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Full Flammability Test of gases and gas mixtures in Air.

An Industrial Training Report from CERN

(European Organisation for Nuclear Research)

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The placement in CERN was an enjoyable and very interesting industrial training as there is a great diversity of activities and opportunities. Besides, I thank Mr H. Schonbächer for allowing me to attend Technical Training sessions.

Abstract

This report will introduce the reader to the fundamentals of fire and explosion, and more specifically to the flammability characteristics of gases and vapours. The tests were performed using a standard (DIN 51 649) apparatus designed according to the latest reseach in the matter. The results are realistic and will probably be accepted as new values for safety promotion at CERN.

Introduction:

The purpose of CERN is stated in Article II of the Convention for the establishment of a European Organisation for Nuclear Research.

> **'...The Organisation shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organisation shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published ...'**

Until recently it was considered that published values by Zabetakis[1] and Coward&Jones[2] of flammability limits of gases were correct but Roberts&Smith[3] showed that the previous accepted values were dangerous. During the 1980's CERN also accepted the previous values but work commissioned by CERN and DESY (Hamburg) at BAM indicated that they were in fact much lower.

Therefore as the Large Hadron Collider (LHC) experiments were proposed using mixtures of gases that now seemed to be flammable, it was decided to purchase an apparatus from BAM (DIN 51 649). The Standard apparatus for Full Flammability Test (FFT) was installed in 1994 and thus this paper describes the results obtained with mixtures of gases in general use at CERN or proposed for the LHC. The TIS Commission, Gas and Chemistry section, is responsible for this research.

A detail description of the Standard apparatus used at CERN is given and explains its operational details and procedures as well as the technical details.

The danger of the use of flammable gases is illustrated by some incidents during this century. All flammable gases or vapours have limits of concentration in air beyond which they will not propagate a flame (sustained combustion). The terminology used when describing the characteristics of flammable gases and a description of the factors affecting the flammability limits, are then explained.

The research of the Gas and Chemistry Section at CERN were focused on the flammability limits of gases and gas mixtures of flammable and diluent components. FFT results are summarised on a graph by a curve characteristic of each gas mixture. Tables of result found from these curve characteristics are given.

Since 1990, an International Standard paper (ISO 10156) has established the practical criteria for Full Flammability Test (FFT): a summary of the past research results is included. Further investigations led to the expression of new mathematical tools for the calculations of multi-componets gas mixtures. These formulas give very good approximations of what the facts are, as far as the parameters used are reliable.

Finally, the problems of the use of flammable gases in particle detectors are demonstrated. The main problem of a safety designer in the case of the use of explosive gases in a system, is to know the flammability characteristics of gases to take into account the problem. In the LHC project, the ideal option would be the universal use of non-flammable gas mixtures. The standard (DIN 51 649) Full Flammability Test (FFT) apparatus has helped to find non-flammable gas mixtures. Nevertheless a number of problems were met with the apparatus and are outlined in this report as well as the way in which there were overcome.

I. A Standard Apparatus for FFT (Full Flammability* Test):

The explosion limits are composition limits of a gas mixture within an explosion can propagate. Outside these limits a flame will not propagate. At ambient conditions the explosion limits can be determined according to a standard method described in EEC directives 84/449 annex V part A.11 (flammability* of gases). According to this method the determination must occur in an vertical glass cylinder (minimum inner diameter 50 mm and minimum height 300 mm). Ignition source occur 60 mm above the bottom and is brought about by a standing induction spark. By variation of the gas concentration in the cylinder it is investigated whether a flame detaches itself from the ignition source and propagates independently or not.

The equipment may be used to determine the explosive limits and the explosion range* of gases and gas mixtures at room temperature and atmospheric pressure.

The use of the FFT apparatus to establish the flammability characteristics of gases in mixtures must be considered very seriously and with great attention. The danger involved in the manipulation of the FFT apparatus is always present although the processing of the apparatus is made simple by the use of the computer and its associated programs. The operator observes the ignition reaction through a Pyrex glass which forms the igniton chamber. Although the ignition chamber is made of two Pyrex cylinder tube, the operator should always be rigorous on his choices of test sample* concentrations to be sure to avoid any violently explosive gas mixture.

Essentially, a test mixture* produced by this equipment is caused to move upwards through an ignition vessel (a glass tube). The gas already in the ignition vessel is driven out by the test mixture. With the test mixture stationary, an induction spark is then generated and the system is observed to see whether or not a flame detachment is generated by the ignition electrodes.

The explosion limit is expressed as the proportion of flammable gas in the test mixture at which no flame is produced on five attempts at ignition. The test mixture is produced from the individual components with the aid of Mass Flow Controllers (MFC).

.1 Structure and method of operation of the equipment:

The equipment consists of 6 operational units (see Fig. 1.1 below: A Full Flammability* Test Apparatus):

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* an asterix indicates that a definition of the term is given in the glossary.

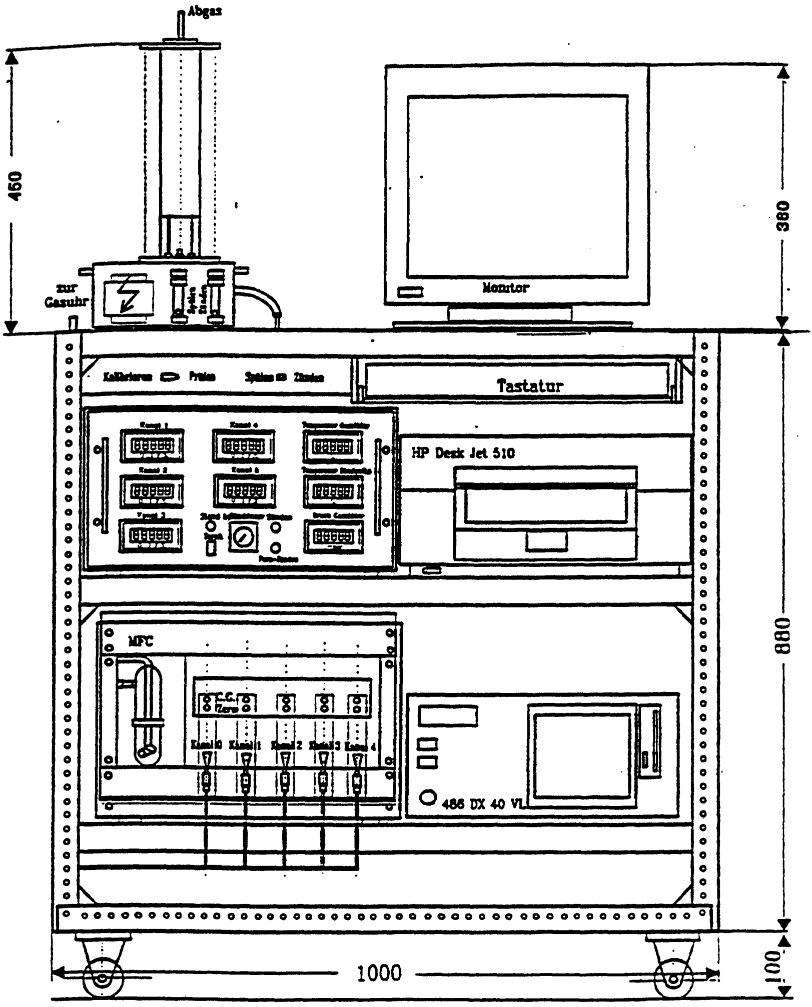


Figure 1.1 Full Flammabilty Test Apparatus [4]

- the gas supply (pressurised gas cylinders with 2-stage pressure reducers, connecting lines and plug connectors),
- the gas metering unit (5 mass through-flow regulators with a mixing vessel),
- the calibration unit (a precision gas meter with pressure and temperature sensors and a pulse generator),
- a display and electronics unit (power supply for the equipment; direct LED display for MFC channels, pressure and temperature; measuring line distribution),
- the ignition vessel and the high-voltage ignition units.

1.11 Gas supply:

The equipment is supplied from pressurised gas cylinders. In an outside gas storage building, a pressure of 3 ± 0.2 bar (abs.) is set with the aid of 2-stage cylinder pressure reducers on the discharge side to increase the precision of the metering unit. The volume flow rates regulated by the MFC depend slightly on the pre-pressure at the MFC and it is therefore recommended that the pre-pressure in all the channels always be the same.

The gases are fed from the cylinder pressure reducers via pipes to the plug connectors at the equipment inlet via Swagelok plug connectors. The MFC channels to be used can easily be selected simply by "re-plugging-in" the pipes.
There are rocker valves directly in front of the individual channels. They make it possible to block the gas flow off with the pipe plugged in. Essentially, only the MFC channel valves that are directly needed for measurement, should be open. This prevents unnecessary loads on the MFC.

1.12 Gas metering unit:

A "mass flow meter (controller)" provides an output signal in the form of a voltage which is proportional to the particle or mass flow rate of a given gas. Unlike other flowmeters, the signal is independent of the pressure and temperature of the gas for the same particle or mass flow rate. The MFC are fitted out at the works manufacturers in such a way that they have a rated measuring range for a calibrating gas. This rated flow range is usually given as the standard volume flow rate of the calibrating gas. The standard volume flow rate, which may be interpreted as the particle flow rate, is unambiguously connected with the mass flow rate via the density of the gas in the standard state (standard density).
The essential gas-specific value which affects the output signal is the molar or specific heat capacity. If an MFC is used for another gas, allowance can be made for its properties via a "gas calibration factor", which is the ratio between the standard volume flow rate of the gas and the calibrating gas for the same reference values.

Nevertheless, the gas calibration factors (partly calculated from specific heat capacities) are often imprecise. As the gas-specific property cannot be covered by a constant factor independent of the reference value, it is not recommended to operate this equipment with gas calibration factors but to calibrate the MFC of the individual channels directly for the gas concerned by means of the existing calibration unit.

As these controllers operate on a thermal measuring principle, it is necessary to allow a warming-up time of about 2 hours in order to achieve a heat balance. The equipment may be left on stand-by, in which case warming up is unnecessary. The 5 MFC channels are fitted on a 10 mm gauge aluminium plate in a shared housing, thus ensuring a heat balance between the individual channels. This prevents temperature differences between the controllers which could result in errors.
Individually, the channels below are installed:

Channel 0 max. standard vol. flow rate 200 cm^3/min, calibrated at the works with H_2
Channel 1 max. standard vol. flow rate 500 cm^3/min, calibrated at the works with H_2
Channel 2 max. standard vol. flow rate 2000 cm^3/min, calibrated at the works with H_2
Channel 3 max. standard vol. flow rate 2000 cm^3/min, calibrated at the works with N_2
Channel 4 max. standard vol. flow rate 2000 cm^3/min, calibrated at the works with O_2

A suitable MFC channel must be selected for the production of a gas mixture. In order to reduce metering inaccuracies to the minimum, channels with lower through-flow rates should be selected for components with smaller proportionate volumes.

The individual controllers are run at a voltage from 0 to 5 V (***reference value*** = 0 to 100%). This condition corresponds to a standard volume flow rate of 0 to full-scale deflection. The internal control electronics process this set value, compare it with a measurement of the standard volume flow rate and control a valve at the controller outlet. The MFC also issues the measurement of the standard volume flow rate as an analog signal of 0 to 5 V. This analog signal is further processed in the display and electronics unit (0 to 1 V signal) and is shown in the program as an ***actual value*** (0 to 100%).

The individual controllers can be directly zeroed by means of a small screwdriver on an adjusting screw ("zero"),in the housing. The channel indicator should then show "0.0000 V". During this process the rocker valves must be closed to prevent errors caused by "leakage currents" at the valve seals.

When a gas mixture is produced, the individual gases flow through the MFC then in a mixing manifold, in which they are premixed. There is an additional glass mixing vessel downstream of the mixing manifold to ensure a uniform mixture. The outlets of the mixing manifold are arranged in such a way that channel 0 is nearest to its outlet and channel 4 is the furthest away (see Fig.1.2). When making a mixture of several components it is best to meter the highest-volume component (usually air) via channel 4. This gas then flows through the entire manifold and ensures the intimate mixture of all the components, thus preventing dead spaces.

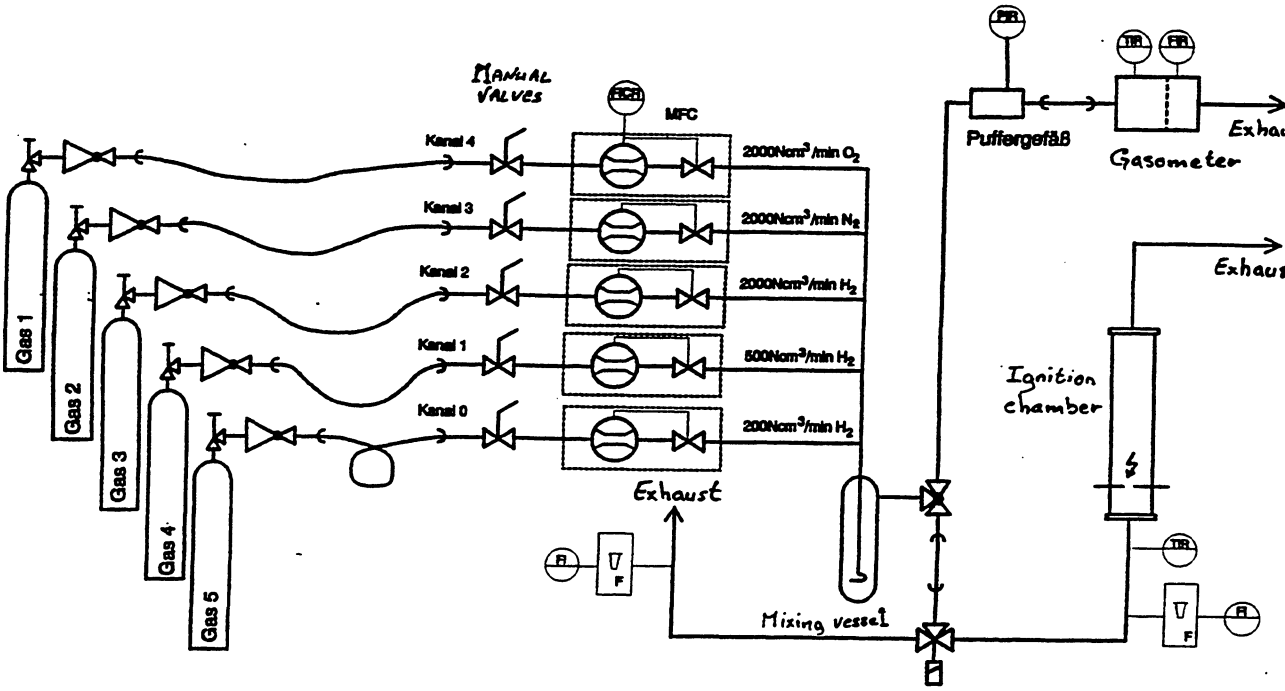


Figure 1.2 Gases distribution [4]

N.B.: The seals in the MFC are made of Viton, a plastic which is highly resistant to organic chemicals. Nevertheless, after work with gases which attack plastics (e.g. coolants, hydrocarbons, ethers, etc.), the system should be immediately flushed with nitrogen.

1.13 Calibration unit:

The calibration unit calibrates the MFC channels for the gases concerned. A precision drum gas meter made by Messrs. Ritter is used (for technical data and method of operation, an instruction for use in the equipment file is available at TIS / CERN).

The use of the gas calibration factors given in the MFC manual are not recommended for precise measurements,but Mass Flow Controller (MFC) channels intended for measurement should be calibrated using the calibration unit with the gas concerned.

The gas flows directly from the MFC channel to be calibrated into the gas meter and moves a drum with a precisely known volume which is connected to a counter and an electronic pulse generator. One electronic pulse corresponds to a volume of 10 cm3. A full drum revolution (1000 cm3) gives 100 pulses.

As only the gas volume (the number of electric pulses), but not the standard volume flow rate, is measured, it is necessary to detect the temperature and pressure in the gas meter and the time in order to calculate the standard volume flow rate, which is done according to the ideal gas law:

$$dV/dt = N_{im} * 0.01\ l/t \qquad (1)$$

$$dV_N/dt = dV/dt * (273.15\ K/t) * (p/1.013\ bar) \qquad (2)$$

dV/dt = volume flow rate (l/min)
N_{im} = number of pulses
t = time >(min)
dV_N/dt = standard volume flow rate (l/min)
p = pressure in gas meter (bar)
T = temperature (K)

For gases, this calculated standard volume flow rate is proportional to the mass flow rate . To calibrate the individual channels it is necessary to find the standard volume flow rate depending on the measurement (actual value) supplied by the MFC channel (drawing a calibration curve). In proper operation of the controllers the actual value differs only very slightly from the predetermined set voltage (reference). The reference is therefore usually used directly for the calibration curve.

The drum gas meter operates with a separating fluid, usually distilled water, and must be set up exactly horizontally (spirit level). The water level and the direction of the gas meter affect the volume of the gas chamber in the drum and hence the accuracy of measurement of the gas meter.
It is therefore essential to check the level of the gas meter and the spirit level before every calibration process.
When water is used as the confining liquid it must be remembered that some gases dissolve readily in water (e.g. ammonia, S02, etc.) and therefore a different confining liquid must be used for these.
For gases with moderate water-solubility (e.g. C02) it is sufficient to flush the gas meter about 30 min. with the gas to attain equilibrium. Gases which are hardly water-soluble (e.g. air, rare gases, hydrocarbons, etc.), flushing is unnecessary. Calibration may be started immediately.

The gas temperature is measured directly in the gas meter using an electronic temperature probe (type AD 592 A, Messrs. Conrad Electronic) which has been calibrated at two temperatures (0 and 40°C) in an ice or water bath. 2 calibrated ordinary mercury thermometers were used as comparaison thermometers (resolution 1/100 K).

The inlet pressure in the gas meter is measured in its inlet line using a pressure gauge with a piezo-resistive pressure sensor (GDH 12, Messrs. Greisinger). This pressure sensor is calibrated *in vacuo* and at atmospheric pressure. The comparison pressure gauge used was a precision type (Messrs. Wallace & Tiernan, cl. 0.06) and a precision mercury thermometer.

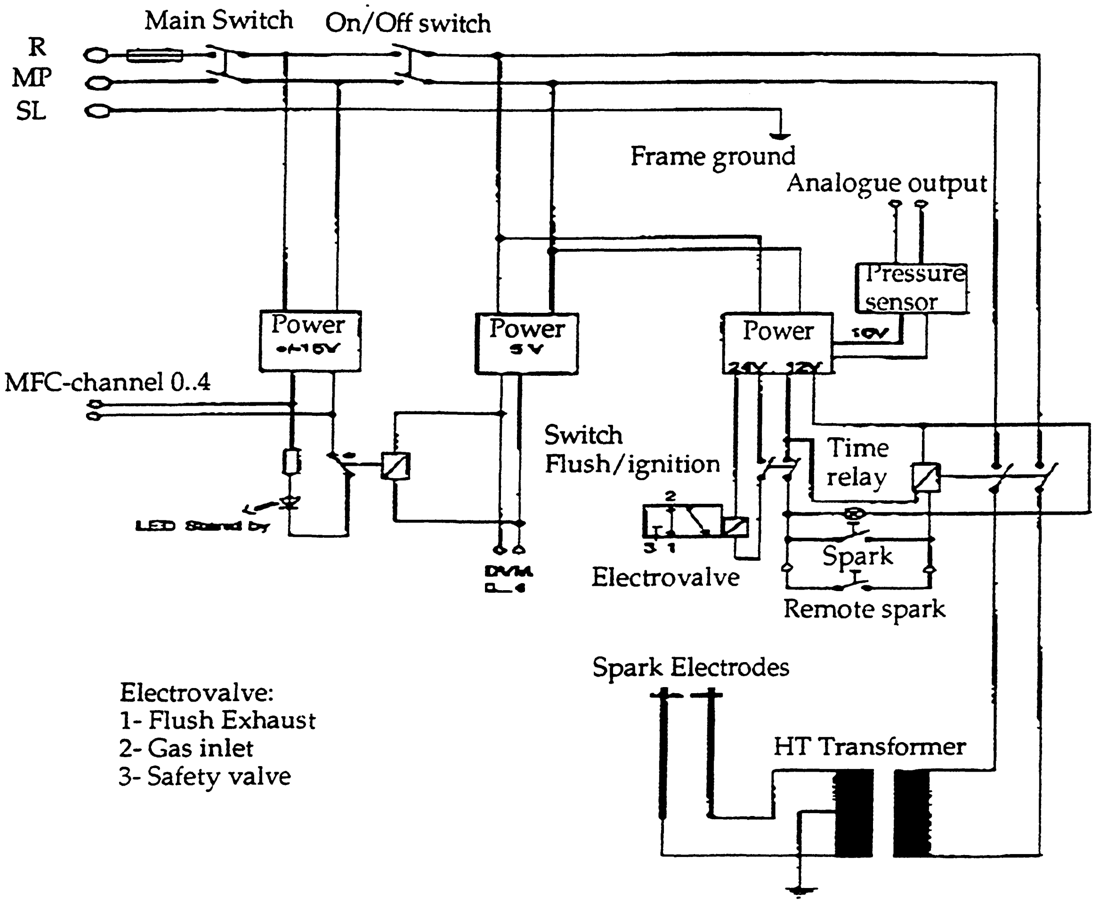
1.14 Display and electronic unit:

The display and electronic unit consists of the power supply to the equipment, a series of digital voltmeters used for indication and 2 boards bearing the circuitry for the MFC channels and the control and measurement detection boards of the computer.

The power supply comprises the mains sections below (see circuit diagram 1.3):

• Double mains unit ± 15 V d.c.; 1.5 A	to power the MFC, the temperature measurement probes and the stand-by LEDs
• Main units +5Vd.c.;3A	to power the digital voltmeters and the gas meter pulse generator

- Main units + 24, + 12, + 10 V d.c., 2 A to power the magnetic valve on the ignition vessel (24 V), the time relay for the high-voltage ignition sparks (12 V) and the GDH 12 pressure measuring unit (10 V).

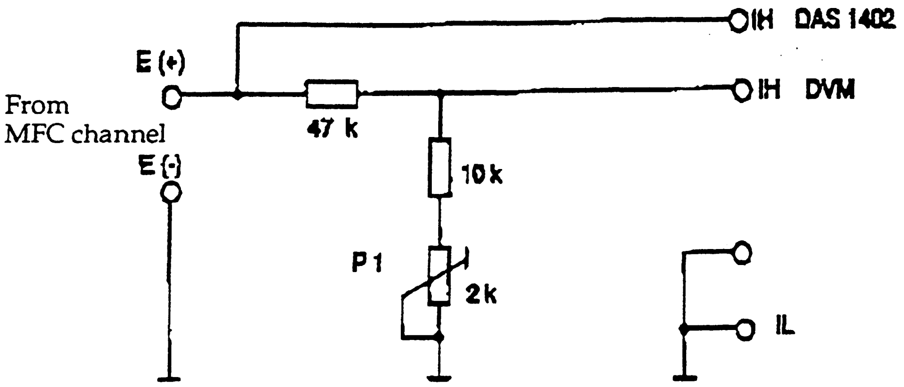


Electrovalve:
1- Flush Exhaust
2- Gas inlet
3- Safety valve

Circuit diagram 1.3 Equipment for the determination of explosion limits [4] - Power supply.

The first two mains units have a shared earth and are connected to the computer earth. The third mains unit is not earthed. On stand-by, all the power supplies (including that of the computer) are switched off, and only the MFC power supply (+ 15 V) is operative.

