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Method of test for burning velocity measurement of A2L flammable gases

Méthode d'essai pour mesurer la vitesse d'inflammabilité des gaz inflammables A2L

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Foreword

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Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Safety classification and relative flammability properties of refrigerants are a critical part of ISO 817. The flammability limits of refrigerant gas in air, as described in Annex B of ISO 817:—[1)] give a partial measure of the relative flammability. Another dimension of flammability is how fast a substance burns, releases energy and spreads a flame. One can measure the rate at which a flame front moves through a cloud of refrigerant gas in air, or its burning velocity (BV). This document describes one method that can be useful for BV measurement, and thereby better quantify and compare relative flame fronts for some refrigerant classes. In this test, a flame is allowed to propagate upward (vertically) through a well-mixed, quiescent column of a refrigerant-air mixture enclosed in an open-ended glass tube. Optical systems are used to measure the upward velocity of the flame front.

The measurement of BV has been widely used in the past to compare highly energetic fluids, such as motor fuels and rocket propellants. The BV measurement of slow burning fluids, such as ammonia and fluorinated refrigerants can be more difficult to measure due to the inherent instability of a slow flame. The low rate of energy evolution from a slow flame makes it susceptible to quenching from a variety of sources. For slow burning refrigerants, turbulence and convection currents, can break the flame front, and hence quench the flame. In addition, the test chamber surface can quench free radical flame intermediates as well as extract some of the heat necessary for flame propagation. Gas-phase thermal radiation is also important for flames with low burning velocity. These effects are important to note as they tend to diminish and sometimes quench a weak flame.

The use of the vertical tube method for BV characterization of slow burning refrigerants was the subject of doctoral research which was used in Annex C of ISO 817:— and is the basis for this document.[1] In addition, ASHRAE research notes the use and limitations of the vertical tube technique.[2][3] While the basic framework of the method is relatively simple, some sophisticated imaging instrumentation and mathematics are necessary to extract an average local burning velocity separate from the bulk burning speed as the flame progresses up the tube. Since 2004 other laboratories have used the basic principle of vertical tube method and have shown acceptable results for reproducing the measurement of R-32, at 6,7 +/- 0,7 cm/s. Slower burning velocities (i.e. <4 cm/s) become more difficult to measure reproducibility, so variability may increase as flame instability is increasing. The lower burning velocity limit of this method, as described, is between 3 cm/s and 4 cm/s, depending on the actual design and geometry of the apparatus being used. The uncertainty of the measurement of flames that burn more slowly than R-32 has not yet been determined in any multi lab comparative testing. The appealing aspects of this test are the relative simplicity and low cost of its implementation.

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Method of test for burning velocity measurement of A2L flammable gases

1 Scope

This document specifies a method of measuring the burning velocity (BV) of slowing burning refrigerants (< 10 cm/s) for use with other standards that utilize the BV for determining safety classification of refrigerants (e.g. ISO 817) or that use the BV in establishing requirements on the use of slow burning refrigerants (e.g. ISO 5149).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
blends
mixtures composed of two or more refrigerants

3.2
burning velocity
S_u
maximum velocity at which a laminar *flame* propagates in a normal direction relative to the unburned gas ahead of it

Note 1 to entry: This value is expressed in centimetres per second.

3.3
combustion
exothermic reaction between an oxidant (e.g. air) and a combustible fuel

3.4
compound
substance composed of two or more atoms chemically bonded in definite proportions

3.5
flame
space where combustion takes place, resulting in a temperature increase and light emission

3.6
flame propagation
combustion, causing a continuous *flame* which moves upward and outward from the point of ignition without the influence of the ignition source

3.7
flame propagation velocity
S_s
velocity at which the continuous *flame* moves upward and outward from the point of ignition without the point of ignition and without the influence of the ignition source

3.8
flame surface area
A_f
surface area of the *flame* generated during the combustion of the *flammable* gas

3.9
flammable
property of a mixture in which a *flame* is capable of self-propagating

3.10
quenching
effect of extinction of the flame near a surface due to heat conduction losses, absorption of active chemical species and viscous effects of the surface

3.11
refrigerant
fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects it at a higher temperature and a higher pressure of the fluid usually involving changes of the phase of the fluid

3.12
stoichiometric concentration
C_{st}
concentration of a fuel in a fuel-air mixture that contains exactly the necessary quantity of air (approximately 21 % O_2 / 79 % N_2 by volume) needed for the complete oxidation of all the compounds (3.1.4) present

4 General test method

4.1 General

The test method is based on:

a) the initiation of the combustion of the gas, or blends of gases, in a stagnant homogeneous mixture with air contained in a vertical cylindrical tube;

b) the observation and the recording of the flame propagation;

c) determining the surface area of the flame.

The burning velocity is a function of the flammable gas concentration in the total mixture with air. The burning velocity reaches a maximum in the vicinity of the stoichiometric concentration.

This test method involves the use of hazardous substances and therefore requires, for a safe handling and testing, the knowledge of safety parameters and prevention measures. These measures shall be the user's responsibility. However, general safety precautions are given in Clause 8.

