

COMBUSTION OF PEROXY-FUELS

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Abstract

The diffusion flames of organic peroxides exhibit quite different characteristics than hydrocarbons. What makes them interesting to study is their fast burning behaviour. As a result the flame temperature enhances and so does the thermal radiation. Due to all these they demand safe handling during processing. However, they can be utilised at several places in different industries where a fuel with fast burning, high temperature and intense radiation are desired. Some of the possibilities to use them as a main or supporting fuel in a wide range of industrial utilities are the major content of this paper.

1 Introduction

Today, the process industries utilise a wide range of liquid and gaseous fuels for combustion. The choice of a particular fuel depends on the economy, efficiency and none the less emissions. When talked about present scenario petroleum fuels, coal, crude oil and sometimes bio-fuels are the obvious choices. As they are cheap, easily available and comparatively less dangerous thus industries rely a lot on them. Because the aforementioned fuels combust relatively slow (under natural burning conditions i.e. $p = 1$ bar), a pressurised input of fuel is necessary to meet the desired production rate. And when do so the supply of oxidiser (air in most cases) has to be proportionately increased in order to make sure that the stoichiometric combustion takes place. An increase in air intake induces the nitrogen as a source of NO_x production in the combustion process. For the reduction of emissions especially NO_x the combustion of fuel in an environment of pure oxygen called as Oxy-fuel combustion is established (Baukal (2003)). This brings additional complexities like safe handling of liquid oxygen, costs and the control of high temperature in the chamber/furnace (Galley (2009)). This article outlines the advantages of using proxy-fuel combustion over the air-fuel and oxy-fuel combustion. The cost justification and emission characteristics of peroxy fuels over the conventional ones are also discussed.

2 Experimental

The fuels investigated are kerosene and for peroxy fuels namely DTBP (Di-tert-butyl peroxide), TBPB (tert-Butyl peroxybenzoate), TBPEH (tert-Butyl peroxy-2-ethylhexanoate) and INP (Diisononoyl-peroxide). Equal sizes of pans (diameter $d = 0.06$ m to 3.4 m) were used to perform fire experiments.

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The measurements of burning rate, flame length and flame temperature were carried out. The details on experiments could be obtained in (Mishra (2010)).

3 Results and discussions

Burning rate

In Fig. 1 the mass burning rate has been plotted against the pan diameter. It can be seen that under atmospheric pressure ($p = 1$ bar) the peroxides are burning 10 to 333 times faster than kerosene (Mishra (2010)). The pressure Δp for a given mass burning rate (or the mass flow rate per unit area, \dot{m}_f'') can be written in the following form

$$\Delta p \propto (\dot{m}_f'')^2 \quad (1)$$

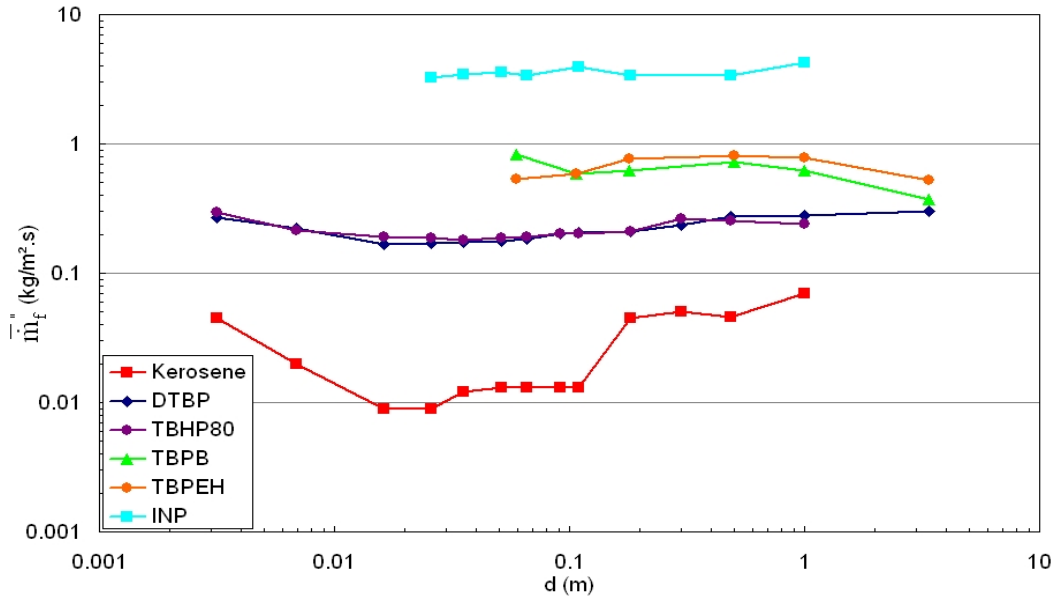


Figure 1: Burning rate of kerosene and organic peroxides under atmospheric pressure