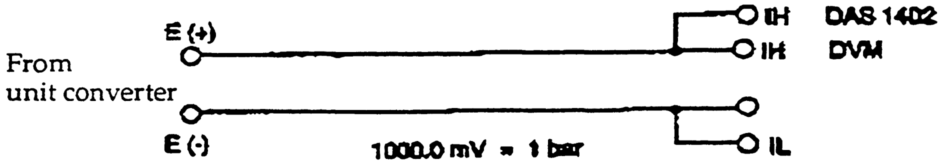
The actual values of the 5 MFC channels are shown in the display unit by 5 digital voltmeters ($4^1/_2$ digits). To this end, the analog signals of the MFC (0-5 V) are reduced with the aid of a voltage dividers to 0-1 V (see circuit diagram 1.4). A display reading of "1.000" corresponds to the full-scale deflection of the MFC channel concerned.



P1 - Precision spinner Potentiometer
scale: full gas flow = 1000.0 mV

Circuit diagram 1.4 MFC - channel indicator [4].

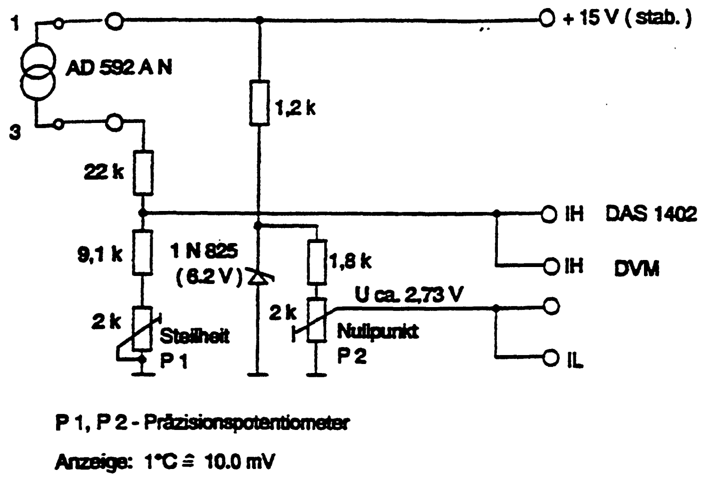
Two further digital voltmeters show the centigrade temperatures in the ignition vessel and gas meter. The eighth digital voltmeter block display the inlet pressure of the gas meter in mbar (see circuit diagram 1.5). All the displays operate independently of the computer measurement detection.



Circuit diagram 1.5 Pressure indicator [4].

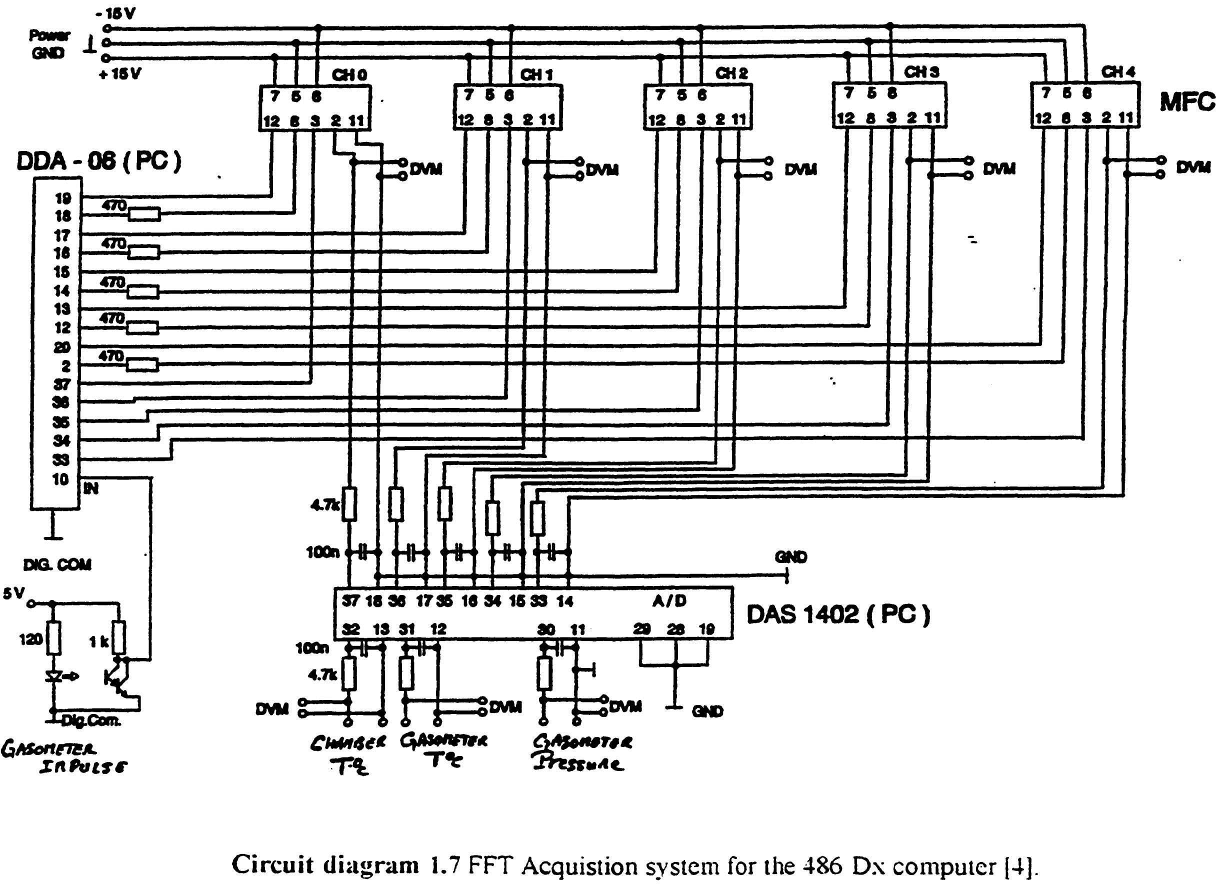
The time relay sets the ignition spark duration and is fitted on the front panel of the housing of the electronics unit. It is an electronic relay which applies a primary voltage of 220 V a.c. to a high-voltage transformer (secondary 2 x 7.5 kV) after a switching pulse. The application of the primary voltage and hence the duration of the ignition spark can be timed on the relay (monoflop function). It should be 0.5s according to DIN 51649. To this end, the time relay must be run in "OS" mode, time range 1s (see operating instructions available at TIS / CERN for the time relay).

The temperatures in the gas meter and the ignition unit are measured by means of type AD 592 AN semiconductor sensors. These are precision sensors supplying a current of 1 µA/K on the output side. They are run in a bridge circuit for slope and zero point correction (see circuit diagram 1.6).



Circuit diagram 1.6 Temperature Measurement [4]

The display circuitry (digital voltmeter on the front panel of the electronics unit) was fitted on a separate board. Two further boards connect the computer to the MFC channels. Both boards are connected via a flat cable. The layout of the plug connectors to the computer, the MFC channels, the ignition unit and the gas meter may be seen on the layout diagrams 1.7 below.



Circuit diagram 1.7 FFT Acquistion system for the 486 Dx computer [4].

1.15 Computer for control and measurement acquisition:

1.15.a Hardware

The computer used for control and measurement acquisition is an IBM-compatible PC (Messrs. Vobis Microcomputer GmbH) with an 804866DX processor having a beat frequency of 40 MHz, a 170-byte fixed disc and a Veso local bus. The installation includes an SVGA monitor, an HP Deskjet ink-jet printer and a serial mouse. Together with the hardware was purchased a standard software package consisting of the MS-DOS 6.2 operating system, Windows 3.11, Works and Ways for Windows .

There is also a type DDA-06 PC insert card (Messrs. Keithley Instruments) in the computer to control the MFC controllers (for technical data see DDA-06 manual at TIS / CERN). This is a 12-bit analog-digital converter (D/A) card having 6 separately adjustable D/A converters with latch and 3 * 8-bit digital inputs and outputs (I/O). On the hardware side it is set to an output voltage of 5 V. One digitisation stage on the card corresponds to 1.22 mV. It is possible with this card to preset the control voltages (references) of the MFC channels.

In addition, 5 bits of the A gate of the digital I/O to block or, when required, release the MFC. Such a facility for blocking the channels independently of the applied control voltage is provided by the "valve closed" input on the MFC. The inadvertent opening of controllers during operation, e.g. through ripple voltages, is thus prevented. One bit of the B gate is used to receive and count the pulses of the gas meter. The clock inside the computer is used as a time base for this counting process. The timer function used has a time resolution of 0.01 s.

There is also a type DAS-1402 PC insert card (Messrs. Keithley Instruments) to acquire the MFC measurements (actual values). It is a 12-bit A/D converter card with 8 differential inputs. On the software side it is set to a single-pole input voltage of 5 V. One digitisation stage of this card corresponds to 1.22 mV. The voltage signals from the individual MFC are acquired with the aid of this card (inputs 0 - 4). It is also used to acquire the temperature of the ignition vessel (input 5), the temperature in the gas meter (input 6) and the signal from the piezoresistive pressure gauge (input 7). A circuit layout of the card can be see from the appendix 3 followed by the different interface connections between the cards and the working blocks.

1.15.b Software:

The software provided is a minimum package enabling the individual functions of the equipment to be accomplished. The results of measurement must be acquired and recorded manually. A set of programs are used for the management of the entire equipment:

- Gasurhr1	Compiled Quickbasic program needed to find calibration curves for the MFCs.
- Gemisch2	Compiled Quickbasic program needed to produce 2-component gas mixtures.
- Gemisch3	Compiled Quickbasic program needed to produce 3-component gas mixtures.
- Gemisch4	Compiled Quickbasic program needed to produce 4-component gas mixtures.
- Spuelen	Compiled Quickbasic program needed to flush the MFC and the explosion vassel at the end of the measurements.

Then advanced programs were created in collaboration with a German University for the ease of the operator and for a quicker operation of Full Flammability Test:

- Calib	Compiled Modula2 program needed to find calibration curves for the MFCs.
- Dosier	Compiled Modula2 program needed to produce up to 6-component gas mixtures.

"Spuelen", "Calib" and "Dosier" programs are the most use during the operation of the apparatus.

.16 Ignition vessel and high-voltage gas ignition unit:

The ignition vessel and the high-voltage ignition unit were made in BAM's Laboratoy. Their dimensions and operation correspond to the test equipment described in DIN 51649 and the draft CEN standard "Explosion limits".
This functional unit consists of the individual parts below (see Fig.1.8):

1. Housing.

2. High-voltage transformer (primary 200 V and secondary 2 x 7.5 kV, shortcircuit current 20 mA) to generate the induction function. The transformer is fitted laterally beneath the ignition vessel in the housing so that the h.v. lines are very short and lead directly to the ignition electrodes.

3. Timing relay.
   The duration of the ignition spark can be adjusted in the timing relay, which switches the primary voltage of the h.v. transformer. the relay is fitted in the front panel of the electronics unit housing.

4. 3-way magnetic valve (24V, 1 A).
   The magnetic valve controls the gas flow. It makes it possible for the test mixture to flow through the test vessel ("Flush" setting) or to feed the test mixture directly into the exhaust gas line ("Test" setting).

5. Float flowmeter to monitor the gas flow.

6. Temperature measuring probe to determine the temperature of the test mixture. Contrary to DIN 51649, the probe for measuring the temperature of the test mixture is not fitted in the ignition vessel. As the equipment is designed only for measurements at room temperature, it is sufficient to measure the gas temperature directly beneath the ignition vessel at the inlet pipe. The sensor is adhesively secured to the inlet pipe at that point.

7. Ignition vessel with the ignition electrodes.
   The ignition vessel consists of aluminium base and cover plates, a 300 mm long internal glass tube with a spacing of 60 mm and an outer protective glass tube. The glass tubes are fitted in the aluminium plates with Teflon seals. The steel ignition electrodes are fitted at a height of 60 mm. The cover plate has a large aperture with an aluminium cover and a connector for the exhaust pipe. In the event of a powerful reaction the aluminium cover opens to prevent any damage to the glass container.

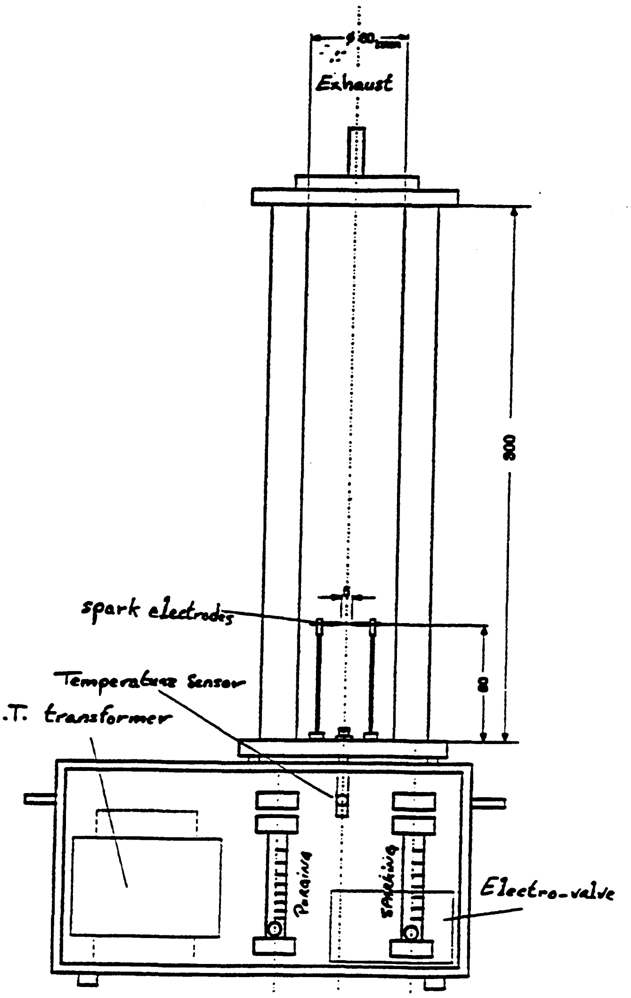


Figure 1.8 Standard Ignition Chamber [4].

The ignition electrodes are at a high voltage during the ignition process. It is important to set the equipment to "stand-by" before the glass tubes are removed to prevent danger. This switches the primary voltage to the H.V. transformer off.

Pictures of the entire equipment are shown in Appendix 3.

2 Starting the equipment up and making tests:

21 Brief description of the process:

At the begining of a test the test mixture flows through the test vessel from below and drives out the gas already there ("Flush" setting). To ensure quantitative clearing the equipment must be flushed with at least ten times the volume of the test vessel, i.e. with 8 litres of test mixture. For a total standard volume flow rate (the sum of the standard volume flow rates of all the components) of 2.0 l/min, the flushing time is about 4 min. Thereafter the magnetic valve is switched over. The test mixture now flows directly into the exhaust line. The now "quiescent" test mixture in the ignition vessel is ignited and the reaction observed. The magnetic valve must be reset after ignition. A new test mixture can be programmed using the software.

.22 Start-up:

The equipment is started up in the steps below:

1. Connect to the 220 - 230 V a.c. mains.
2. Switch the mains switch on the rear wall of the electronics unit on.
3. Switch the "Run" switch on the front panel of the electronics unit on. All the electronics unit displays now light up.
4. Switch the computer on.
5. Allow a warm-up stage (about 2 hours). If the equipment was already in stand-by mode ("Run" switch off, "stand-by" LED lit up), there is no need for warming up.
6. Flush the gases to be used through the MFC channel.
7. Set the MFC zero points. The rocker switch must be closed. The electronics unit indicators then display 0.0000 V.
8. Prepare the gas supply.
   Connect the pressurised gas cylinders containing the gas to be calibrated via a pressure reducer and a pipe to the plug connector of the channel to be calibrated. Set a pressure of 3 bar (abs.) at the pressure reducer outlet.

23 Calibration of MFC channels:

If the channels have not been yet calibrated with the gases to be tested, this must be done. To this end:

1. Connect the gas meter to the 1 /2" connector of the equipment via a pipe, which must not be linked. Connect the 5-pin diode cable to the gas meter.
2. Set the gas meter to a horizontal position using the spirit level.
3. Check the liquid level in the gas meter. If necessary, top up with distilled water with the overflow open until the water level reaches the upper edge of the overflow pipe. The water level in the overflow pipe must be stress relieved with a drop of flushing medium.
4. Lay the gas meter exhaust pipe in an extractor. The end of the pipe must never be laid directly in the extraction aperture of the extractor as errors in measurement may occur through the underpressure there.

5. Set the three-way cock at the top left of the equipment to "calibrate"

6. Start up the "Gasuhr 1" calibration program.

7. Open the rocker valve of the channel to be calibrated.

8. Enter the channel number, the MFC channel reference (in %) and the desired gas volume (in litres). For higher volume flow rates, the recommended volume is 3 litres and for lower rates 1 litre.

9. Start up the calibration process, which runs automatically and the gas meter pointer moves.

10. At the end of the calibration process, note the reference and actual values and the standard volume flow rate. If the controllers are working properly, the reference and actual values differ only slightly. Malfunctions during the calibration process can be detected by means of the standard deviation of the actual values (as a rule, they are smaller than 0.2% (abs.)).

11. To calibrate a channel fully, it is best to calibrate at 10 points from 0 to 100 %.

12. From the references and the relevant standard volume flow rates calculated from the measurements, draw a calibration curve. The latter must be linear.

13. Terminate the program after calibration and close the rocker valve.

14. Flush with nitrogen or air if you have calibrated with gases which could attack the MFC Viton seals, using the "Spuelen" program.

II. Liquids, Gases and Vapours:

2.1 Industrial use of Gases:

During this century, the use of gases greatly increased with the development of the industry. Depending on their characteristics, the use of gases has expended into multiple applications such as: the Tungsten Inert Gas (TIG) welding and cutting in steel and iron industry; the refrigerator and the car temperature regulator with gases such as Freon, 1,1,1,2-tetrafluoro-ethane or in medecine, the use of liquid nitrogen for cooling and providing inert atmosphere and the use of oxygen gas and anaesthetic gases for hospital patients. Gases have been used for the lightening and the heating,or in dirigibles (e.g. the helium and the hydrogen).

The number of accidents rise as flammable gases use increased. Initially, the main use of hydrogen was as a component in town gas and subsequently as lighter than air in flying machine and the much safer non-flammable, non-toxic helium, but more expensive was sustituted.

On 4 January, 1966, at Feyzin[6] refinery in France, a leak on a propane storage sphere ignited, caused a fire which burned fiercely around the vessel and led to a boiling liquid expanding vapour explosion (BLEVE).

The operator has opened two valves in series on the bottom off-take line from the sphere in order to drain off an aqueous layer at the bottom of the vessel. When this operation was nearly complete, he closed the upper valve and cracked it open again. There was no flow and he opened the valve further. The blockage, which was presumably hydrate or ice, cleared, and propane gushed out, but the operator was unable to close the upper valve. He did not think at once to try to close the lower valve and by the time he attempted this, this valve also was frozen open.

The alarm was raised and steps were taken to stop traffic on the nearby motorway. A vapour cloud about 1 m deep spread towards the motorway. It is believed that a car about 160 m distance on the motorway may have been the source of ignition. It was afterwards found with its engine not running but its ignition on and may have been stalled by taking in a propane-rich mixture at the air intake. Flames appeared to flash back from the car to the sphere in a series of jumps.

The sphere was enveloped in a fierce fire. The pressure relief valve on the sphere lifted and the escaping vapour ignited.

The storage installation of which the sphere was a part consisted of four 1200 m2 propane and four 2000 m2 butane spheres (see Picture 2.1). The fire brigade was not experienced in refinery fires and apparently did not cool the burning sphere, presumably on the assumption that the relief valve would protect it. They concentrated instead on cooling the other spheres. About one and a half hours after the initial leakage the sphere ruptured, killing the men nearby. A wave of liquid propane was flung over the compound wall and flying fragments cut off the legs of the next sphere, which topped so that its relief valve began to emit liquid.

The accident caused 18 deaths and 81 injuries and the destruction by fire of the spheres as well as other damage.

A great number of major accidents in the process industries[5] could be related. Another one was on 24 February, 1978 a derailed 45 ton propane railtank car exploded in the small town of Waverly, Tennesse, hurling fragments and creating a fireball. Twenty buildings were set alight and people ran from them with clothes alight.
Twelve people were killed and about 50 were injured.

All these incidents demonstrate how the neglect of details can lead to the risk of major hazards.
Most chemists know that mixtures of fuels and oxidizers release energy once the reactions are initiated. This does not prevent someone else from mixing a fuel that he does not recognize as a fuel with an oxidizer that he does not recognize as an oxidizer. The result is always the same, and the person responsible is always amazed that he has violated a well-known natural law. Even though the person is well-intentioned, the resulting destruction is still very real.

Picture 2.1 Fire at the storage vessels of Feyzin refinery, 1966 [5]

2.2 Use of gases at CERN:

The organisation has two main sectors, the physics and the industrial support. Both use gases and gas mixtures of all kinds, the main ones are methane, ethane, propane, butane, nitrogen, carbon dioxyde, helium, argon and oxygen.

The use of gases in the industrial sector at CERN is similar to the use of any other industries, i.e. welding, cutting, inerting, etc ... The physics sector uses large amount of gases and particularly flammable gases in the detectors. In the past, hydrogen was used in large amount in the famous bubble chambers, 2m and BEBC (N.B. at BEBC the chamber held approximately 36 m^3 of liquid hydrogen). Today, flammable gas mixtures are used mainly in smaller detectors called the wire chamber detectors. These detectors are either used in the underground experiments in the tunnel or on floor in the surface experimental halls where the beam line goes up.

The cryogenic workshops at CERN uses liquid helium at 4 °Kelvin to cool prototype magnets for the new high energy accelerator (Large Hadron Collider) in which large amounts of helium will be used. Liquid nitrogen is used in large quantities as a source of gas purging before flammable gas use and in the liquid form for heat screens in the super conductivity magnets and radiofrequency cavities. Also some of the calorimeter detectors use liquid argon to detect charged particle. Many other applications could be related.

The main problem at CERN is the use of flammable gases in physics where the normal safety regulations in terms of security cannot be entirely followed as would mean that the chamber would not work.

2.3 Safety at CERN:

The safety at work is regulated by the Legislation papers generally in accordance with those of the member states. The document "Safety Policy at Cern" (SAPOCO 42, Revision: September 1994) regulates the safety at CERN and the "CERN Flammable Gas Safety Manual" [6] regulates specifically the use of flammable gases. This manual gives rules for safe design and operation of flammable gas systems. Further restrictions in the use of flammable gases in underground experiments at CERN are stipulated in "CERN Safety Instruction No. 38" [6]. The total amount of saturated aliphatic hydrocarbon gases (such as methane, ethane and iso-butane) is limited to 100 kg. If however a mixture of these gases with inert gases (such as argon and carbon dioxide) can be shown to be non-flammable, then there is no limitation on its use.

The Technical Inspection and Safety Commission (TIS) is responsible for drawing up the regulations, enforcing their application, providing advice and, in general, stimulating actions designed to improve occupational health and safety conditions and to protect the environment.

The TIS commission encourages and maintains a high level of co-operation and exchange of information on Safety among CERN's Divisions by its activities and via various committees dealing with safety.

The technical and supervisory personnel must develop a better knowledge of the fundamentals of fire and explosions not only to apply in plant design and daily plant operation, but also to deal quickly with process malfunctions.

The control of experimental and test installations using flammable gases is done in co-operation with the Flammable Gas safety Officer (FGSO) and by the Gas and Chemistry section of TIS Commission. The pride of CERN is its Large Electron Positron Collider (LEP) where the limit of 100 kg of Flammable gas in the underground experimental areas is imposed.

In view of the installation of the new collider LHC (Large Hadron Collider) again with large experimental underground areas and because of the limiting quantity of flammable gas, mixtures of flammable with inert gases continues to be of great interest, and to enable accurate and safe elimination of flammable gas, an apparatus for Full Flammability* Test (FFT) was ordered from the Bundersanstalt für Materialforschung und-prüfung (BAM) in Berlin. It was installed then tested CERN.