4.2 Principle of the test method

The test method consists of initiating the combustion of a homogeneous mixture of a flammable gas (or a flammable mixture of gases) and air, contained in a vertical tube opened at the lower ignition end, and propagating a flame upwardly to the upper closed end; see Figure 1. In the early stages of this propagation, there is a phase of uniform movement during which the shape and the size of the flame are constant.

Taking into account the mass and species balance through the flame front, the burning velocity, S_u, is calculated from the knowledge of the flame propagation velocity, S_s, in the tube and the ratio of the flame front area to its base cross-sectional area. The volume of burned gas per second and per unit area, or the burning velocity, S_u, is obtained by dividing the mixture volume which is consumed per second, at the test temperature and pressure, by the flame surface area, A_f (the subscript “f” denotes the flame). The volume consumption of the mix per second is the volume swept by a cross-sectional area of the flame base, a_f, with a velocity equal to the flame propagation velocity S_s. Formula (1) is used to determine volume consumption per unit time.

$$S_u = S_s \times \frac{a_f}{A_f} \tag{1}$$

where

a_f is the cross-sectional area of the flame base;

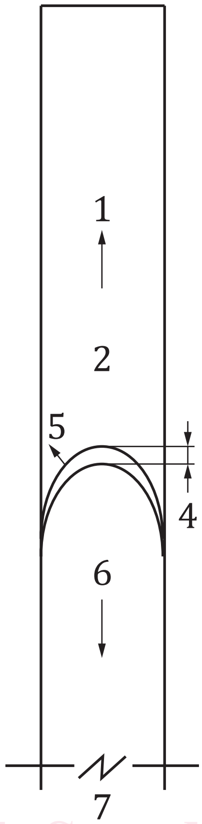
A_f is the flame surface area;

S_s is the flame propagation velocity;

S_u is the burning velocity.

NOTE The cross-sectional area of the flame base is equal to the tube cross-section reduced by the quenching area (the area between the edge of the flame and the tube wall).

At a given temperature and pressure, the burning velocity is only a function of the type of flammable substance and its concentration with the oxidant and is dependent to a limited extent on the experimental apparatus.



Key

1 direction of flame propagation
2 unburned mixture
3 flame front displacement
4 dx thickness of the combustion region
5 S_u
6 burnt gas
7 ignition

Figure 1 — Schematic of the flame propagation in a vertical tube

5 Measurement parameters

5.1 General

The measurement of the burning velocity requires the knowledge of the following three parameters of Formula (1):

a) the flame propagation velocity, S_s;

b) the flame front area A_f;

c) the cross-sectional area of the flame base a_f.

5.2 Flame propagation velocity

The flame propagation velocity in the tube is required for the measurement of the burning velocity. As a condition to the derivation Formula (1), only parts of uniform flame propagation shall be considered in the measurements (constant S_s).

The linear propagation velocity of the flame is obtained from the direct measurement of the flame front displacement determined by two successive images with a known time interval (30 Hz to 50 Hz) of the camera acquisition frequency. More than one succession of images shall be used to check that the flame propagation is uniform. An image treatment is necessary in order to enhance the flame front shape and to locate on both images an identical luminous spot (pixels with equal brightness level) that corresponds to the same location on the front and deduce the flame front displacement. This procedure is proved necessary with low luminosity flames since any uncertainty in the flame front displacement leads to an uncertainty in the flame propagation velocity and thus on the burning velocity.

5.3 Flame front area

The flame front shape cannot be generated by the revolution of a parabola nor by the approximation by an ellipsoid segment, even though in many cases this shape is symmetrical. An accurate method is needed to calculate the flame front area A_f. For an upward propagation, the flame usually shows a symmetrical front surface referred to the tube axis. For a uniform propagation, the shape of the flame front remains constant. Fast moving flames are almost hemispherical, the slower flames are somewhat elongated.

9.7 describes a mathematical and geometrical model to calculate the flame front area. In summary, the flame front profile is marked with fitting points (20 to 40 fitting points) then divided into two or more horizontal sections. The fitting points shall be selected on the rim of the most luminous zone on the flame front.

For each section a polynomial fit equation of appropriate order is made in order to give the best fit curve to the points selected on that section. The best fit gives the minimum deviation of the fit curve to the fitting experimental points. The area of each section shall then be calculated separately by dividing it into many small elementary sections. The area of each elementary section is then calculated from the assumption of a revolution shape., taking into account the bottom edge of the flame not being horizontal.

5.4 Cross-sectional area of the flame base

The cross-sectional area, a_f, of the flame base shall be calculated from knowledge of the diameter d measured at the base of the flame as illustrated in 9.7. In that case, use Formula (2):

$$a_f = \frac{\pi d^2}{4} \tag{2}$$

where

a_f is the cross-sectional area of the flame base;

d is the diameter of the flame base.

6 Test method

6.1 General

Measuring the burning velocity in a tube consists of

a) propagating a flame in a vertical transparent tube, opened at the lower ignition end, closed at the other upper end, and filled with the flammable mixture,

b) measuring the velocity of the flame propagating along the tube, and

c) recording the flame front area with a camera.

Measurements are performed at atmospheric pressure.

The test bench layout is shown in Figure 2. The main elements of the bench are

— mixing vessel,