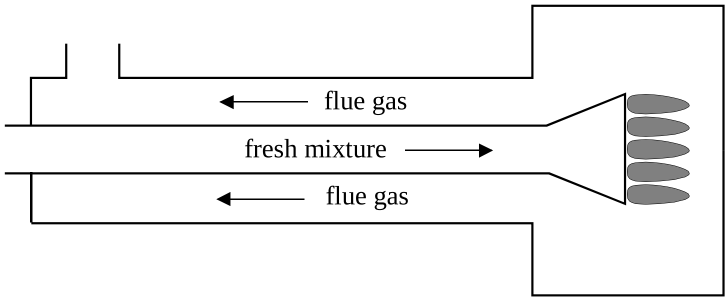

Fig. 3. Schematic diagram of a simple device for thermal incineration of lean mixtures

The aim of the exercise

The aim of the exercise is to examine the influence of heat recuperation on the widening of flammability limits of gaseous mixture.

The test facility

Schematic diagram of the test facility used during this exercise is presented in Fig. 4. Natural gas from gas pipeline flows through a rotameter to a steel tube where it is mixed with a stream of air flowing from a compressed air network. The air flows through a second rotameter. The mixture formed at this stage flows through a stainless steel tube. End of the tube is placed in a hole made in a massive steel cylinder. If the flame front stabilizes at the outlet of the stainless steel tube, the flue gasses flow through the gap between the stainless steel tube and the cylinder hole (cf. Fig. 4). This allows transferring heat to the fresh mixture flowing through the stainless steel tube and increasing its temperature, which in turn widens flammability limits of the mixture.

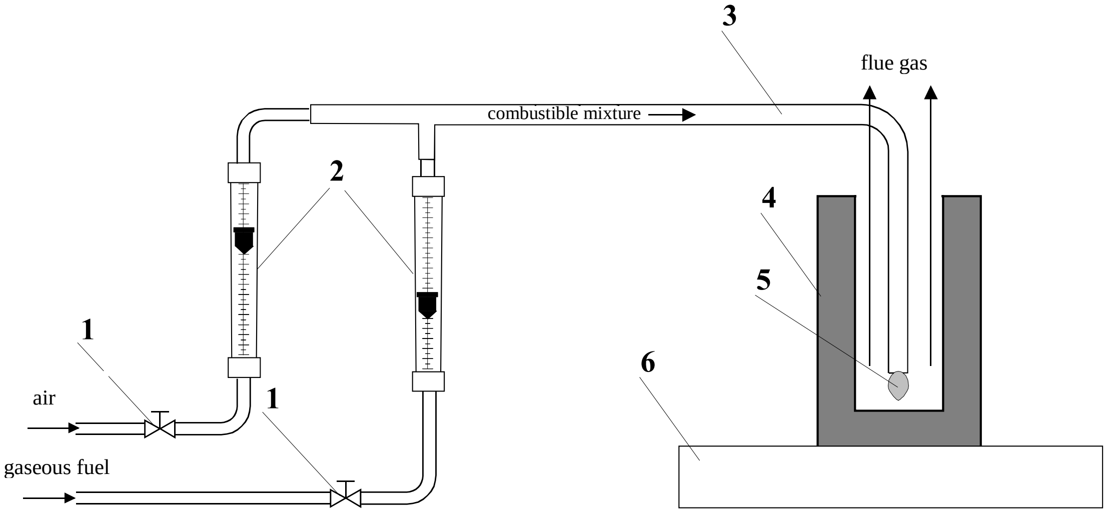

Fig. 4. Schematic diagram of the test facility. 1, flow control valves; 2, rotameters; 3, stainless steel tube; 4, steel cylinder; 5, flame; 6, cylinder basis

Methodology of the measurements

The task is realized in two stages. First the setup without heat recuperation is used. This allows examining the flame behavior during 'regular' operation. In the second stage the setup is changed, so that heat is recuperated from the flue gases and widening of the flammability limits can be observed.

Before starting the experiments check the general condition of the equipment and connections of the gas supply piping and then:

1) open the gas flow control valve gradually so that the flow rate, indicated by the gas rotameter, equilibrates at the upper end of its scale. Ignite the flowing gas,
2) open the air flow control valve and set the flow rate to the maximum possible indicated by the air rotameter,
3) decrease slightly the gas flow rate every 2 minutes and note down the current flow rates. Continue decreasing the flow rates until the flame extinguishes and take note of that event,
4) repeat points 1-3 for lower air flow rates,
5) ask the supervisor to change the setup of the test facility to recuperation mode and repeat points 1-4.

After completing the measurements close the gas and air valves and report this fact to the supervisor. Note down the results of the measurements in Table 1.

Tab. 1. Results of lean mixture combustion

No.	$\dot{V}_g$, m^3/h	$\dot{V}_a$, m^3/h	Presence of a flame
1			
2			

Analysis of the results

Calculate excess air ratio for each measurement:

$$\lambda = \frac{\dot{V}_a}{n_{a,min}\dot{V}_g} \tag{1}$$

where:

$\dot{V}_a$ - air flow rate, $\mathrm{m_n^3/s}$

$\dot{V}_g$ - gas flow rate, $\mathrm{m_n^3/s}$

$n_{a,min}$ - minimum air requirement

In order to calculate $n_{a,min}$ assume that the natural gas is composed of methane (98 % vol.) and nitrogen (2 % vol.). Calculate the total flow rate as:

$$\dot{V}_t = \dot{V}_a + \dot{V}_g \tag{2}$$

Plot the excess air ratio as a function of the total flow rate $\lambda = \lambda(\dot{V}_t)$. The plot should exhibit that there exists a maximum λ for a certain total volumetric flow rate $\dot{V}_t$. Annotate the plot with the values of lower flammability limit of methane-air mixture.

References

[1] Weinberg F.: Advanced Combustion Methods, Academic Press, London, 1986

[2] Kordylewski W.: Spalanie i paliwa, Oficyna wydawnicza Politechniki Wrocławskiej, Wrocław, 2001