According to the eq. (1) the peroxides deliver 225 (DTBP) to 10^6 (INP) times more pressure than kerosene. This pressure difference in case of kerosene or any other slow burning hydrocarbon fuel is normally achieved by means of a hydraulic pump. The pressure drop depends on the heat flux (see eq. (2)) requirement inside the chamber/furnace which drives the total production or pull rate/day.

$$\dot{q} = \dot{m}_f'' \times \text{Heat of combustion} \quad \text{kW/m}^2 \quad (2)$$

As the heat of combustion is fixed for each fuel the heat flux \dot{q} can only be varied by changing the mass flux \dot{m}_f'' of supplied fuel through a pump. This pumping power (electrical boost in kWh) is saved by a factor of 225 to 10^6 in case of peroxides when compared to kerosene. Additionally 15 to 333 times amount of fuel is also saved for a given heat flux and the combustion of peroxides requires comparatively less amount of air as they contain the oxygen atoms within the molecule itself. The consequence of the reduction in air supply is the lower emission of NO_x .

Flame lengths

The visual result of higher mass burning rate is the larger lengths of flame as can be seen in Fig. 2. The peroxides show 4 to 10 times larger flames than kerosene. In practice the flame length is defined by the following equation

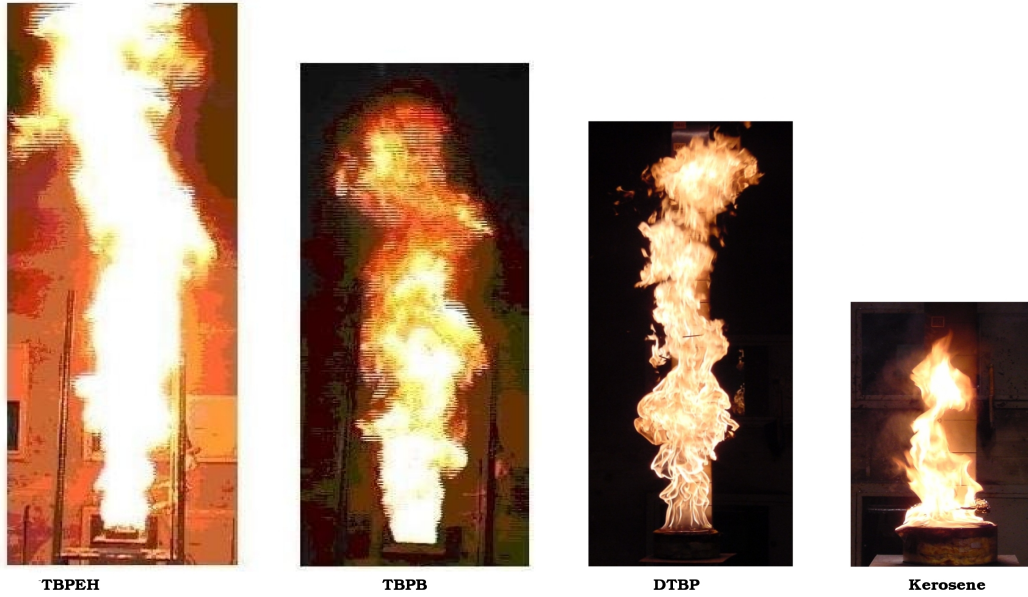


Figure 2: Flame lengths of kerosene and organic peroxides under atmospheric pressure

$$H \propto (Fr_f)^{2/3} \quad (3)$$

where Fr_f is the fuel Froude number can be written as

$$Fr_f = \frac{\dot{m}_f''}{\rho_a \sqrt{gd}} \quad (4)$$

ρ_a is the density of air and g is the acceleration due to gravity. Eq. (4) states the fuel Froude number of peroxide flames is 50 to 100 times higher than for a kerosene flame. Usually for a natural burning fire the initial velocities of fuel vapours leaving the surface lie within a range of 0.02 to 0.1 m/s (Mishra (2010)). For organic peroxides this range was determined to be between 1 to 4 m/s. Due to this rapid initial velocity peroxide flames give an appearance of a jet flame which can be observed in Fig. 2.

Flame temperatures

The averaged temperatures of a DTBP flame measured by a thermographic camera for various pan sizes are shown in Fig. 3 (Chun (2007), Mishra *et al.* (2011a)). A 150 K to 500 K higher temperature than for kerosene has been measured. The thermographic images taken by the camera are shown in Fig. 4 (kerosene and TBPB). Due to this higher temperatures the radiation is also enhanced. If considers radiation emitted by corresponding DTBP and kerosene flames it turns out that DTBP emits more than twice as much of radiation than kerosene (Chun (2010)). Soot production may also have a great influence on the measured temperatures depending on the chemical structure of peroxides.