Since installation, two technical student have worked on FFT on the standard (DIN) apparatus and provided information on the characteristics of mixtures of these flammable and inert gases of interest to physicists.

III. Flammability of Gases and Vapours in Air:

Explosion indices play an important role in explosion prevention and protection. In field of gas explosions the greater part of these indices can be determined in accordance with standard methods and can be regarded as fixed parameters although they are apparatus and test dependent. In general it is therefore possible to use published data if available. Nevertheless one should consider the situation in which the explosion index is to be used. It is important to compare the process conditions with the conditions prevailing in the test method.

A great number of publications has been made on flammability limits of gases and vapours; some of the more notable ones are "Purge limits for paraffin hydrocarbons in air and nitrogen", P.Roberts & D.B. Smith, "Flammability Characteristics of combustible gases and vapours", U.S. bureau of Mines, Zabetakis and "Limits of flammability of gases and vapours"Coward&Jones. The method of measuring flammability limits and the apparatus used in the earlier work are described in appendix 1.

3.0 Definitions: "LEL and UEL"

Not all mixture of combustible gases with air burn. The concentration of the flammable gas in air plays an important role of the flammability of the gas mixture. Fig 3.1 illustrates three zone delimited by the Lower Explosion Limit (LEL*) and the Upper Explosion Limit (UEL*). Below the LEL concentration, the mixture is too lean to burn; the energy from combustion of one particle being dissipated before it can activate another particle to propagate the flame. Above the UEL concentration, the mixture is too rich to burn; that is , the oxygen is used up in the combustion of one particle leaving insufficient oxygen to burn the next adjacent particle of fuel. Products of combustion surrounding the first particle tend to quench the flame.

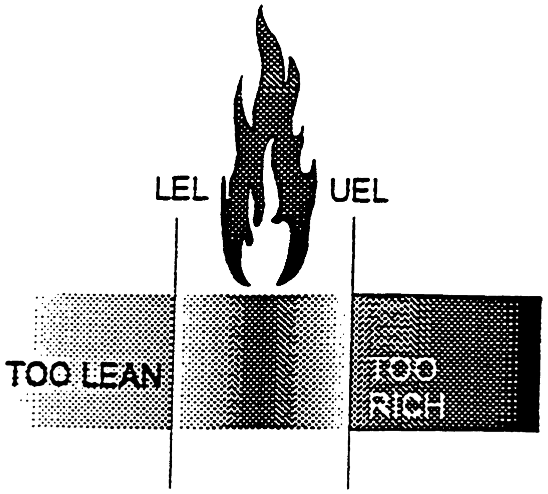


Figure 3-1 Limits of Flammability

The UEL could be also explained as the minimum limiting concentration of oxygen needed for the combustion of the sample* for instance, a bottle filled of alcohol is lighted on his neck, the alcohol inside the bottle will not burn at all but a flame will be visible just over the neck of the bottle. This illustrates that the concentration of oxygen inside the bottle is not sufficient to burn the substance, on the contrary as the alcohol vaporised in air through the neck of the bottle, then the concentration of oxygen is sufficient to allow the combustion.

All gas compositions between lower and upper limits are flammable. The energy produced by the combustion reaction is a minimum at the limits and proceeds with increasing magnitude to the maximum energy at the stoichoimetric composition at which the propagation of a flame through a gas is dependent on a number of factors, such as the pressure, temperature, composition, thermal conductivity, density of the heat generated, and the type of event that iniated the reaction.

3.1 Effect of Increased Oxygen:

Air is a mixture consisting of 20.94%vol oxygen, 78.09% vol nitrogen and 0.93%vol argon together with lesser amounts of carbon dioxide and noble gases. Increasing the oxygen content of air has only a small effect on the lower explosive limit and a large effect on the upper explosive limit. At the lower limit there is already an overstochiometric concentration of oxygen to enable total combustion of the fuel, whereas at the upper limit it is the lack of oxygen that prevents a flame propagation.

In the case of methane, the UEL increases from about 15% in air to 61% in pure oxygen.

.2 Effects of the Ignition Energy:

The energy of the ignition source plays an important role in the flammability of gases. The electrical energy (spark energy) required to ignite a mixture is function of the particular gas and of the concentration air. The minimum usually occurs close to the stoichiometric mixture. Figure 3.2 .shows how the spark energy affects the ignitability of methane-air mixtures. Table 3.1 gives the minimum spark energy to ignite a selection of gases in air.

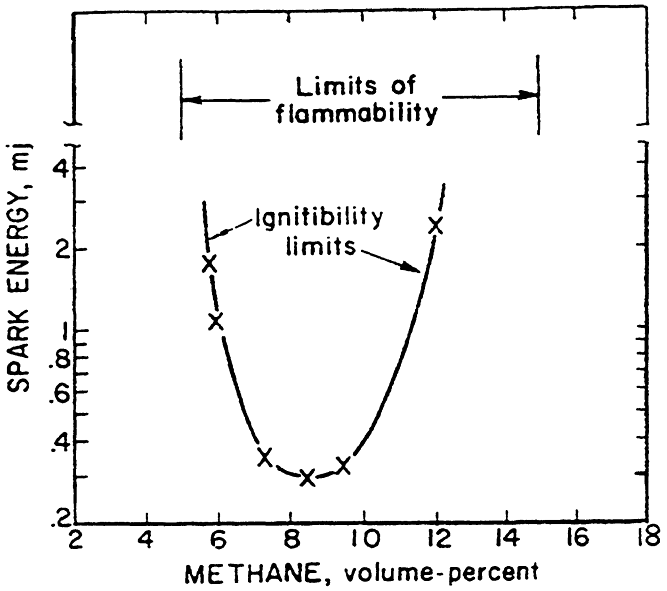


Figure 3-2 Effect of the electrical ignition energy on the flammability limits of a Methane-Air gas mixture [1].

Gas	Autoignition temperature °C [7]	Minimum ignition energy (mJ) [5]
Hydrogen (H2)	560	0.019
Methane (CH4)	600	0.29
Ethane (C2H6)	515	0.24
Acethylene (C2H2)	305	0.02
Ethylene (C2H4)	425	0.12
Propane (C3H8)	470	0.25
n-Butane (C4H10)	365	0.25
iso-Butane (C4H10)	460	-
n-Pentane (C5H12)	285	-
n-Hexane (C6H14)	233	0.25

Table 3.1. Autoignition temperature* and minimum ignition energies of selected gases (at stoichiometric concentration).

.3 Influence of design of test apparatus:

It can be seen in Fig.3.3 that the 60 mm tube used in the BAM apparatus should give reliable results.

Coward and Jones used a cylindrical tube with a diameter of 50 mm, but more recent work stated by Roberts and Smith has shown that the wall quenching effect is significant.

Roberts and Smith carried out tests in a spherical vessel with a diameter of 0.6 m and their results were in excellent agreement with results obtained in a 3.65 m diameter sphere. Values of total inertisation of flammable gases mixed with nitrogen obtained in a vertical tube apparatus by Zabetakis and Coward & Jones compared with the values obtained in the 0.6 m diameter sphere by Roberts and Smith are shown in table 3.2. The figures given by Roberts and Smith give substantially lower limiting concentrations of flammable gas in the mixture than the previously accepted limits of Zabetakis and Coward & Jones.

	Reference		
Gas	Roberts & Smith [3]	Zabetakis [1]	Coward & Jones [2]
	Maximum % of Flammable gas in Nitrogen		
Methane	11.4	14.7	13.9
Ethane	6.0	7.2	7.2
Propane	5.1	6.0	6.2
Butane	4.2	5.6	5.5

Table 3.2. Flammability limits of flammable gases in nitrogen
A comparaison of results of different sources.

Values of flammability limits are experimentally determined and the results are dependent on the test apparatus and the method of carrying out the test. Apparatus designed to promote upward flame propagation gives wider limits than those obtained in apparatus in which flame propagates downward.

The size and geometry of the ignition chamber also affect the flammability limits. The propagation of a flame depends upon the transfer of energy from the burned to the unburned neighbouring gas and at the limiting concentration the amount of energy transferred is just enough to maintain flame propagation. Therefore the ignition vessel has to be wide enough to prevent quenching of the gas mixture from its walls: Figure 3.2 below, shows that the diameter of 60 mm.of a cylindrical tube is just the right size give good results.

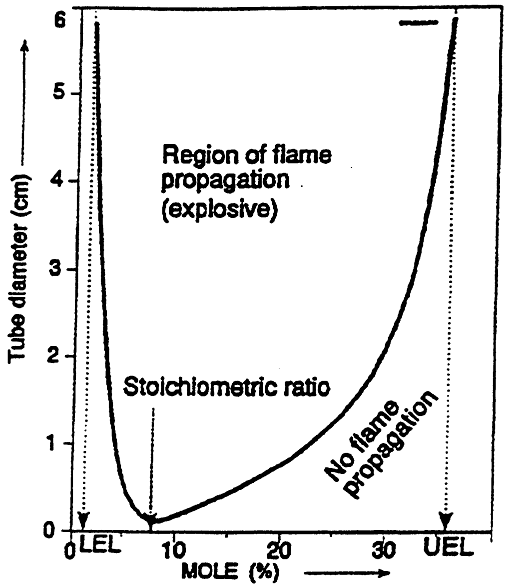


Figure 3.3. Explosion* (UEL and LEL) as a function of the cylinder diameter for a stoichiometric ethylene-air mixture (T = 25 °C. P = 1 Bara) [8].

4 The Effects of Pressure:

Flammability limits are extended by increasing in pressure and gases that are just non ignitable at low pressures become ignitable at higher pressures. A rise in pressure increases the concentration of fuel and oxygen with the result that the density of thermal energy released in the combustion increases.

This is important when particle detectors or other systems are designed to work at pressures greater than atmospheric, although pressures greater than 10 bars are exceptional.

Figure 3.4 shows the effect of pressure on the flammable limits of natural gas in air at 28°C.

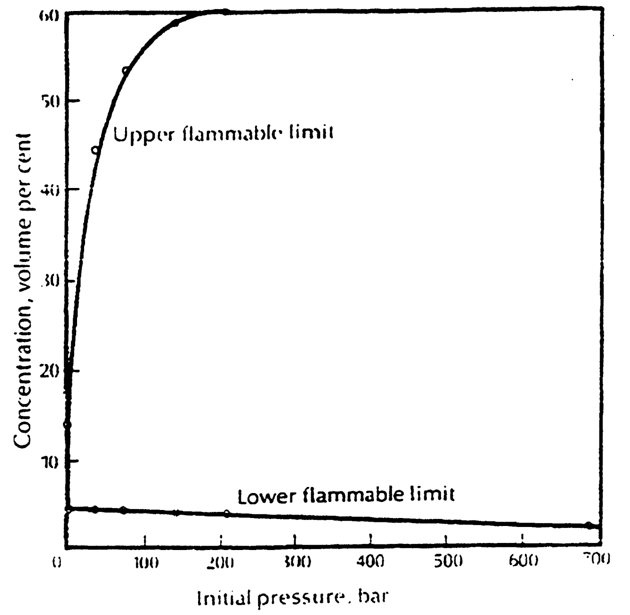


Figure 3.4. Effect of pressure on flammable limits of natural gas in air at 28°C [9]

The flammability envelope closes at the lower end because the gas is of too low concentration to support combustion.

At pressures below atmospheric the flammability limits converge until the mixture becomes non-flammable. Figure 3.5 shows the effect of sub atmospheric pressures on the flammable limits of methane at three different temperatures. At 20°C methane is non-flammable at a pressure below 0.16 bar.

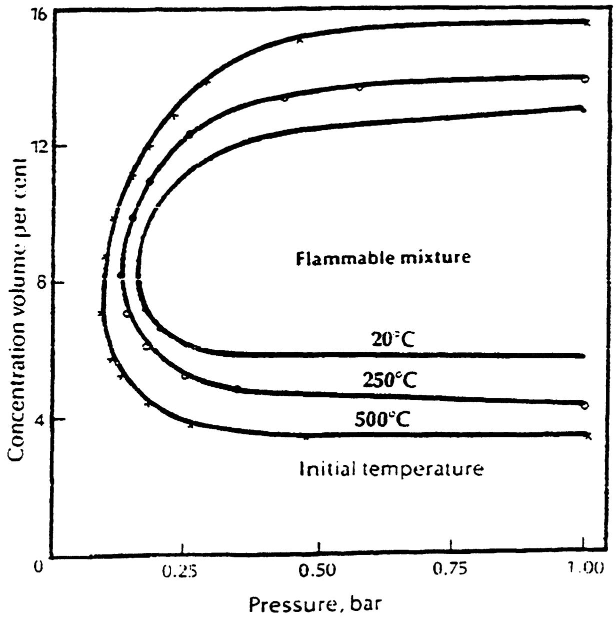


Figure 3.5. Effect of sub atmospheric pressure on the flammability limits of methane in air at different temperatures [9]

3.5 Effects of Temperature:

Increasing the temperature also extends the flammability range. At the limiting concentration the energy generated in the combustion is just sufficient to ignite the next layer of unburned reactants, but when the temperature is increased the molecules in the mixture possesses a greater initial energy and less energy is required from the burning gases to activate further molecules.

When the temperature is increased to the *autoignition temperature** then the more easily ignitable mixtures become spontaneously combustible. The gas mixture ignite without the application of an external energy source and may ignite on a hot surface. Thus it is of great importance when considering the surface temperatures that may occur in a particle detector.

The lower and upper flammability limits decreases and increases respectively more or less linearly with temperature. The rate of change is fairly slow and normal variations in the ambient temperature have little effect on the limits.

Figure 3.5 shows schematically the variation of the flammability limits and the autoignition temperature* of a mixture of flammable gas and air. Autoignition temperatures are given for some gases in Table 3.1.

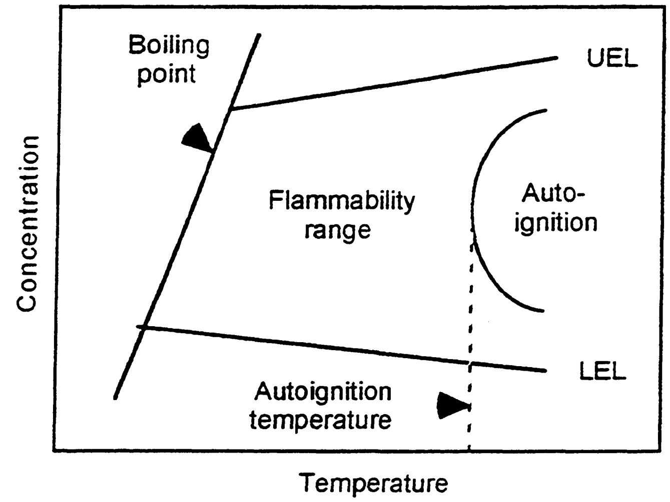


Figure 3.6.Relation of vapour pressure with temperature in determining the Lower and Upper Flash Points* and their relation to, respectively LEL* and UEL*. MIT* and explosive range also shown.[1]

3.6 Composition:

The plot in Figure 3.6 shows how the molecular weight (or the fuel concentration per molecule) is related to the lower limit for paraffin hydrocarbons in Air. Hydrocarbons with molecule weight of 198, tetradecane $C_{14}H_{30}$, have a lower flammable limit of about 0.5 volume percent in air compared to a molecule weight of 16, for methane CH_4, with a lower limit of about 5.5 volume percent in air. Thus, molecules that contain a higher density of fuel will have depressed lower flammable limits compared to molecules that contain lower fuel densities. The volatility* (or vapor pressure) of the fuel plays an important role in the ease of ignition.

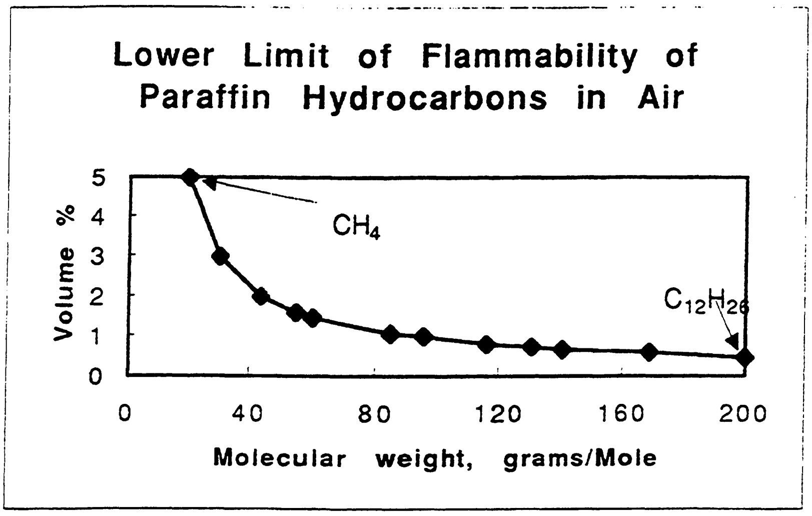


Figure 3.7 Effects of the weight of Hydrocarbon gases on their respective LEL*[10].

.7 Thermal Conductivity:

Suppose a very small spherical group of molecules of a flammable mixture gets hot enough to begin to react. As this spherical group of molecules on the left of the Figure 3.7 burns, the product gases are heated. They expand to diameter, d, and are surrounded by a layer of unburned gases.

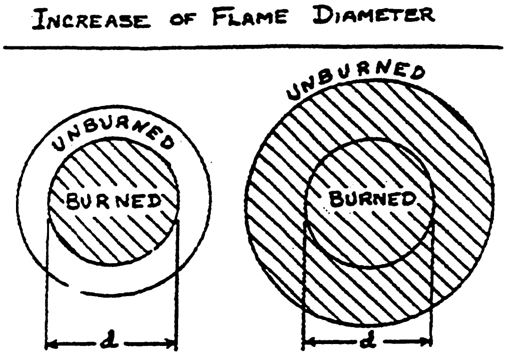


Figure 3.8 [5]

The expansion takes energy from the cluster that reacted causing the unburned products to cool somewhat. If the temperature at the interface between the burned and unburned gases is greater than the minimum threshold temperature for flame propagation into the unburned layer, the reaction will continue into the unburned layer; but if the interface temperature is below the minimum threshold temperature, the reaction will slow down and be quenched by the colder unburned gas layer.

The rate of heat production and the rate of heat dissipation to the unburned gas will determine whether the minimm threshold temperature at the interface will be exceeded, causing flame propagation, or whether the threshold temperature will not be reached, causing flame quenching and cessation of reaction.

3.8 Effects of inert diluents:

Nitrogen being a natural component of air may be considered as the "natural" diluent for flammable mixtures. However other inert gases or vapours can be used with similar effect. The influence of diluents on the flammability of methane can be seen in Figure 3.8. It can be seen that a greater percentage volume of Argon than nitrogen is required to narrow the flammability limits of methane to the point where the mixture is no longer flammable. Water vapour (steam) and carbon dioxide exerts greater inerting effects than nitrogen. This effect can be explained by the fact that water vapour and carbon dioxide have greater thermal capacities than nitrogen and so reduce the flame temperature to a greater extent.

The curve for helium shows that the thermal capacity is not the only factor determining the quenching effect of an inert gas as although helium has a thermal capacity equal to argon, it is a more efficient flame extinguisher, due apparently to its high thermal conductivity. It seems, however, that the effect of different thermal conductivities are insignificant unless the difference is great. The thermal conductivity of helium is about nine times higher than the thermal conductivity of argon.

Halogenated hydrocarbons have a stronger effect on flame suppression than that due to their thermal capacities alone. This effect is due to their ability, after decomposition, to combine with free radicals produced in the initial stages of the fuel/oxygen reaction and so conclude the oxidation process.

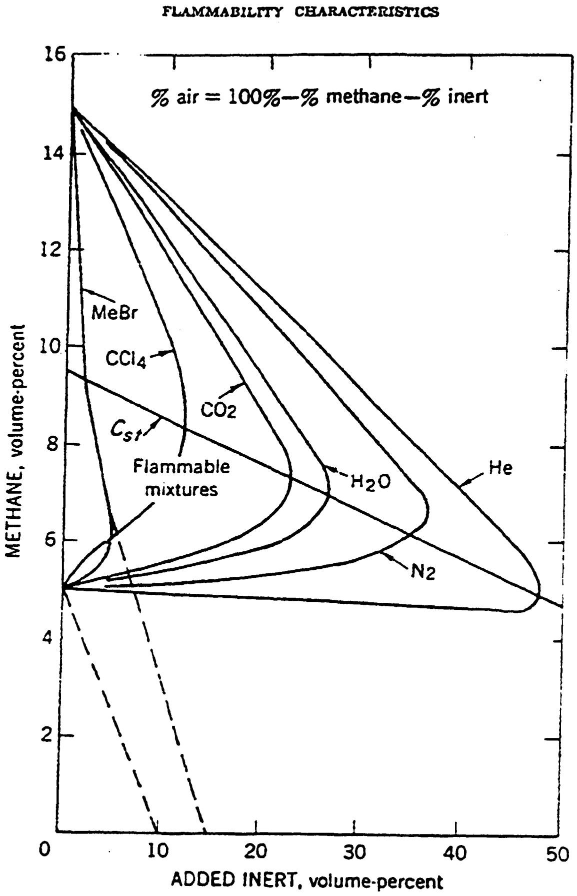


Figure 3.9. The influence of inert diluents on the flammability* of methane [2].

The maximum concentration of a flammable gas in an inert diluent, for which the mixture is just not flammable in air, is called the value of *total inertisation* or the T_{ci}-value*

.9 Purity of Gases:

The previously accepted values from Coward & Jones and Zabetakis were published in the fifties and the sixties respectively although some of the work quoted dates from before the World War II. The gases used in the tests were of questionable purity (for example a high content of water vapour, which exerts a considerable inerting effect), the flow metering methods were not so accurate and the experimental methods were probably not so rigorous as those in use today, as there were no agreed standard method.

Nowadays, precise purity can be ordered from gas supplier, although most of the purchase are gases with standard purity decided by the industry.

Table 4.1 and 4.2 in the following chapter gives the purity of each gases use during our tests.

IV. Research and Measurement:

The Full Flammability Tests results are mainly based on binary combination gas mixtures and more specifically with the following Hydrocarbons gases: Methane, Ethane, Propane, iso-Butane, n-Butane. Some test were also carried out with Hydrogen.

As diluents, the following inert gases were used : Argon, Neon, Nitrogen, Helium, Carbon Dioxide, Carbon Tetra fluoride, Sulphur Hexafluoride and the Freon R134a. A great number of binary flammable/inert gas mixture were tested and for each, the flammable curve characteristic was drawn and forms the basis of all of our results.

From them, a certain number of results can be deduced such as: the Total Inertisation value (Tci-value*) of each combination of a flammable gas with an inert gas, new values for the coefficient of equivalency relative to Nitrogen (Ki-value*) for each independent inert gas, etc.

Therefore these new results forms a new data base to be compared with older values given by the International Standard 10156 for the approximation and the calculation of the flammability of "Flammable/Inert" gas mixture, or by Robert&Smith in the 4th International Symposium on "Loss Prevention and Safety Promotion in the Process Industries", etc.

.1 Practical Results and Measurements:

When bought, gases are delivered and conditioned in bottle with a specific purity reference such as: 24, 36, 45, 20 ... Those numbers correspond to the percentage of pure gas in the bottle, the remainders being generally water vapour, oxygen and derived gases due to micro-reactions such as "oxidation" or "reduction" within the gas.

Flammable Gas	Purity
Hydrogen (45)	99.995%
Methane (35)	99.95%
Ethane (24)	99.4%
Propane (35)	99.95%
iso-Butane (25)	99.5%
n-Butane (25) & (30)	99.5% & 99.90%

Table 4.1 Purity of Flammable gases used for FFT at CERN.

Inert Gas	Minimum Purity
Argon (46)	99.996%
Neon (40)	99.990%
Nitrogen (45)	99.995%
Helium (46)	99.996%
Carbon Dioxide (30)	99.90%
Carbon Tetrafluoride (45)	99.995%
Sulphur Hexafluoride (30)	99.90%
Freon R134a (27)	99.7%

Table 4.2 Purity of the Inert gases used for FFT at CERN.

In table 4.1, It can be seen that the n-Butane was tested with two different purities. This was done to determine in what proportions, a variation of the purity of a gas affects the results of our researches. It was seen that, within limits, the purity does not affect the results enough to take this factor into consideration for the purpose of CERN's particle detectors.

The Tci-values of all the gas mixture tested, the LEL and UEL of each flammable gas measured at CERN are shown in table 4.3; table 4.4 gives the new values of the coefficient of equivalency of inert gases relative to Nitrogen and compares it with the actual Ki-values according to ISO 10156.

	Flammable gas						
Inert gas	H_2 45	CH_4 35	C_2H_6 24	C_3H_8 35	i-C_4H_{10} 25	n-C_4H_{10} 25	n-C_4H_{10} 30
Ar (46)	-	6.15	3.05	2.76	2.4	2.16	2.28
Ne (40)	-	9.2	4.37	3.45	3.26	2.70	2.74
N_2 (30)	-	9.9	4.94	4.25	4.1	3.26	3.55
He (46)	-	11.86	5.45	4.41	4.15	3.55	3.58
CO_2 (30)	-	22.45	9.09	7.95	7.95	6.45	6.52
CF_4 (27)	-	33.4	13.0	11.76	9.5	9.1	9.28
SF_6 (30)	-	50.4	20.4	20.4	19.43	14.97	16.97
R 134a (27)	-	11.98	7.14	6.7	5.75	6.15	5.8
LEL	3.5	4.4	2.4	1.8	1.55	1.4	1.45
UEL		16.9	14.6	10.4	8.4	8.9	9

Table 4.3. Proposed Total Inertisation value (%) of Flammable gases in different Inert diluents.

Inert gas	N_2 (30)	Ar (46)	Ne (40)	He (46)	CO_2(30)	CF_4 (27)	SF_6 (30)	R 134a (27)
Ki-value(1)$_{(\mathbf{new})}$	1	0.65	0.85	1.1	1.95	2.75	4.70	1.45
Ki-value **(from ISO 10156)**	1	0.5	0.5	0.5	1.5	1.5	1.5	-

Table 4.4. Proposed diluent coefficient of different inert gases relative to **Nitrogen**.

(1) the given Ki-value calculated from experimental measurements correspond to an Average value.

A detailed table of all the Ki-values calculated is shown in appendix 4.

Significant difference can be observed from table 4.4 above, between our new calculated Ki-values and those given in ISO 10156. This shows the problem of evaluating gases characteristics.
The latter parameters were deduced from the FFT curve characteristic results. A record of all the curves is shown in appendix as it follows:

- Methane vs Inert gases :	Appendix 6M
- Ethane vs Inert gases:	Appendix 6E
- Propane vs Inert gases:	Appendix 6P
- iso-Butane vs Inert gases:	Appendix 6I
- n-Butane vs Inert gases :	Appendix 6N

1 a The Flammability Characteristics of iso-Butane/Inert gas mixtures:

To see how the flammability data is acquired, Fig. 4.1 gives typical flammability curves showing the effects of diluents on a hydrocarbon gas. In this example iso-butane gas is mixed sucessively with Sulfur tetrafluoride (SF6), 1,1,1,2 tetrafluoroethane, Carbon dioxide, nitrogen and argon.
The following basic values were determined:

LEL = 1.55%

UEL = 8.4%

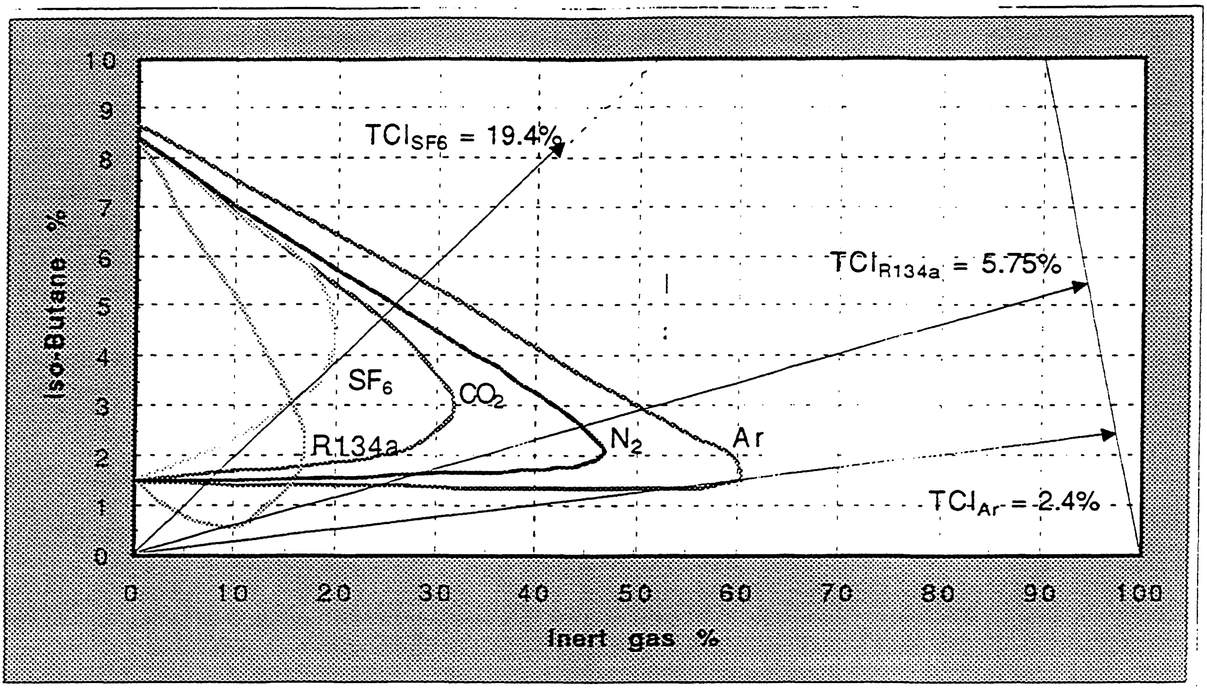


Figure 4.1 Proposed Flammability Characteristics of iso-Butane / Inert gas mixtures at 20-25 C and atmospheric pressure.

The Tci-values of iso-butane mixed with the different inert gases are determined on the graph with the tangent line of the curve characteristic as shown above. All of these results that can be checked from the curve characteristics in the appendix (6M,6E,6P,6I & 6N) are summarised in this chapter IV, table 4.3 & 4.4. The shape of the different curve characteristic observed from Fig. 4.1 are generally similar except for the Freon (R134a) one that is explained later. Depending on the choice of the diluent, the addition of the inert gas makes the flammable range (UEL - LEL) of the gas mixture narrower until the UEL and LEL are joined thus the gas mixture has no more flammable range and can be considered as a non-flammable gas mixture.

Considering mixture of flammable and inert gas only (without air), the tangent to the flammable zone has a slope corresponding to the ratio of flammable to inert gas (ref. Tci-value* of the gas mixtures that are "just" non-flammable in air ("just" is referring to the gas mixture with the concentrations of flammable/inert/air correspond to the coordinates of the tangent point between the line and the flammability curve).

Each inert gas has a capacity of reducing the flammable range. This capacity characteristic also called "inerting capacity", is linked to the Tci-value and can be calculated with reference to the inerting capacity of a given inert gas:

This value was called the "Ki-value" and is always relative to the inerting capacity of the nitrogen gas $Ki_{N2} = 1$. (ref. table 4.4)

In the case of the freon gas, the flammable range is reduced as in the case of the other inert gases, but ever more shifted downward. This effect with argon gas can be noted too but only slightly. Finally this seemingly effect on the LEL should be taken in account in some cases:
for example, a mixture of 1.4% (ref. Fig.4.1) of iso-butane in air that is non-flammable, is stored in a container with electrical devices. Accidentally, a pipe of freon R134a passing through the container has a leak and releases the gas in the iso-butane/air gas mixture. The resulting concentration of the freon gas in the gas mixture can raise the value of about 2-3% at least, therefore the gas mixture is flammable.

4.1 b Comparaison of results:

A great number of investigations were made on the research of the flammability* limits of gases and gas mixtures through this century. Some of the researches were published all over the world and accepted as a basis for the use in industries. Coward&Jones (1952), Zabetakis (1965), from the United States Department of the Interior, Bureau of Mines and Roberts&Smith (1983), in the International Symposium on Loss Prevention and Safety Promotion, England were people to the fore in this field.

A comparaison between the proposal of Roberts&Smith and our results are shown on the following table 4.5

	Reference	
Gas	Roberts&Smith [4]	FFT results(2)
	Maximum % of Flammable gas in **Nitrogen** (Tci-value)	
Methane	11.4	9.9
Ethane	6.0	4.9
Propane	5.1	4.2
Butane	4.2	3.5

(2) this work with the Standard DIN apparatus.

Table 4.5 The limits of Flammabilty of Flammable-Inert gas (N_2) mixtures.
A comparaison of results from different sources

Some of the values cited are taken from work published more than forty years ago and should be used with care. The limiting value of 2% ethane in argon from tests carried out at BAM in 1983 - 84 [11] would appear to be very low and not in line with those from other sources. This does indicate the problems in arriving at "correct" values.

Table 4.6 shows the Tci-value of binary gas mixtures measured in early work [18],[13] and in the last ten years for [5],[17],[12],[14],[15],[16] references, including those of this paper. Values in bold are from CERN and were already given in table 4.3. Note that the results performed in BAM[14] and at CERN with the same DIN apparatus are in accordance and show that the method used is repeatable and reliable. Note that early sources were too optimistic on the flammability of gases.

			Flammable	gas		
Inert gas	H_2	CH_4	C_2H_6	C_3H_8	i-C_4H_{10}	n-C_4H_{10}
Ar		**6.15**	**3.05**	**2.76**	**2.4**	**2.16**
	4.4 [5]					
		9.5 [11]	2 [11]			
		6.0 [14]	6 [12]		4.1 [12]	5.5 [12]
				< 5 [13]		
		9 [18]				
Ne	-	**9.2**	**4.37**	**3.45**	**3.26**	**2.70**
		≥ 8.5 [17]				
N_2		**9.9**	**4.94**	**4.25**	**4.1**	**3.26**
		8.7 [14]	4.5 [14]			
	5.6 [15]	14.3 [15]	7.1 [15]	6.3 [15]		5.6 [15]
	5.7 [18]	14 [18]	7 [18]	6.3 [18]	5.6 [18]	5.5 [18]
He		**11.86**	**5.45**	**4.41**	**4.15**	**3.55**
	8.7 [18]	13 [18]				
CO_2		**22.45**	**9.09**	**7.95**	**7.95**	**6.45**
	9.1 [15]	23.3 [15]	11.8 [15]	11.1 [15]		9.5 [15]
	8.9 [18]	23 [18]	12 [18]	11 [18]	9.3 [18]	9.7 [18]
CF_4	-	**33.4**	**13.0**	**11.76**	**9.5**	**9.1**
		20.3 [14]				
SF_6	-	**50.4**	**20.4**	**20.4**	**19.43**	**14.97**
R 134a	-	**11.98**	**7.14**	**6.7**	**5.75**	**6.15**
LEL	**3.5**	**4.4**	**2.4**	**1.8**	**1.55**	**1.4**
		4.4 [14]	2.5 [14]	1.7 [14]	1.4 [14]	1.4 [14]
	4.0 [16]					
UEL		**16.9**	**14.6**	**10.4**	**8.4**	**8.9**
		17.0 [14]	15.5 [14]	10.9 [14]	9.3 [14]	9.3 [14]
	77.0 [16]					

Table 4.6. Limits of flammability of selected gases in the presence of inert diluents

maximum % of flammable gas in the mixture

V Calculation Method:

5.1 International Standard ISO 10156 [19] Calculation:

The purpose of the document is to establish practical criteria for determining of the flammability of gas and gas mixtures. It takes severals situations into consideration for calculations. Firstly, the flammability of gas mixtures containing only flammable and inert gases. The flammability of such a gas mixture if *released in air and ignited*, can be determined by a simple calculation.

Secondly, gas mixtures containing three components: Flammable, inert and oxidizer (in our case always air), are considered. As the proportion of each individual component is known, the flammability of the gas mixture can be determined. Using the same metholdology as ISO 10156 a method for calculating the flammability of multi-component gas mixtures has been developed using the data from tests carried out on DIN 51 649.

Mixtures containing *m* flammable gases and *n* inert gases:

The composition of a mixture of this kind can be expressed as follows:

$$\left[a_1\%F_1+...+a_i\%F_i+...+a_m\%F_m\right]+\left[b_1\%I_1+...+b_i\%I_i+...+b_n\%I_n\right]$$

(general gas mixture form of Flammable/Inert gases)

Where

ai and **bi**	are the molar fractions of the *i*th flammable gas and the *i*th inert gas respectively;
Fi	designates the *i*th flammable gas;
Ii	designates the *i*th inert gas;
m	is the number of flammable gases;
n	is the number of inert gases.

The composition of the mixture is re-expressed in terms of an equivalent composition in which all the inert-gas fractions are converted into their nitrogen equivalent, using the coefficient of equivalency KI*i* value given previously in table 4.4:

$$a_1\%F_1+a_2\%F_2+......+a_m\%F_m+\left(KI_1b_1+KI_2b_2+......+KI_nb_n\right)N_2$$

Taking the sum of all the component gas fractions to be equal to 1, the expression for the composition becomes:

$$\left(\sum aiFi+\sum KIibiN_2\right)\left(\frac{1}{\sum ai+\sum KIibi}\right)$$

where

$$\frac{ai}{\sum ai + \sum Klibi} = a'i$$

is the equivalent flammable gas content.

Table 4.3 previously , gives values for the maximum content T_{CI} of flammable gas which, in a mixture with nitrogen gives a composition which is not flammable in air. Expressed mathematically, this condition for the mixture not being flammable in air is

$$\sum \frac{a'i}{T_{CI}} \times 100 \leq 1.$$

The following are an example of application.

a. Binary gas mixture of Flammable/Inert gas (released) in Air:

An explanation of the method used to calculate whether or not a gas mixture containing Flammable and inert gas is flammable once released in air, is displayed below in a example:

Considering the gas mixture 2% $\underline{i\text{-}C_4H_{10}}$ + 8% $\underline{CH_4}$ + 25% Ar + 65% He

This mixture is equivalent (with a Nitrogen proportion) to

$$2\ (i\text{-}C_4H_{10}) + 8\ (CH_4) + (25*0.65 + 65*1.1)\ (N_2)$$

knowing that the coefficient of equivalency of Argon is equal to 0.65 and of Helium is equal to 1.1 (see table 4.4).

i.e. adjusting the sum of the molar fraction to 1.

2.05% $i\text{-}C_4H_{10}$ + 8.18% CH_4 + 89.77%N_2

Then using the Tci-value of iso-Butane and Methane relative to Nitrogen (respectively 4.1% and 9.9%), from the previous table 4.5.

Since the sum

$$\frac{2.05}{4.1} + \frac{8.18}{9.9} > 1$$

, the gas mixture is flammable.

It should be noted that if the Tci-value of the flammable gas is known withrespect to any other inert gas, the calculation can be based on this inert gas instead of Nitrogen in the previous example.

Part b. and c. following are given for completion since we only used air as oxidizer component.

b. Flammable/Inert/Oxidizer gas mixture:

In these cases, the Oxidizer potential must be determined and compared with the air potential. The calculation given for oxidising mixtures will show us if the mixture is more oxidising than air (next part c).

If the mixture is less oxidising than air, calculate, as above, whether the mixture obtained by eliminating the oxidising agents is flammable in air. If this is the case, the initial mixture is taken to be flammable in air.
Otherwise, carry out a test measurement to check if the mixture is flammable in air.

However, a mixture can be considered as non-flammable without carrying out a test measurement if one of the following conditions is fulfilled:

a) Condition 1

The mixture obtained by eliminating the oxidising agents is not flammable in air, and the initial mixture is composed of less than 0.5% of oxygen equivalent.

b) Condition 2

The sum of the flammable-gas contents in the initial mixture is less than 90% of the lower flammability limit in air on the flammable-gas mixture. This occurs when the following condition is fulfilled:

$$\sum_{i=1} \frac{fi}{0.9 \times Li} \times 100 \leq 1$$

where

fi is the molar fraction of the *i*th flammable gas.

Li is the lower flammability limit(LEL) in air of the *i*th flammable gas.

Example :

Consider a mixture comprising $1\%\ C_2H_6 + 4\%\ CH_4 + 11\%\ O_2 + 84\%\ He$

1)The mixture obtained by eliminating the oxiding agent is equivalent to

$1\ (C_2H_6) + 4\ (CH_4) + (84*1.1)\ N_2$

Since the sum

$1.02/4.94 + 4.1/9.9 = 0.203 + 0.415 = 0.618$

is less than 1., the mixture obtained by eliminating the oxiding agent is not flammable in air.

2)The mixture contains more than 0.5% of oxygen equivalent. Condition 1. is not fulfilled.

3)The calculation to check condition 2.

$$1/(0.9*2.4) + 4/(0.9*4.4) = 0.463 + 1.01 = 1.473$$

shows that the mixture may be considered as flammable in air.
In this case, it is necessary to carry out a test measurement to demonstrate whether this mixture is really flammable or not.

c. Oxidizing Power of gases and gas mixtures:

This method is only applicable to special gas mixtures, contained in cylinders in small quantities. The highly oxidising gases O2 and N2O are used: their respective concentration ***xi*** in a mixture being expressed as a percentage by volume.

If the following condition is satisfied

$$\sum_{i=1} XiCi \geq 21$$

where ***Ci*** is the coefficient of oxygen equivalency(specific to each gas), the gas mixture is considered to be as oxidising as, or more oxidizing than, air.

By definition, ***Ci*** = 1 for oxygen and ***Ci*** = 0.6 for the nitrous oxide.

Example :

Consider a mixture comprising 9% O_2 + 16% N_2O + 75% N_2

This gives

$$\sum xiCi = (9*1) + (0.6*16) = 18.6 \text{ which is } < 21$$

The mixture is less oxidising than air.

5.11 Further Investigations:

For the convenience of researchers, new powerful formulae were evolved from equations based on the simple calculations (above) given by the international standard. These new formulae are more powerful and gives direct results.

The first investigation was evolved from the calculation based on the binary gas mixture of Flammable/Inert gas (previous part a.). The idea was to develop a formula, to calculate directly the Tci-value of a gas mixture with one to m^{th} flammable component(s) and one to n^{th} inert component(s).

$$\left[a_1\%F_1 + \ldots + a_i\%F_i + \ldots + a_m\%F_m\right] + \left[b_1\%I_1 + \ldots + b_i\%I_i + \ldots + b_n\%I_n\right]$$

is the general gas mixture form of Flammable/Inert components.

Now by taking the other way round of the calculation method used in part a. and putting:

$$\begin{cases} \sum \frac{Tcif}{Tci} \times 100 = 1 \\ Tcif = \frac{ai}{\sum ai + \sum KIibi} \end{cases}$$

where a'i is replaced by $T_{CI}f$ and is the maximun flammable gas content of the gas mixture (non-flammable).

The equation is solved for $T_{CI}f$ giving the following formula which calculates the maximum flammable gas composition content (TCIf) for which the mixture of flammable gas and inert gas is not flammable once released and ignited in air:

$$TCI_f = \frac{100 \times \sum_{k=1}^{n}(i_k \cdot KI_k) \times \prod_{k=1}^{m} TCI_k}{100 \times \sum_{k=1}^{m}\left[f_k \times \prod_{\substack{j=1 \\ j \neq k}}^{m} TCI_j\right] + \prod_{k=1}^{m} TCI_k \times \left[\sum_{k=1}^{n}(i_k \cdot KI_k) - \sum_{k=1}^{m} f_k\right]} \qquad \text{(E1)}$$

$$\text{with } \sum_{k=1}^{m} f_k = 1$$

where

- the proportions $0 \leq i_1, i_2, \ldots, i_n$ & $f_1, f_2, \ldots, f_m \leq 1$ are respectively the molar fraction of the Inert components and of the flammable components respectively.

- **KI_k** designates the *k*th coefficient of equivalency of the *k*th Inert gas relative to Nitrogen

- **TCI_k** designates the *k*th maximum flammable gas content for which a mixture of the flammable gas in Nitrogen is not flammable in air.

-**TCIf** designates the calculated total inertisation value for the gas mixture considered.

The calculations in our case were made with no more than two components in each composition. For convenience, the original formula was reduced to the following one:

$$\mathrm{TCI}_f = \frac{100\cdot \mathrm{TCI}_1\cdot \mathrm{TCI}_2\cdot\left(i_1\cdot \mathrm{KI}_1+i_2\cdot \mathrm{KI}_2\right)}{\left[100\cdot\left(f_1\cdot \mathrm{TCI}_2+f_2\cdot \mathrm{TCI}_1\right)+\mathrm{TCI}_1\cdot \mathrm{TCI}_2\cdot\left(i_1\cdot \mathrm{KI}_1+i_2\cdot \mathrm{KI}_2-1\right)\right]} \qquad \text{(E2)}$$

The second investigation is a kind of integral of the previous equation. The system equation (S1 next page), used will allow to determine the Tcif-value of a mixture (given the relative proportion of each components for each composition) as reference to formula E1. In addition it will enable us to claculate a range of Tcif-values as a function of the relative proportion of each component (argon, air, methane, ...) for each composition (Flammable, Inert and Oxidizer) of the gas mixture.

The system equation applies specifically to gas mixtures of three gas components (2 flammable / 1 inert or 1 flammable / 2 inert). The equation can be solved only if at least one of the variables (x, y, z, w) is set to a specific value in the range of 0-100%. With the help of two calculated values, a straight line can be plotted on an x-y axis graph. This gives the full range of solutions for the concentration limits of the gas mixture.

The possible gas mixtures for calculation are :

$$z\%\ F_1 + w\%\ F_2 + x\%\ I_1 \qquad (m_1)$$

or

$$z\%\ F_1 + x\%\ I_1 + y\%\ I_2 \qquad (m_2)$$

Then in this investigation the proportions "$\mathbf{i_k}$", "$\mathbf{f_k}$" are variable and can be writen as

$$ik = \frac{bk}{\sum_{k=1}^{n} bk} \quad ; fk = \frac{ak}{\sum_{k=1}^{m} ak}$$

ai and bi are, respectively, the molar fractions of the *i*th flammable gas and the *i*th inert gas of the gas mixture;

then replaced in equation (E1) to obtain the following system of equations:

$$\begin{cases} TCIf = \dfrac{100\times\sum\limits_{k=1}^{n} bkKIk \times \prod\limits_{k=1}^{m} TCIk}{\sum\limits_{k=1}^{n} bkKIk\times\prod\limits_{k=1}^{m}TCIk + \sum\limits_{k=1}^{n} bk\times\left[100\times\sum\limits_{k=1}^{n}\left(\dfrac{ak}{\sum\limits_{k=1}^{m}ak}\times\prod\limits_{\substack{j=1\\ j\neq k}}^{m}TCIj\right)-\prod\limits_{k=1}^{m}TCIk\right]}\% \\ TCIf=\sum\limits_{k=1}^{m} ak\% \\ \sum\limits_{k=1}^{m}ak\% + \sum\limits_{k=1}^{n} bk\% = 100\% \end{cases} \tag{S1}$$

that ends with the **useful second order equations** given below:

(Em$_1$) for (m$_1$)

$$\begin{aligned} &[100.TCI_1+TCI_1TCI_2.(KI_1-1)].\mathbf{z}^2 \\ &+\{100[TCI_2+2.KI_1.TCI_1.TCI_2]+TCI_1.TCI_2.(KI_1-1)\}.\mathbf{z} \\ &+100.KI_1.TCI_1.TCI_2.\mathbf{x} = 0 \end{aligned}$$

Used for (2 flammable / 1 Inert) gas mixtures

(Em$_2$) for (m$_2$)

$$\begin{aligned} &[TCI_1(1-KI_2)-100].\mathbf{z}^2 \\ &+\{\mathbf{x}.[TCI_1.(KI_1-KI_2)]+100(100+2.KI_2.TCI_1-TCI_1)\}.\mathbf{z} \\ &+100.TCI_1.\mathbf{x}.(KI_2-KI_1)-(100)^2.KI_2TCI_1 = 0 \end{aligned}$$

Used for (1 flammable / 2 Inert) gas mixtures

where

$0 \le \mathbf{z} \le 100\%$ is the proportion of flammable gas composition.