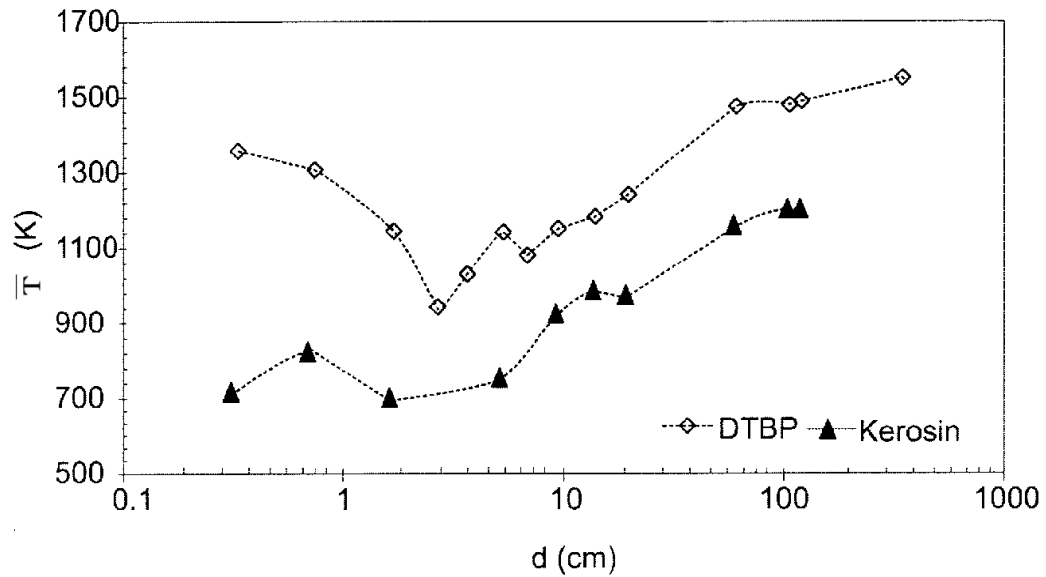


Figure 3: Flame temperatures of kerosene and DTBP under atmospheric pressure

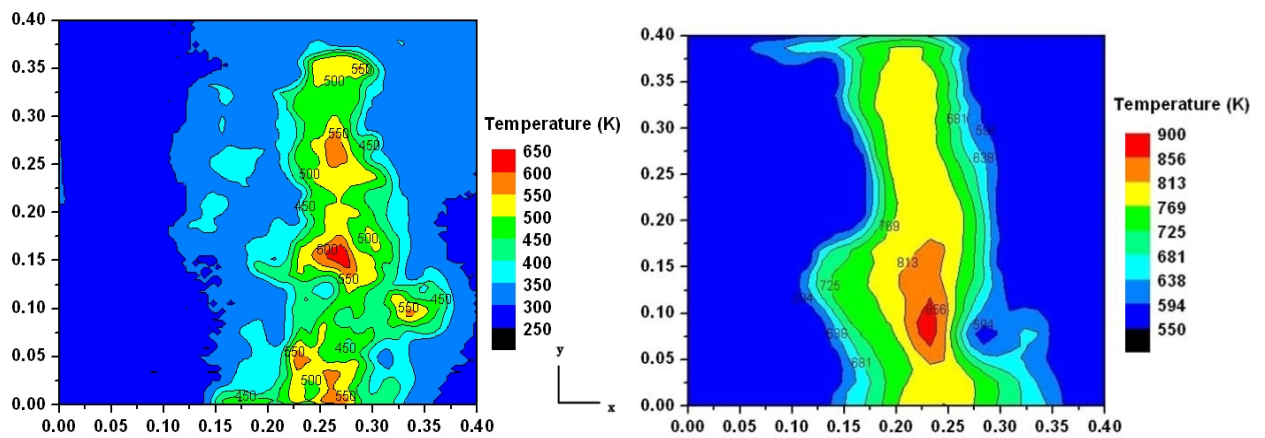


Figure 4: Flame temperatures of kerosene (left) and TBPB (right) under atmospheric pressure

4 Emissions

As higher temperature directly contributes towards NO_x production emissions from peroxide flames are also important to be discussed. As far as the emission of NO_x in peroxy fuel flames is particularly concerned a much more still left to be investigated although a negligible amounts of NO_x were measured for all the flames burning under atmospheric conditions (Mishra *et al.* (2011a, 2011b)). Also the residence time of peroxy fuel elements are expected to be very less in comparison to hydrocarbons to turn the NO_x level further down.

5 Conclusions

Combustion properties of peroxy fuel flames are investigated. A much higher natural burning rate of peroxides leads to the reduction in the amount of fuel for a given heat flux, pump pressure and thus the electrical power. The result of higher burning rates are the larger flame lengths and flame temperatures. Altogether the use of peroxy fuels in process industries is emphasised.

The future work will focus on the use of these fuels in realistic environments. We are therefore looking for industrial cooperations for the further research work.

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