$0 \le \mathbf{x} \le 100\%$ is the proportion of the first (I_1) inert gas.

Example :

Let us consider the following gas mixture:

$$(4 - 6)\%\ i\text{-}C_4H_{10} + (50 - 60)\%\ Ar + C_2H_2F_4 \qquad (m3).$$

We are interested in finding non-flammable gas mixtures possible with mixture (m3). Using (Em2) with the following parameters:

KI_{AR}	= 0.58	(from appendix 4.)
KI_{C2H2F4}	= 1.40	
$TCI_{i\text{-}C4H10}$	= 4.1%	

it simplifies (Em2) to

$$-101.64\ .\mathbf{z}^{2} + (10738 - 3.362\ \mathbf{x}).\mathbf{z} + 336.2.\mathbf{x} - 57400 = 0.$$

The range of solutions(z1, z2) of this secondary equation are z2 = 100% (constant) and 2.4 %≤ z1 ≤ 5.8% , where only the solution "z1" is taken into account. Figure 5.1 below illustrates the solution's characteristic.

Note that

z1 = % of iso-Butane = 5.8%	as	**x** = % of Argon = 0%	(% R134a = 94.2%)
z1 = 2.4%	as	**x** = 97.6%	(% R134a = 0%)

In the first case, the value of "z1" is actually the Tci-value of iso-Butane in Argon and in the second case the value of "z1" is the Tci-value of iso-Butane in Argon (check table 4.3).
If the Tci-values of the Flammable gas or gases relative to the inert gases used are known, there is no need to solve the above secondary equation to find the two points of the characteristic (line) needed to draw it. The range of Tcif-values for the flammable gas or gases mixed with the inert gas or gases lies on the line formed by the two extreme points of the characteristic which represents the Tci-value for each possible composition (flammable/inert) of the initial gas mixture.

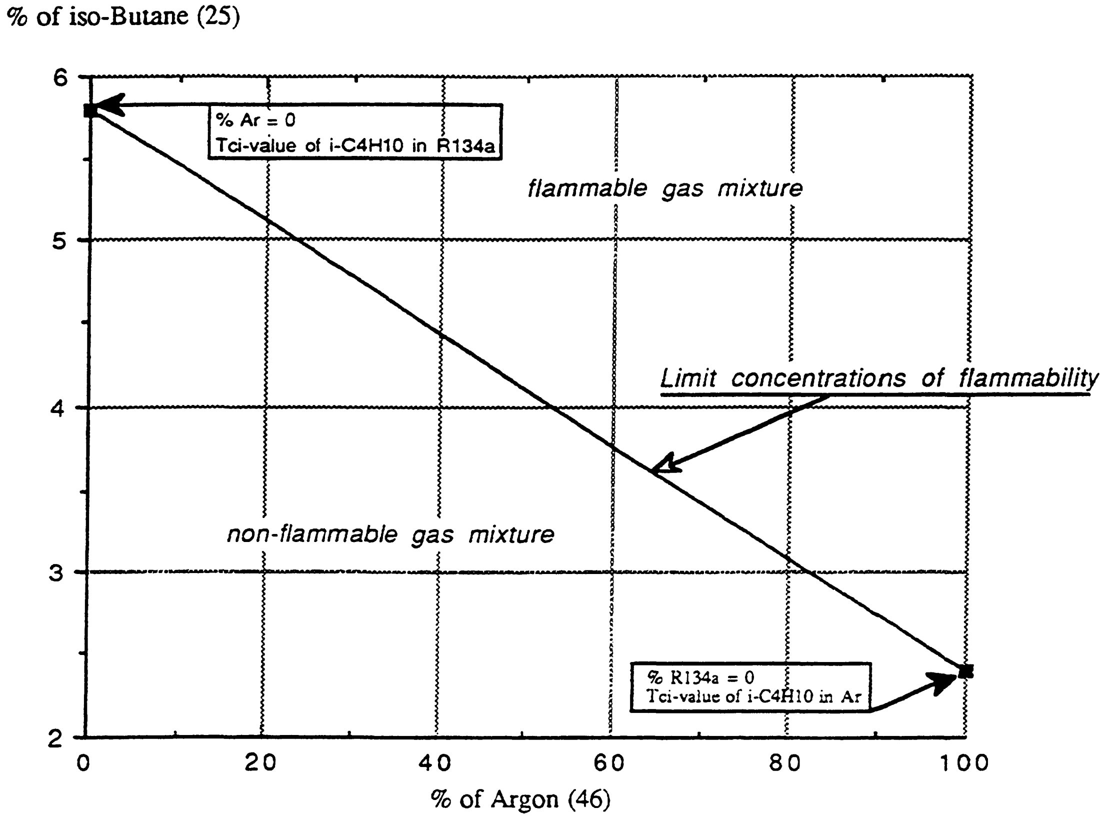


Figure 5.1: Proposed characteristic of the limit concentrations of the non-flammable gas mixture of the iso-Butane/Argon/Freon R134a gases.

.2 Mixture Composition Characteristics:

The flammability limits of a mixture of several *flammable* gases in air can be calculated from a knowledge of the flammability limits of each individual gas in air.

The limiting concentration L of the mixture containing n flammable gases is given by the following equation based on Le Chatelier's law:

$$L = \frac{1}{c_1 / L_1 + c_2 / L_2 + \ldots + c_n / L_n}, \sum_{i=1}^{n} c_i = 1,$$

where

$c_1, c_2, \ldots, c_n$ are the concentrations of each flammable gas

$L_1, L_2, \ldots, L_n$ are the flammable limits in air for each gas separately.

The equation applies to both the lower and upper limits, but is obeyed more closely for LEL calculations. The law is closely followed by the common hydrocarbon gases, hydrogen and carbon monoxide but gross exceptions are observed with mixtures that contain hydrogen sulphide, carbon disulphide or diethyl ether (See Coward and Jones [2] for further development).

Example 3.1: Consider a mixture of 20% Methane (LEL 5%), 30% iso-Butane (LEL 1.8%) and 50% Ethane (LEL 3.2%). The lower limit of flammability of the mixture is

$$LEL = \frac{1}{20/4.4 + 30/1.55 + 50/2.4} = 0.022 = 2.2\%,$$

with lower limits of the components taken from Zabetakis [3].

5.3 Molecular Structure Approximation:

There is a "rule of thumb" for determining the lower and upper limits of flammability with the aid of the stochiometric concentration. The lower flammable limit is in many cases approximately half the stochiometric concentration and the upper limit is approximately 3.5 times the stochiometric concentration. The rule fails with low molecular weight compounds as can be seen in table 5.2 and is only used with hydrocarbon gases to give a first approximation. It should therefore be used with great care.

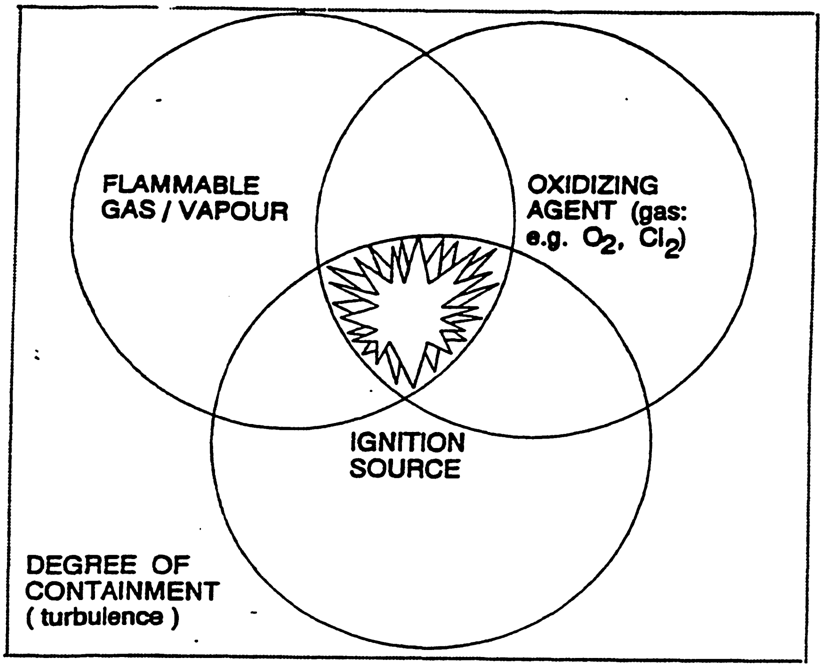
Hydrocarbon	**Lower limit**	**Upper limit**
	(% * stoichiometric)	
methane	53.5	156
propane	53.8	251
n-butane	60.1	288
n-pentane	58.2	323
n-hexane	55.2	368
n-heptane	63.9	378
Theory	50	350

Table 5.2 Relationship between flammability limits and shoichiometric measures [10]

VI. CERN 's FFT* apparatus ... a prototype:

6.1 CERN vs Explosion Scheme:

The risk of explosion is dependent on the probability of occurence of three components together at the same place and at the same time (see picture 6.1). The probability of explosion, also called "Explosion sensitivity", is defined by a series of physical properties of the flammable gas: Lower explosion limit (LEL*), Upper explosion limit (UEL*), Explosion range* = (UEL)-(LEL), Lower/Upper flash point (vapours of liquids), Minimum ignition energy (MIE*), Minimum auto-ignition (or self-ignition) temperature (AIT*), Limiting oxygen concentration (LOC*), Maximum experimental safe gap (MESG*); and is of interest when searching for non-flammable gas mixture including flammable gas or gases.

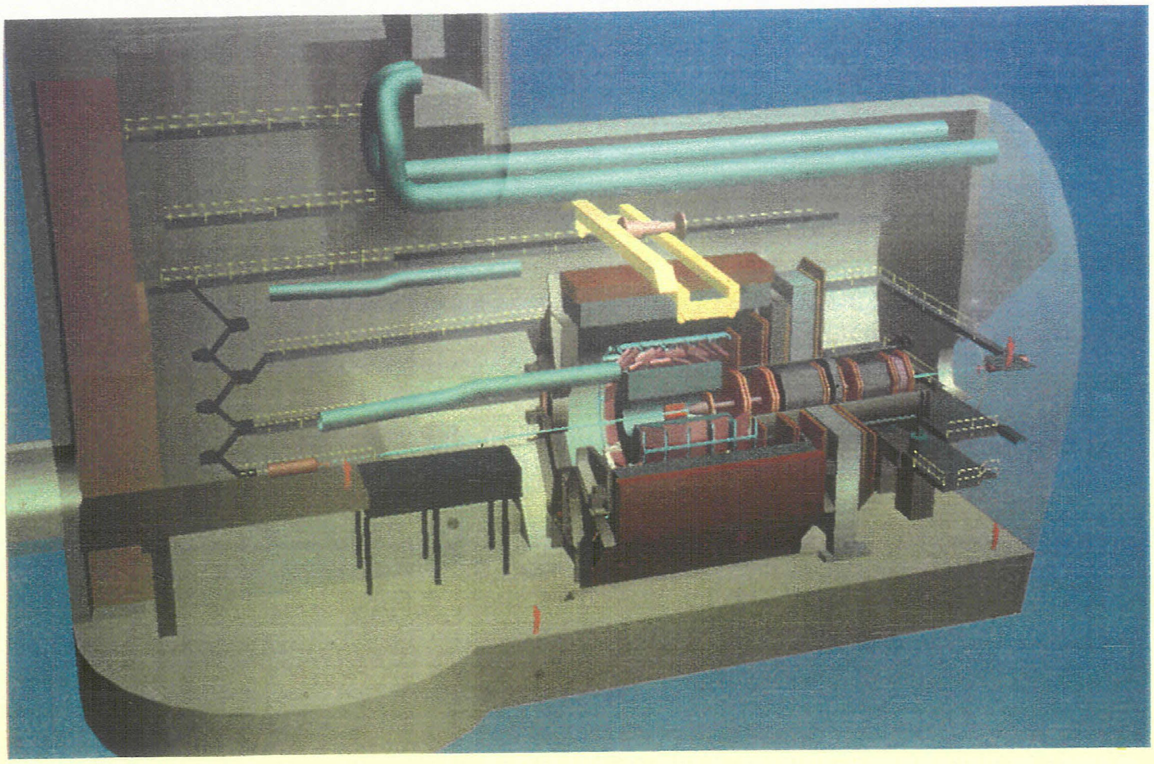


Picture 6.1 Occurence of gas/vapour explosion.

Traditionally, the avoidance of potential (effective) ignition sources has played a major role in a gas and vapour explosion safety. Using the concept of hazardous area classification, areas are identified in which an explosive gas mixture must be expected with a certain probability. It is therefore straightforward to adjust measures to prevent ignition of such gas mixture, the more severe the measures to avoid ignition must be.

Nevertheless, CERN with its high energy accelerator complex comprising the large particle collider, Large Electron Positron (LEP) with beam line at energy of about 192 GeV, has to deal with the use of large amounts of flammable gases needed in particle detectors.

The problem is still of great interest as a new large particle accelerator, the Large Hadron Collider (LHC) with a beam line at energy of about 14 TeV, will start early in the next century.
The detectors used at present will at least triple their size and weight with the arrival of the LHC; this will result in the use of greater amounts of gas mixtures in underground experiments (see Fig. 6.2).



Picture 6.2 Overview of a particule detector in its cavern hundred meter underground.

The detection of a collision event is made by several types of detectors piled up in the form of a big cylinder around the collision point. The data from the entire detector formed are loaded via these individual particle detectors to the computers by millions of triggers and wires. A detail description of one of the famous particle detector, the "Multiwire Proportional Chamber" of the Nobel Prize 1992, M J. Charpac; see Fig. 6.3, is given next page. The reasons of the choice of the gas filling the detectors are then briefly explained.

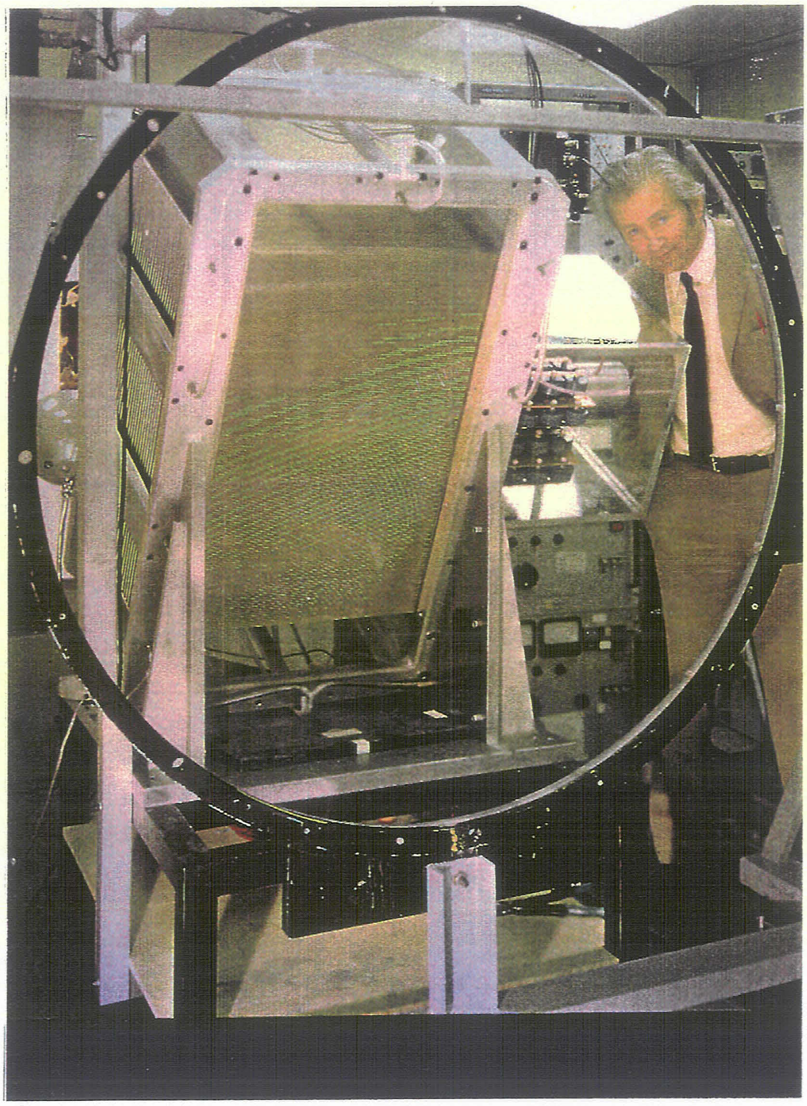


Figure 6.3 a Multiwire Chamber particle detector

a. principle of operation:

A multiwire proportional chamber consists essentially of a set of thin, parallel and equally spaced anode wires, symmetrically sandwiched between two cathode planes; Fig. 6.4 gives a schematic cross-section of the structure.

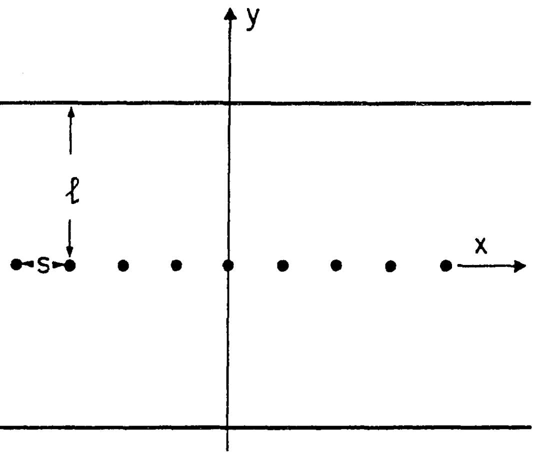


Figure 6.4 Principle of construction and definition of parameters in a multiwire proportional chamber. A set of parallel anode wires is mounted symmetrically between two cathodes planes.

For proper operation, the gap 'l' is normally three or four times larger than the wire spacing 'S'. When a negative potential is applied to the cathodes, the anodes being grounded, an electric field develops as indicated by the equipotentials and field lines in Fig. 6.5 and in a magnified view around the anodes, in Fig. 6.6.

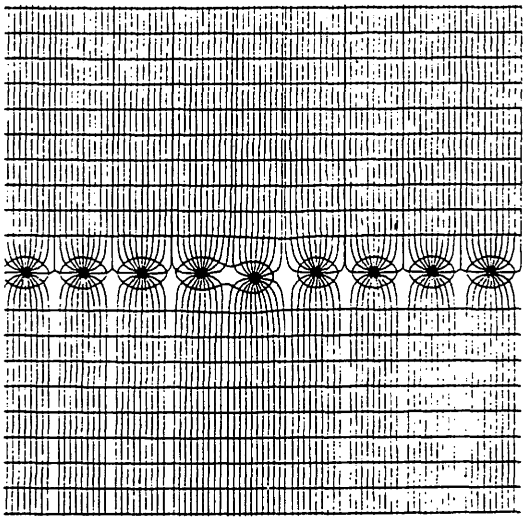


Figure 6.5 Electric field equipotentials and field lines in a multiwire proportional chamber. The effect on the field of a small.

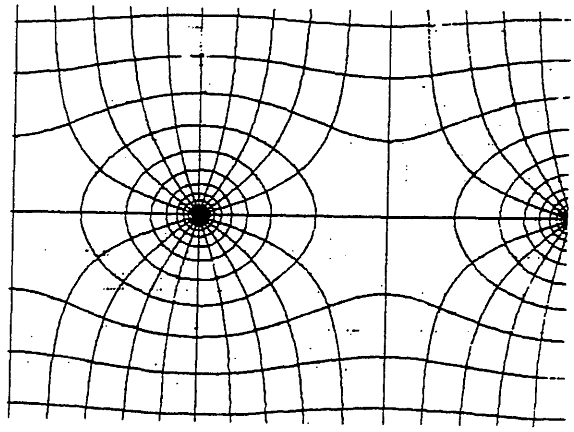


Figure 6.6 Enlarged view of the field around the anode wires
(wire spacing 2 mm, wire diameter 20 μm)

Suppose now that charges are liberated in the gas volume by an ionizing event; as in a proportional counter, conditions are set such that the electrons will drift along field lines until they approach the high field region, very close to the anode wires, where avalanche multiplication occurs (see an illustration of the event in appendix 5).

b. choice of gas filling:

Since avalanche multiplication occurs in all gases, virtually any gas or gas mixture can be used in a proportional counter. In most case, however, the specific experimental requirements restrict the choice to several families of coumpound; low working voltage, high gain operation, good proportionality, high rate capabilities, long lifetime, fast recovery, etc., are examples of sometimes conflicting requirements. Other important reason of choice is the cost and safety aspects.

From the conceptual design of operation of the detector, it can be observed that two main components (igniton source and gas mixture) of explosion scheme are already present if the gas mixture used in the detector is flammable in air. Secondly, although the working pressure of these gas mixtures are often very low (less than 3 Bars), gas leakage is always possible. Thus the presence of electronic equipment in the surroundings can result in explosion hazards. This problem can be solved using intrinsically electronic devices, but this greatly increases the cost and is not necessary always applicable.

The avoidance of all potential ignition sources is impossible and the use of flammable gases is for the performance of the detectors. The other option would be to remove the oxidant (air) by purging the entire experiment with an inert gas, for instance. The problem of purging experiments is extremely difficult and would result in high costly inert gas use and danger of potential asphyxiation. It is used in certain cases where an hermetically sealed "box" can be designed.

Further investigations has shown that the detectors does not always need use of flammable gas mixtures. Moreover great interest has been shown by physicist on binary (2-components: flammable/inert) gas mixture such as hydrocarbon gases with carbon dioxyde, argon and nitrogen. The way of limiting the use of flammable gas has been to test gas mixtures of flammable/inert components. The Gas and Chemistry Section of the Technical Inspection and Safety comission (TIS) of CERN helps in testing gas mixtures used by physicists and in finding non-flammable gas mixtures useful for the detectors using the Standard apparatus described in this work (§I).

6.2 The Standard Apparatus for Full Flammability Test (FFT): "Problems"

6.21 Gases exhausts:

The detail description of the apparatus was given in §III. The entire equipment being a prototype, a number of weaknesses were recorded during the year of research.
An unsolved problem is the exhaust of the gases. The gases flow through the apparatus at just above than atmospheric pressure. Although they go to an outdoor exhaust it was noticed that when using heavy gas mixtures, the gas goes back through the two other exhausts.
The problem can be seen from the configuration of the exhaust pipe below:

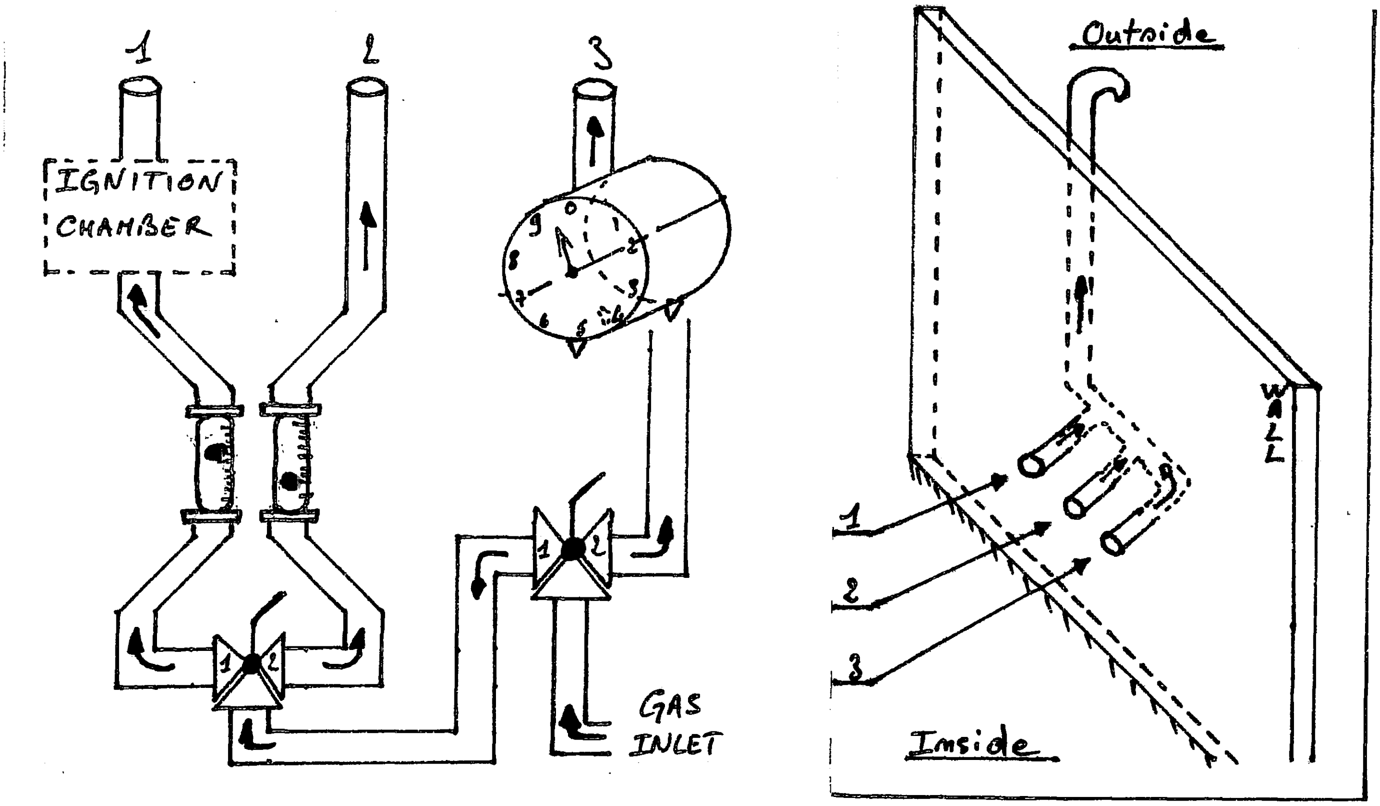


Figure 6.7 exhaust pipe circuitry.

The exhausts (1,2 and 3) are used independently of the others via the manual valves. When purging the ignition chamber with a test sample* the out flow of gas goes through the exhaust noted "1" on the figure, then as the ignition is processed the flow out of gas is headed through the direct exhaust "2", but there is no valve preventing going back from the exhaust pipe down to the exhaust "1" of the ignition chamber. Moreover if iso-butane gas that is heavier than air, is used thus the gas mixture do not goes up and out of the long and high exhaust pipe "P" and simply fills down the exhaust "1" of the ignition then entering the chamber and could affect the ignition test. At the same time, the gas mixture also fills down exhaust "3" and fills the gasometer then making the operation of apparatus unsafe as far as the gas mixture could be explosive.

The difficulty in this problem is that the operational pressure of the gases is too low for the use of bubbler at each exhaust. A solution was designed below:

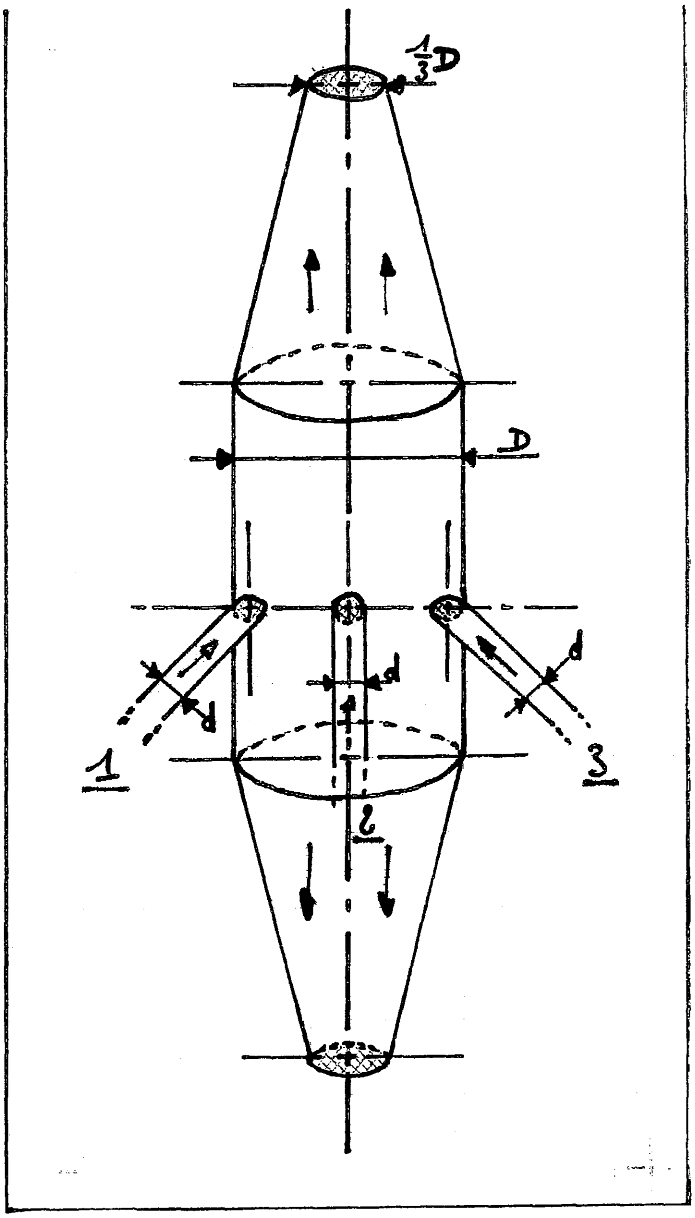


Figure 6.8 An exhaust solution for atmospheric$^+$ pressure flows of gases.

6.22 Electrical and Hardware:

One of the interfaces, the Analogue to Digital Converter, linking the computer system to the functional equipment had an heat malfunction and was replaced by a new one. At first when the apparatus did not respond, it was thought that the problem was coming from a bad earthing of the entire equipment. It has been in the past that significant voltages appear in the metallic frame of the apparatus.

The earthing of the entire equipment was then made correctly in accordance with Electro-Magnetic Compatibility (EMC) rules.

6.23 Software:

The concept of multi-components gas mixture developped in §V with the mathematical calculations was also considered for FFT test by adapting the program. A specifications paper for an evolved program was made at CERN.

The new software was compiled by Paderborn University and is available for the test of multi-components gas mixtures.

6.22 Practical Advices and Remarks based from FFT* Operation:

A. The flame detachment:

The Standard paper which described the theoretical FFT procedures does not take into account the individual behaviour of the different flammable gases. The operator should bear in mind that the detachment of a flame from the ignition spark means theoritically that the limit of flammability of the gas mixture was reached. In practice, the operator must be adaptable and is the link between the theory and the real event.

A number of different flame detachment reaction from the ignition were observed. Size, shape, propagation and duration of the flame are the four parameters that composed the range of the different flame "detachment" seen during Full Flammability Test. Seven kind of flame "detachment"were recorded and are described below:

a. a nice flame detachment with propagation up to the roof.
b. a nice flame detachment with propagation up to the half of the chamber length but resumes as the ignition spark stops.
c. a flame with the shape of a mushroom is formed but without a detachement and disappear as the ignition resumes.
d. an heavy flame detachment that rises but during the ascent the flame burns out at half of the tube length.

e. With time the halo from the spark grows up and resumes as the ignition stops with a non-propagating but detached flame burning off.

f. the detachment of one or several little balls of fire turning on a circle and propagating up and burning off at half of the tube length.

g. the flashed picture of a flame detachment (sometimes relatively big) just above the halo formed on the ignition spark.

In the case a, b, c and d events, the gas mixture were considered as flammable mostly because of the propagation and important size of the flame detachment; e, f and g events have either a good size or a good propagation but never both together, thus the gas mixtures were considered as non-flammable.

B. The gases characteristics:

As FFT were produced, it was noticed that each gas has its proper reaction characteristics: colours, flame shape, propagation speed, etc ... Also the use of different flammable gases showed that one flammable gas could be less sensitive to an ignition than another: in one case the increase of the flammable amount in the mixture would not alter the reaction but in another, this would result in a violent explosion.
The different possible reaction of a gas mixture to an ignition are: "no reaction", the spark stays alone. "Halo", a halo (about 0.5 to 5 cm high) is visible over the spark; "flame detachment", the spark and a halo are observed and a flame detached from the halo and propaged through the unburned gas mixture which is then flammable; "strong reaction", this can start from a simple flame detachment which then burns and expands in all direction: downward and upward in the tube.

These reactions have different ranges width depending on the flammable considered. Methane has the widest ranges for all the possible reactions, then come ethane, propane and butane which have narrower ranges. From a first point of view, methane could be considered as less dangerous for the operator because there are no surprises, but also it is the more difficult in the determination of the flammability limits.

Probably the most dangerous gas used for test in the FFT apparatus was hydrogen gas. Two main problem were met: the determination of the flammable limits and more specifically of the UEL. The combustion of hydrogen is nearly colourless. Experience showed that for correct results the operator must stay approximetely 1 minute in dark before ignition. The determination of the UEL limit caused a few problems: as the gas mixtures saturated of hydrogen were ignited, it happened that sometimes the gas mixture produced a "no reaction" event and another time the same gas mixture proportions produced a violent explosion. It was concluded that the gas was too sensitive to the external parameters such as the temperature and also to the ignition energy given to the gas mixture which is probably never exactely the same.

Nervertheless the addition of inert gas with hydrogen and air sometimes allowed to find some UEL limits of gas mixtures. For safer conditions, a screen protection made of plexiglas was installed around the ignition chamber.

VII CONCLUSION:

This paper presented an overview of explosion indices for flammable gases and vapours. Standard methods to determine them are described as well as factors influencing these data. More specifically, this paper highlights the results of flammability test of parrafin Hydrocarbons gases: methane, ethane, propane and butane mixed with inert diluents using a DIN standard apparatus designed in accordance with latest researchs on FFT* methods and proposed for European Normalisation. It gives precise and realistic results for new considerations of flammability indices of gases at CERN and in industry. As the equipment is a newly designed apparatus, some problems were recorded during operation; nevertheless furnished tables of reliables results were produced.

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Methods of measuring Flammability Limits

As with all properties of materials, values of flammability limits are dependent on the test apparatus and the method of carrying out the test. Thus the more intense the ignition source the more the flammability limits are extended. Wider limits are also obtained in apparatus designed to promote the upward propagation of a flame than those obtained in apparatus in which the flame propagation is downwards. The size and geometry of the reaction chamber also influence the flammability limits; large diameter tubes and vessels lessen wall quenching effects and tend to give wider limits than similar, but smaller scale apparatus.

Originally, "standard" measurements of the flammable range were made on an apparatus, shown in Figure A1, developed by the US Bureau of Mines and described by Coward and Jones [2].

The glass flame propagation tube, **a**, is closed at its lower end by the ground glass plate, **b**, sealed with mercury, **c**. Tube, **a**, is evacuated through tube, **d**, by a pump. The flammable gas or vapour to be tested is drawn from the gas holder, the amount being monitored by the manometer, **k**. Air, or other gaseous oxidant is introduced after passing through drying tube, **q**, until atmospheric pressure is attained. The gases are thoroughly mixed by circulation for 10 to 30 minutes using the mercury vessel, **g**, as a pump. Then the bottom of tube, **a**, is opened and,almost simultaneously, a spark is passed between the electrodes at, **y**, or a small flame applied across the open end at the bottom of the tube. It is then observed if a flame is propagated upwards through the tube.

Some years ago it was thought that the results obtained under these conditions represented,with only a few exceptions, a good approximation to limits obtaining in larger volumes, but more recent work has shown that significantly wider limits are obtained in spherical closed vessels of 0.6m in diameter [1].

The basis of the ASTM 681-79 *Standard Test Method for Limits of Flammability* is a spherical combustion chamber and is shown in Figure A2. The igniter electrodes are positioned so that flame propagation is upwards and outwards. The vessel is evacuated before flammable gas or vapour is introduced in a quantity determined by the pressure measured by a transducer. Air is admitted until the pressure reaches atmospheric and the components are mixed with a magnetic stirrer until the mixture is homogeneous. flaming combustion is induced by a spark or by passing current through a fuse wire. The mixture is considered flammable if the flame emanating from the igniter reaches the walls of the vessel.

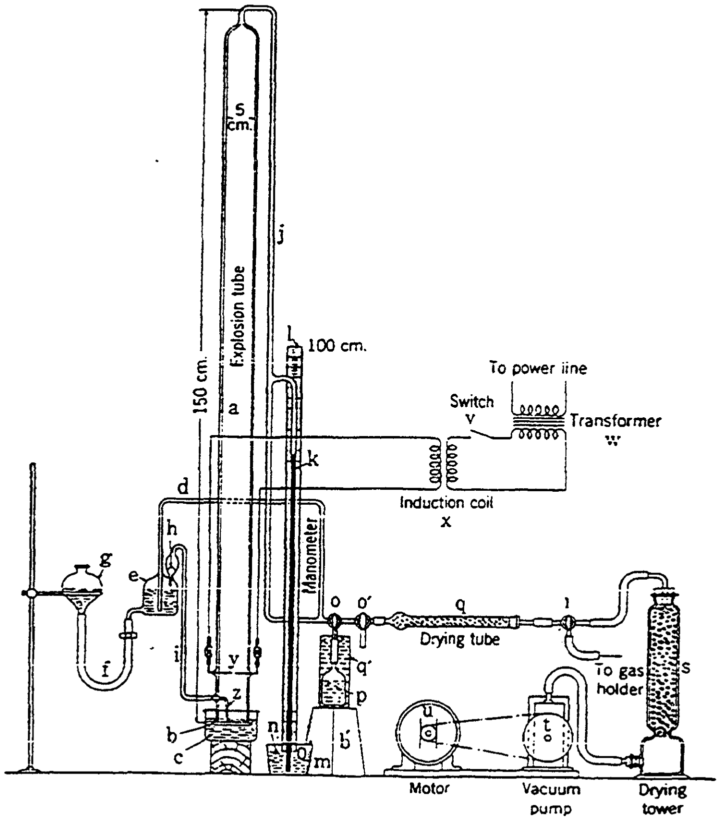


Figure A1 - Apparatus for Determining Limits of Flammability of Gases and Vapours

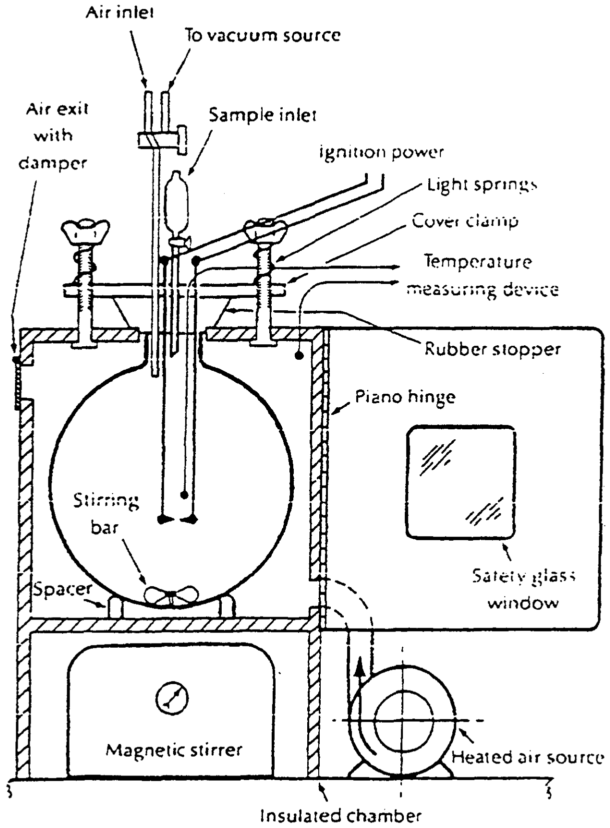


Figure A2 - Schematic Diagram of the ASTM Apparatus.

Appendix 2

Determination of limits of Flammability of Gases and gas mixtures in Air.

Steps to make a full flammability test

From the point of view of a Triangular diagram

Presentation of data:

Limits of flammability data that have been obtained at a specified temperature and pressure with a particular combustible-oxidant-inert system may be represented on either a rectangular or a triangular plot. The latter presentation is frequently used because of all mixture components are included in the diagram. However, as the sum of all mixture compositions at any point on the triangular plot is constant (100%) the diagram can be simplified by use of a rectangular plot where a better precision is obtained.

For example, the flammable area of figure B1 may be presented as illustrated in figure B2. as noted, the air concentration at any point is obtained by subtracting the methane and nitrogen concentrations at the point of interest from 100 as follows:

$$\%Air = 100\% - \%CH_4 - \%N_2$$

With either type of presentation, addition of methane, air or nitrogen to a particular mixture results in formation of a series of mixtures that fall along the line between the composition point (for example, M1 in figure B1 and B2) and the vertices of the bounding triangle. For example addition of methane (CH_4) to mixture M1 yields initially all mixture compositions between M1 and C (100% of CH_4). After a homogeneous mixture is produced, a new mixture composition point, such as M2, is obtained. Similarly , if air is added to the mixture represented by point M1, all composition between M1 and O (100% of Air) are obtained initially; if nitrogen is added, all compositions between M1 and N (100% of nitrogen) are obtained initially. If more than one gas is added to M1, for example, methane and air, the resultant composition point may be obtained by considering that the mixing process occurs in two steps. First, the methane is added to M1 and the gases are mixed throughly to give M2. Air is then added to M2 with mixing to give new (flammable) mixture, M3.

Thus two different important constructions lines must be considered. Mixtures with constant oxidant content are obtained by constructing the straight lines parallel to zero oxidant line; such mixtures also have a constant combustible-plus-inert content. One particular constant oxidant line is of special importance. The minimum constant oxidant line that is tangent to the flammability diagram or, in some cases, the one that passes through the extreme upper-limit of flammability value. This line gives the minimum oxidant (air, oxygen,..) concentration needed to support combustion of a particular combustible at a specified temperature and pressure. In figure B1 and B2, the tangent line gives the minimum oxygen value (Min Air, 12 volume percent) required for flame propagation through methane-air-nitrogen mixtures at 20-25 °C and 1 atmosphere.

Another important contruction line is that which gives the maximum non-flammable combustible-to-inert ratio (critical C/N) or in other term the Tci-value. Mixtures along and below this line form nonflammable mixtures upon addition of oxidant. The critical C/N ratio is the slope of the tangent line from the origin (Figure B1 & B2), 100 percent oxidant, to the the lean side of the flammable mixtures curve.

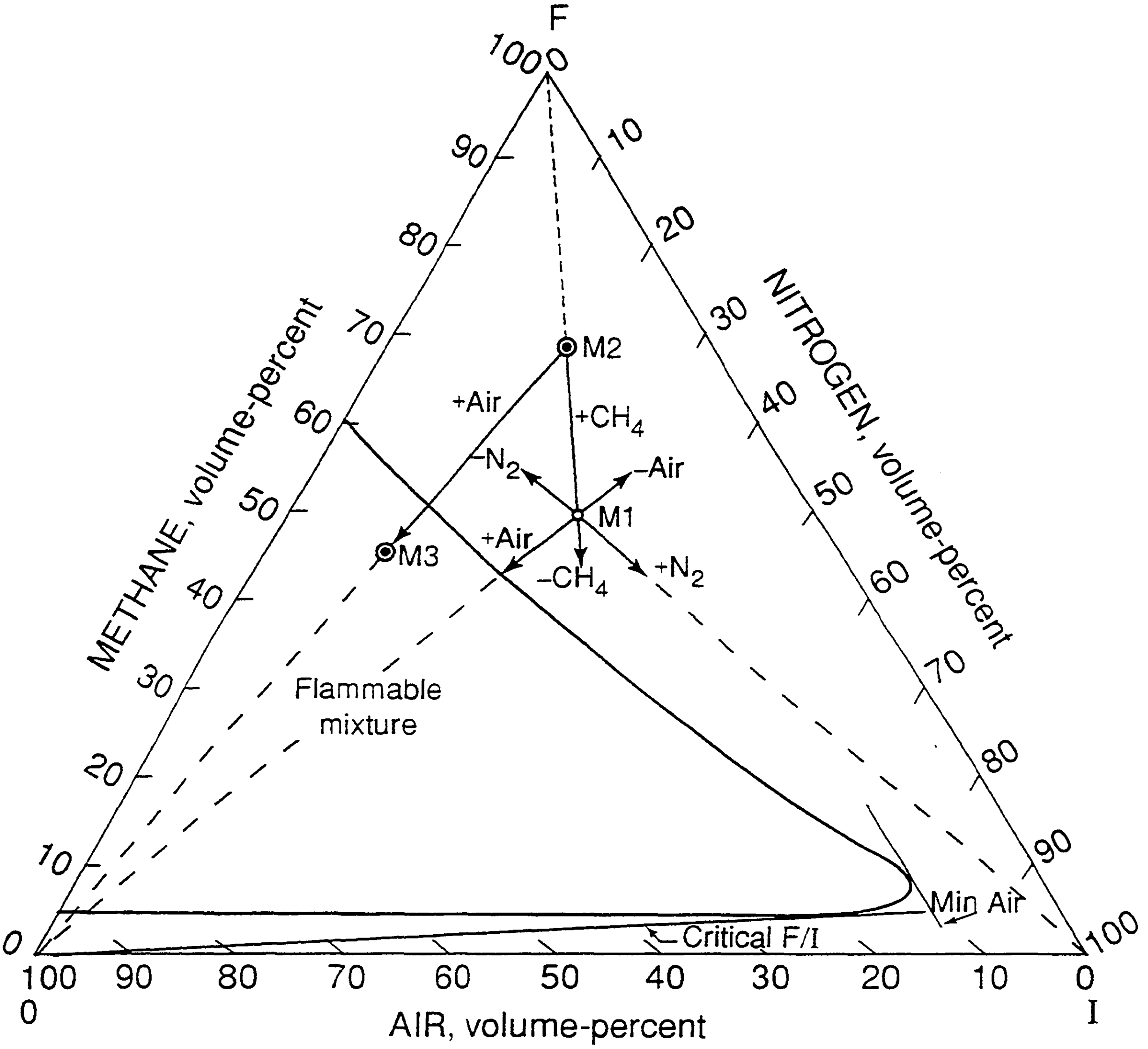


Figure B1 Flammability Diagram (Triangular) for the System Methane-Air-Nitrogen at atmospheric pressure and 20-25° C.

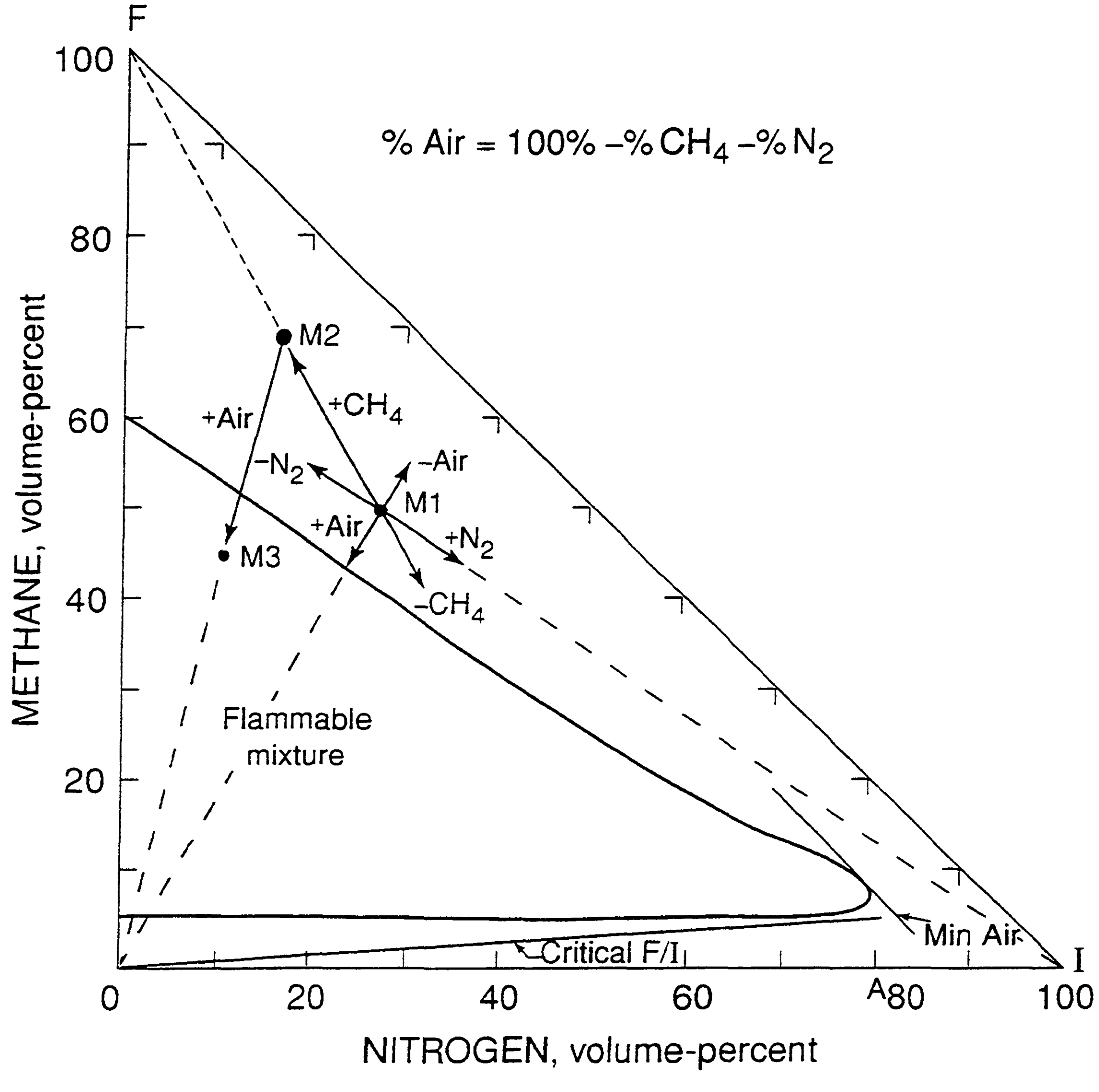


Figure B2 Flammability Diagram (Rectangular) for the System Methane-Air-Nitrogen at atmospheric pressure and 20-25 C.

Determination of an explosion range:

1. Determination of the LEL, point 1 (without inert gas)

Start below the LEL and make a test using the standard apparatus. If there is no flame propagation, then increase the part of flammable gas by steps of a half percent. Once the flammable range is reached (flame propagation) then return to the last point and increase the part of flammable gas by steps of 0.1 %. On reaching the explosion range again, take the last "non-flammable" point and repeat the test on this point five times. If there is no flame propagation, then this point is taken as LEL and put it in the diagram. If there is a flame propagation only in one of the five individually tests, then decrease the amount of flammable gas in a next step and repeat the procedure.

2. Determination of the UEL, point 2 (without inert gas)

Same procedure as 1.). Starting above the UEL decrease the amount of flammable gas. For the fine steps it is enough to take steps of 0.2 %.

3 Determination of point 4 and 5

With the next part it is nessesary to determine two points with a volume part of inert gas. The best way is to fix the volume part of the inert gas, e.g at 30% and making the tests along a line of a constant volume fraction of inert gas (see the green little lines). That means, in such sequences of tests thet the volume part of inert gas is to be constant and the volume fraction of the flammable gas is increased or decreased. Looking for the limits is the same procedure described in 1.)

4 Determination of point 3

For the determination of point 3 it is nessesary to make tests along a line of a constant volume fraction of flammable gas (little blue line) by varying the amount of nert gas. The constant volume part of flammable gas should be fixed a little higher than in point 4. Then starting in the explosive range (an estimation of the flammable range is possible by connecting the points 1, 4 and 2, 5) increase the portions of the inert gas in steps of 1%. If there is no longer any flame propagation, then go back with smaller steps (0.2%). The last point without flame propation should be repeated 5 times.

5. Determination of further points

If it is nessesary to establish more points of the boundary of the explosion range, they can be determined on the same way.

6. Draw the boundary by connecting the experimental points.

Determination of the maximum concentration of a flammable gas in an inert gas, for which this mixture of the flammable gas with the inert gas is not flammable in air. (value of total inertisation, Tci-value)

1. Drawing the tangent

First draw the tangent from the point B to the curve of the explosion range. The tangent should just touch the curve, but never cut it. This tangent is a line, where at every point the ratio of inert gas to flammable gas is constant.

2. Reading the cross point

The cross point (point D) of the tangent with the line AC is the point of the maximum concentration of the flammable gas in an inert gas, given in percent by volume. On the left side of the diagram the value of the inert gas is obtained (in the example 78 Vol.-%), on the right side the value of the flammable gas (22 Vol.-%). That means in our example, a mixture of 78 Vol.-% inert gas and 22 Vol.-% flammable gas ist total inertized. Such a mixture is non flammable at every dilution with air.

You can calculate the Tci-values, too. Then you need a point of the tangent (Yflammable; xinert).

$$TCi = y/(x+y) * 100\ \% \qquad (1)$$

This method is useful if you have only a part of an triangular diagram (not up to 100%) or a x/y-diagramme with flammable gas as y-coordinate and an inert gas as x-coordinate.

From the point of view of a Apparatus

This is an abstract of the standard **DIN 51 649**, for determination of limits of flammability of gases, vapours and their mixtures in air. The standard applies to gases at atmospheric pressure and at temperatures from ambient temperature to 200°C. I will only treat the part which considers *gases at ambient tempararure*.

It has to be noted that flammability (or explosion) limits are not substance characteristics in the physical sense because they are influenced by various parameters of the method used for their determination.

Principle of the test method

The test mixture is led through a cylindrical ignition chamber from below towards the top until it is fully purged with the new mixture. Then the forced flow is stopped and an ignition is initiated using an induction spark. The possible flame detachment* is visually observed through the cylinder, which is made of glass. The test substance content is varied step by step until the lower or upper explosion limit hes been determined or until it is certain that there exists no explosion range*.

The apparatus

The standard apparatus consists of (see figure):

Ignition device

- Cylindrical ignition chamber of glass (1) with electrodes (2), inlet pipe for test mixture with three-way cock (3), outlet pipe for test mixture and pressure venting at the upper end.
- Thermocouple with indicating unit (4).
- High-voltage transformer (7) with timer (8).

Metering devices

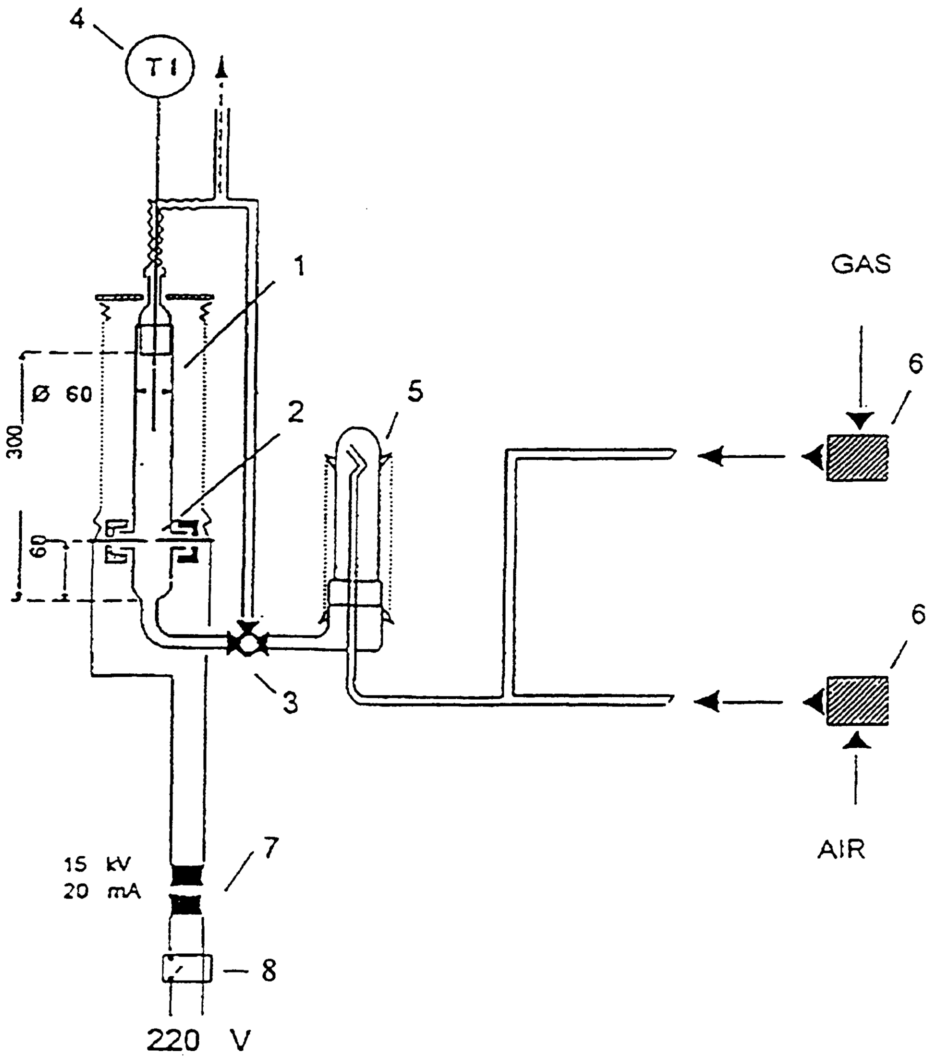
- Metering devices for air and test substances (6): mass flow controllers or gas metering pumps.

Device for the production of test mixture

- Mixing vessel of glass (5)

Device for leading off the gas without risk

Splinter protection



1 ignition chamber
2 electrodes
3 three-way cock
4 thermocouple
5 mixing vessel
6 metering devices
7 high-voltage transformer
8 timer

Figure. Basic diagram of the apparatus for determining the explosion limits of gases.

Further description of the apparatus

The ignition chamber consists of a glass cylinder, 300 mm in height and an internal diameter of 60 mm. The test mixture is introduced into the chamber from below via a three-way cock. At the upper end a waste gas tube is arranged, which is connected to an exhaust system. The exhaust system must not produce sub-atmospheric pressure in the chamber, to avoid leakage the surrounding air into the appartus.

The temperature of the test mixture in the ignition chamber is measured using a thermocouple. As ignition source, an induction spark between two electrodes is used. Tungsten and stainless steel are suitable materials of the electrodes, which are pointed rods with a diameter of maximum 4 mm. The angle of the tips should be 60°. The electrodes are arranged at a level of 60 mm above the bottom of the chamber with a distance of about 5 mm between the tips. The induction spark is produced by a high-voltage transformer, which supplies a voltage with a root mean square value of approximately 15 kV. The short-circuit current has to be 20 - 30 mA, which gives a spark with a power of about 10 W.

The spark discharge time is to be adjusted to 0.5 s, therefore the transformer is connected to the mains via a adjustable timer. If there is a doubt about if there has been a flame detachment or not. the spark discharge time can be reduced to 0.2 s at the most. Mass flow controllers or volumetric gas metering pumps are used to meter the componens in the test mixture. Due to flow conditions in the ignition device, the volume flow rate of the air shall not exceed a maximum value of *two litres per minute* (related to standard state, 0°C and 1 atm).

To achieve a completely homogenous test mixture, it has to be led through a mixing vessel made of glass, before going into the ignition chamber. The mixing vessel can be left out if homogenization is already ensured by the metering device. The metering devices have to ensure that the absolute deviation of the concentrations of the different gas components in the mixture does not exceed the values given in the following table 1.

Concentration of the gas component [vol-%]	Absolute deviation [vol-%]
up to 5	± 0.06
5 to 10	± 0.1
more than 10	± 0.2

Table 1 . Maximum permissible absolute deviation of the gas components in the test mixture.

Gas supply

The gases are usually supplied from pressurised gas bottles. Air may be supplied differently if free of oil and water. The initial pressure required for the metering devices is adjusted using pressure reducers.

Measurement procedure

The temperature in the ignition chamber has to be be kept constant, in this case at 20°C. It shall not differ from this value by more than 5°C.

The determination of the explosion limits consists of a series of attempts to ignite, which are carried out with test mixtures whose test substance content is varied. For reasons of safety, the attempts to ignite are started with a test substance content which lies, if possible, outside the explosion range

The ignition chamber must be purged with the test mixture before each ignition attempt. The purging volume must be at least ten times the volume of the ignition chamber. The three-way cock at the inlet of the chamber is used to stop the flow during ignition and instead lead the test mixture directly through the exhaust system. Then, without flow, an ignition is attempted with the induction spark and it is visually observed whether a flame is detached from the spark gap or not.

If an inflammation (flame detachment*) is observed, the test substance content is iteratively varied until no further flame detachment follows. Close to the explosion limits the step size for the variation of the test substance content is selected as in table 2.

Test substance [vol-%]	Step size [vol-%]
up to 10	0.1
more than 10	0.2

Table 2. Step size for the variation of the test substance in the test mixture close to the explosion limits.

The test mixture with which no further flame detachment* is observed, is used to carry out another five check tests. If all five checks have taken place without flame detachment the limit is determined and if not, the concentration must be varied again by one step and another five check tests carried out.

In order to recognize nul adjustments of the metering devices or leakages, it is useful to check the qualitative composition of the non-ignited test mixture flowing out of the ignition chamber. This can be done using for example a gas chromatograph (not done here at CERN but leak checks were caried out).

Expression of results

The result is estimated from the determined volume fraction in percent of test substance in the test mixture and the absolute deviation. The absolute deviation is determined from the deviation of the test substance content as given in table 1 and by the step size. A smaller deviation is to be stated if it can be derived from the inaccuraces of the test mixture production. The result is given as:
value confirmed by five check tests ± absolute deviation.

Check of the apparatus

It is advisable to check the apparatus. For this purpose, the limits of flammability can be determined for methane and/or ethylene and compared with the results given in table 3.

Test substance	LEL [vol%]	UEL [vol-%]
Methane	4.4 ± 0.1	16.5 ± 0.4
Ethylene	2.3 ± 0.1	32.4 ± 0.4

Table 3. Flammability limits for checking of the apparatus.

Safety advice

The following advices are to be followed:

a) Check the apparatus for tightness.

b) Ensure that the mixtures or waste gases flowing off or leaking out are led off without risk and check the alarm operation for the detection of gas leak (permanent ventilation, 2 detection heads).

c) When mixtures are produced, check whether the substances can be mixed without risk and whether the mixtures can be made available without risk.

d) Take into account potential toxic properties of the samples, test mixtures and waste gases and take up protective measures, if necessary.

e) Guard the high-voltage connections on the transformer, the supply lines and the electrodes in the ignition chamber so that protection against electric shock hazard is ensured.

f) Start the attempts to ignite a test mixture with a test substance content outside the explosion range.

g) Ensure protection in case the ignition chamber bursts. Carry out the work behind a splinter protection device and wear a face shield.

h) In case the ignition chamber bursts, the after flow of explosive mixtures must be immediately prevented by interrupting the test substance supply.

i) Ensure that the vent device on the ignition chamber works.

j) Flammable gas leak detectors at regular interval calibrate.

k) Ensure the ventilation system is working.

l) Shut off all gas bottles at end of test session.

Appendix 31

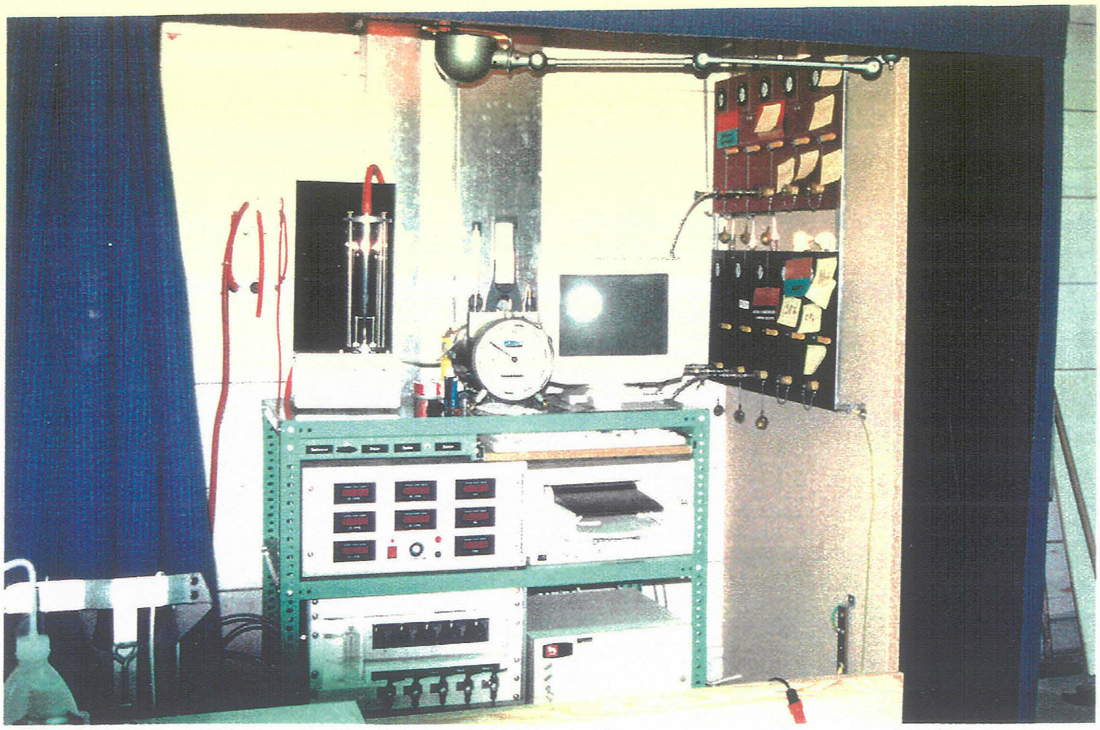
"Pictures of the apparatus"

Picture C1 below shows the entire equipment except the alarm and ventilation systems which are respectively on the right of the picture, just behind the blue curtain and above the picture on the top of the equipment. Nevertheless a part of the ventialtion system is seen just behind the FFT apparatus on the wall. In case of gas leaks, Flammable gas detectors were placed: one is just behind the lamp on the picture for the detection of light flammable gases and the second is behind the FFT apparatus, on the floor to detect the leak of heavy flammable gases. As a detection is raised, the ventilation is increased.

The blue curtain seen on the picture, is used by the operator to put the ignition chamber in dark so that it can see clearly the ignition reaction. The curtain can also protect from the fire and do not burn.

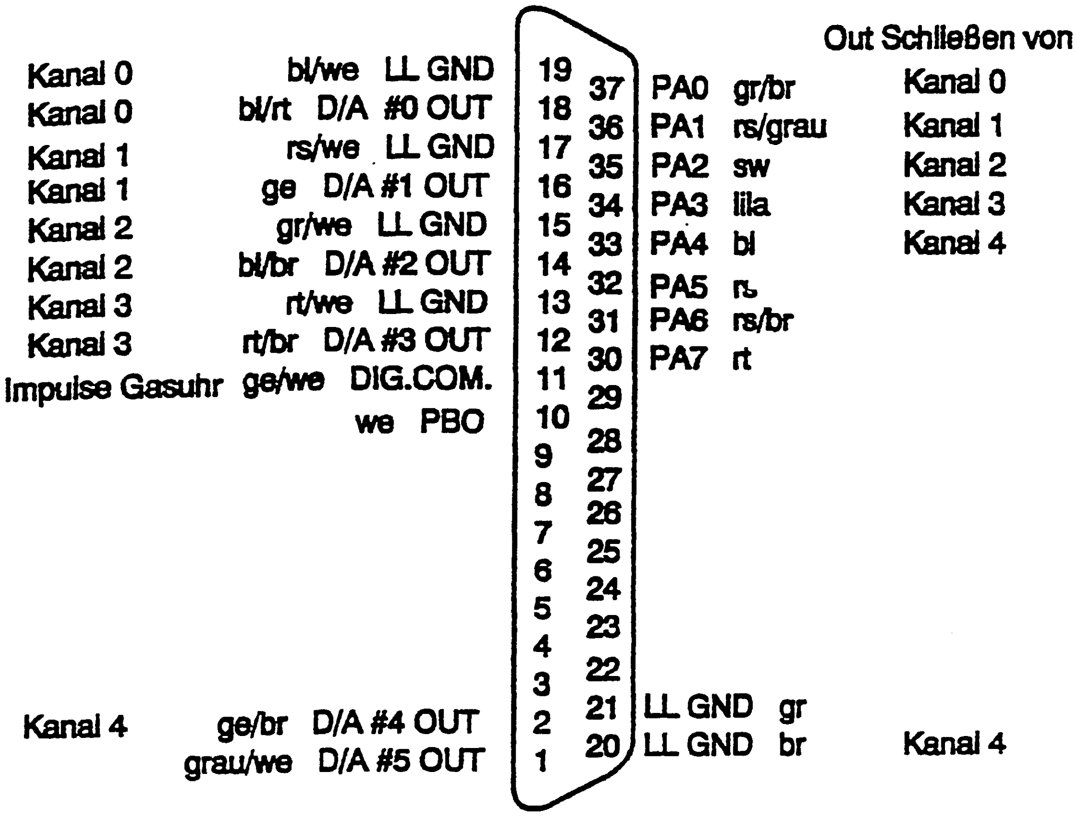
Elsewhere two boards of gases supplies are seen on the right of the apparatus. Both are connected to pressurised bottles of gases stored outside in another building. The red one is the flammable gases supplies board and the black one is used for the inert gases.

Next page is showing the FFT apparatus in details.



Picture C1 The Standard DIN Full Flammability Test equipment

APPENDIX 32

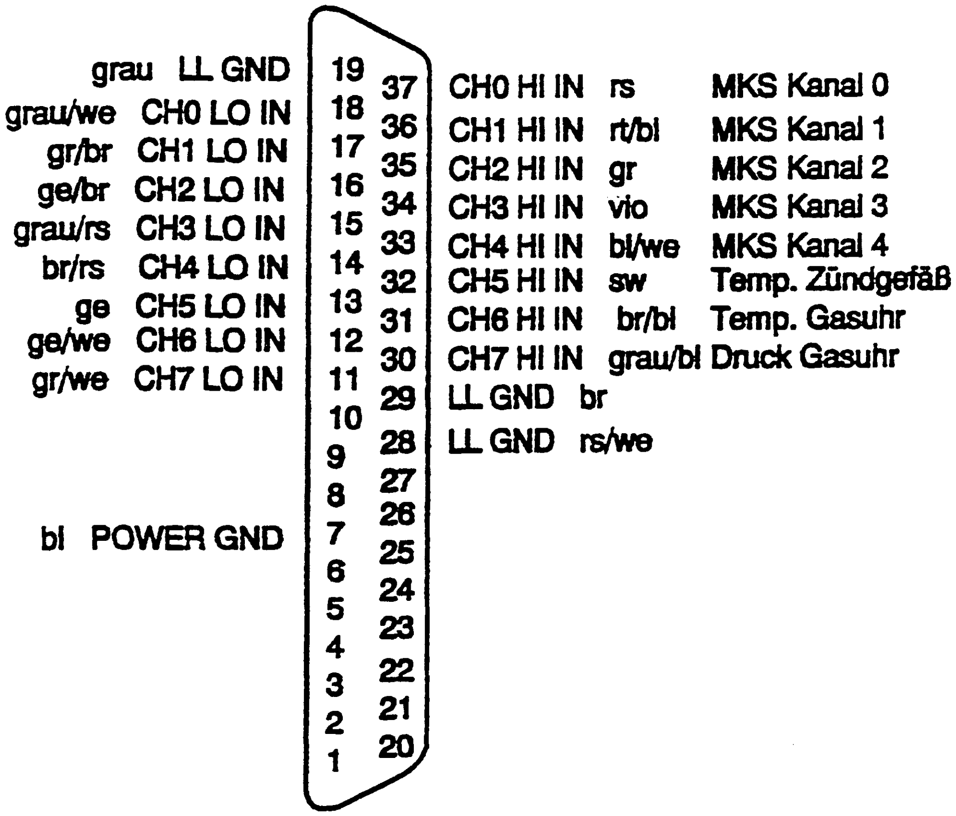


Kanal 0	bl/we	LL GND	19
Kanal 0	bl/rt	D/A #0 OUT	18
Kanal 1	rs/we	LL GND	17
Kanal 1	ge	D/A #1 OUT	16
Kanal 2	gr/we	LL GND	15
Kanal 2	bl/br	D/A #2 OUT	14
Kanal 3	rt/we	LL GND	13
Kanal 3	rt/br	D/A #3 OUT	12
Impulse Gasuhr	ge/we	DIG.COM.	11
	we	PBO	10
			9
			8
			7
			6
			5
			4
			3
Kanal 4	ge/br	D/A #4 OUT	2
	grau/we	D/A #5 OUT	1

			Out Schließen von
37	PA0	gr/br	Kanal 0
36	PA1	rs/grau	Kanal 1
35	PA2	sw	Kanal 2
34	PA3	lila	Kanal 3
33	PA4	bl	Kanal 4
32	PA5	rs	
31	PA6	rs/br	
30	PA7	rt	
29			
28			
27			
26			
25			
24			
23			
22			
21	LL GND	gr	
20	LL GND	br	Kanal 4

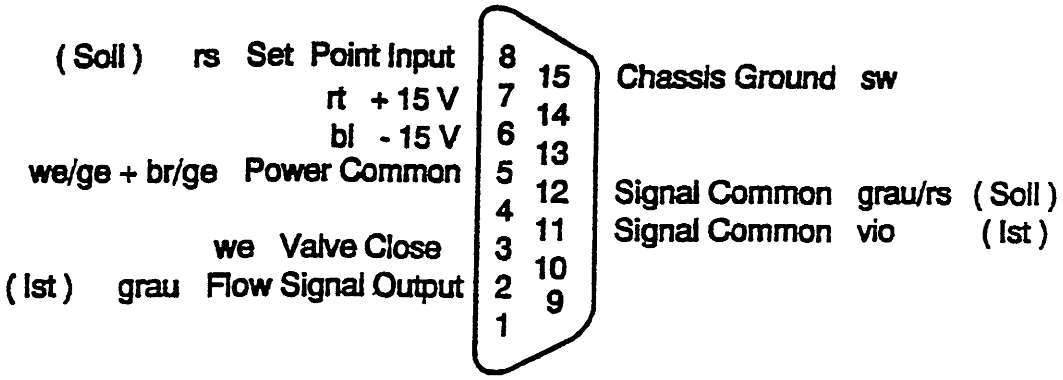
Plan 1:

JS FOR FULL FLAMMABILITY TEST
)DA 06)



Plan 2: STANDARD APPARATUS FOR FULL FLAMMABILITY TEST
DAC CONNECTION (DAS1402)

APPENDIX 34



Plan 3: STANDARD APPARATUS FOR FULL FLAMMABILITY TEST MFC CONNECTION.

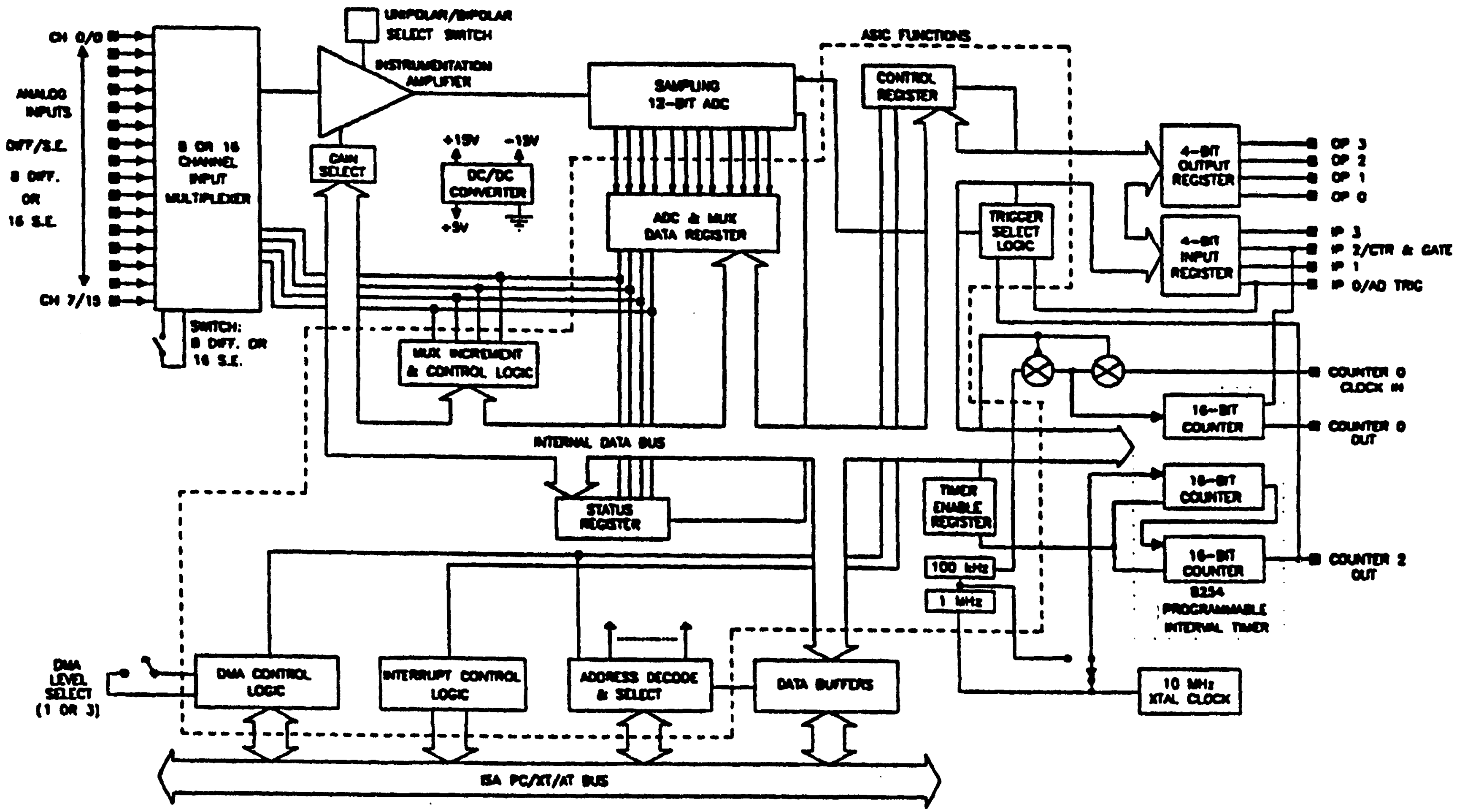
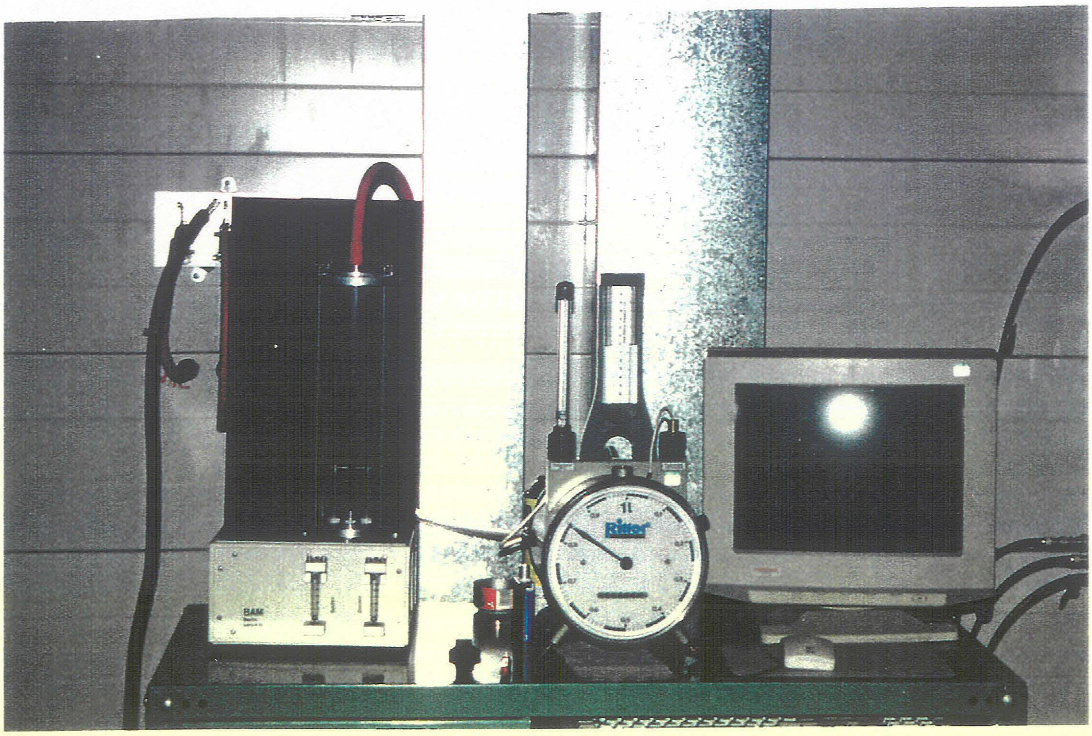


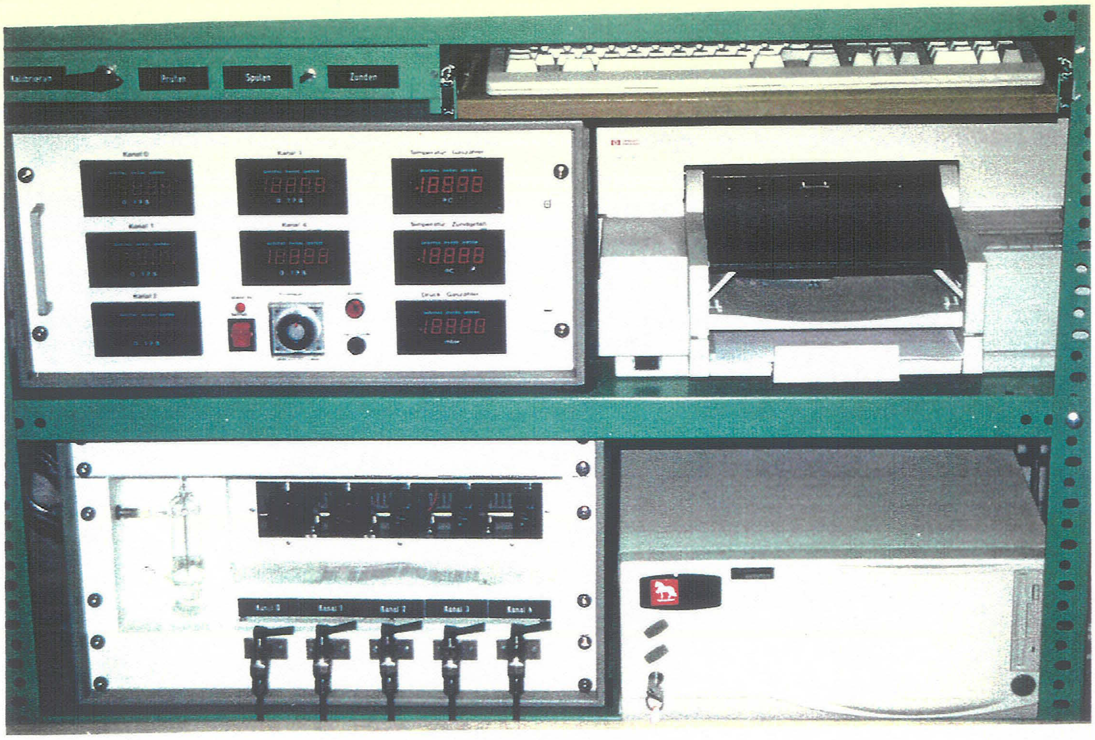
Figure 1-1. DAS-1400 Functional Block Diagram

Picture C2 shows respectively from the left to right: the ignition chamber with the spark electrodes seen at 60 mm from the bottom of the chamber, the gasometer measuring precisely the volume of gas going through and the SVGA monitor from where the FFT operator can control the procedures.



Picture C2

Picture C3 shows respectively from left to right, the control display of the opening of the MFC channel valves with the display of the temperatures of the gasometer and of the ignition chamber and the display to of the atmospheric pressure. The on the other side, there are the keyboard and the printer of the 486 computer which is then placed just beneath.

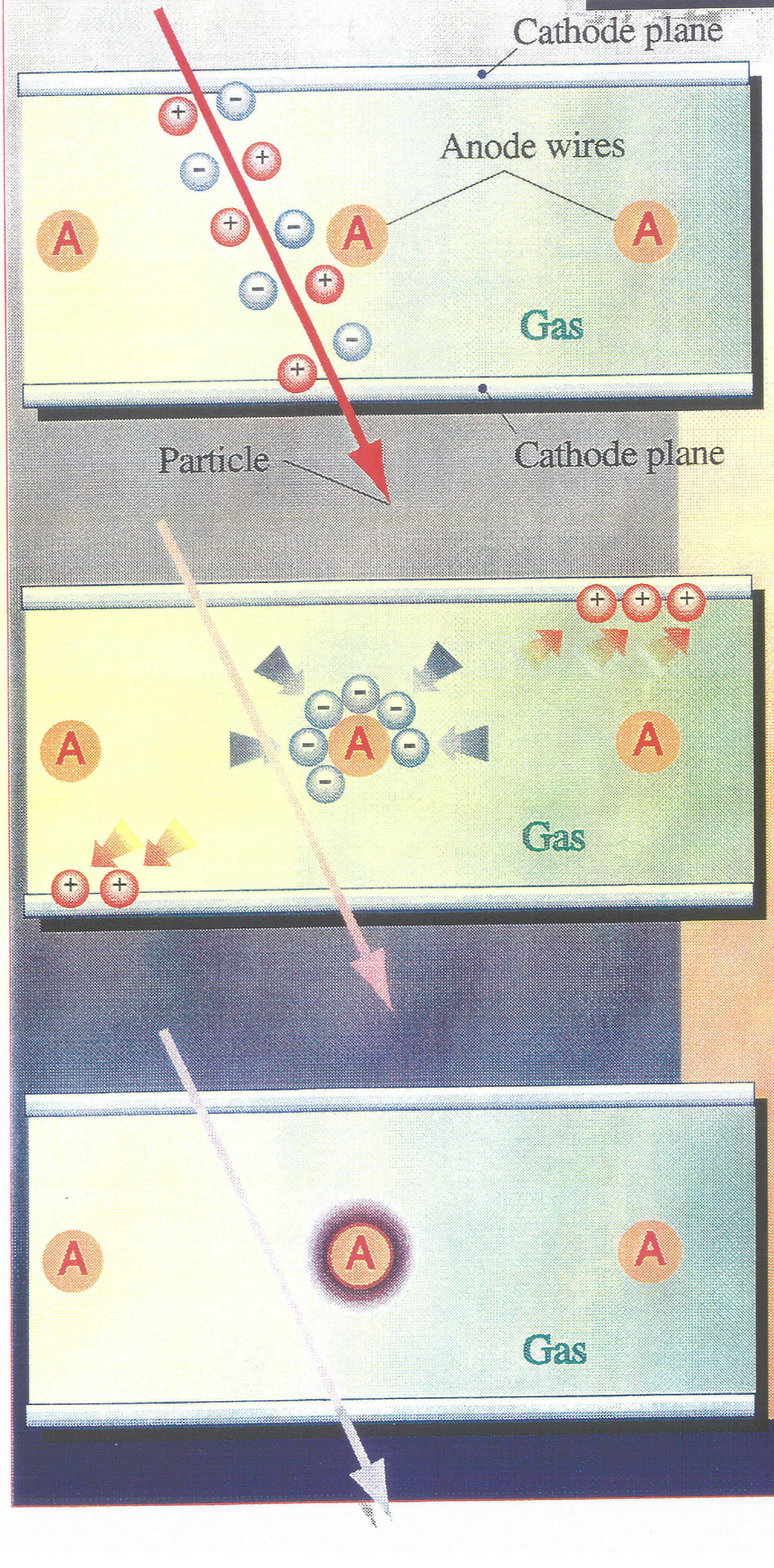


Picture C3

Appendix 5

WIRE CHAMBER :

The film recording the passage of a particle



Ionisation of the gas by the passage of the electrically charged particle .

Ion migration :

- + Towards the cathodes
- - Towards the anodes

Multiplication effect : Electron avalanches near the anode .

Appendix 6

Appendix 4

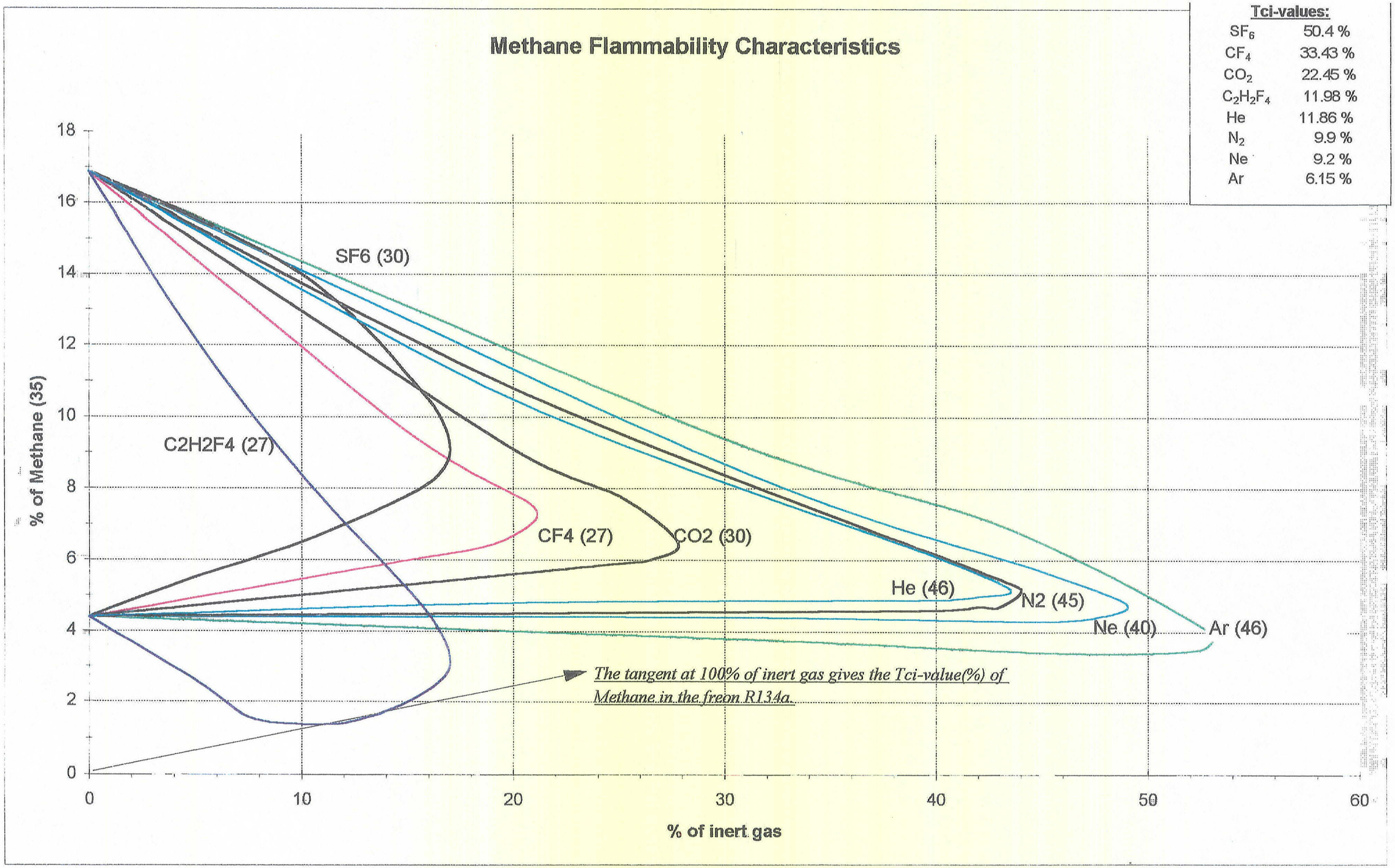
calculated Ki-values

(Coefficient of equivalency of inert gas relative to Nitrogen).

Inert gases			Flammable	gases					
	Hydrogen	Methane	Ethane	Propane	Iso-Butane	n-Butane			
	(45)	(35)	(24)	(35)	(25)	(25)	(30)	Deviation Ki	Average Ki
N2 (45)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00
CO2 (30)		2.27 (+)	1.84	1.87	1.94	1.98	1.83 (-)	0.44	1.95
He (46)		1.20 (+)	1.09	1.04	1.01	1.09	1.00 (-)	0.20	1.07
Ne (40)		0.93 (+)	0.88	0.81	0.79	0.83	0.77 (-)	0.16	0.83
Ar (46)		0.62	0.62	0.65 (+)	0.58 (-)	0.66	0.64	0.07	0.63
SF6 (30)		5.09 (+)	4.13 (-)	4.80	4.74	4.59	4.78	0.96	4.69
CF4 (27)		3.37 (+)	2.63	2.77	2.32 (-)	2.79	2.61	1.05	2.75
R134a (27)		1.21 (-)	1.44	1.57	1.40	–	1.63 (+)	0.42	1.45

These numbers were calculated from the proposed Tci-values only.

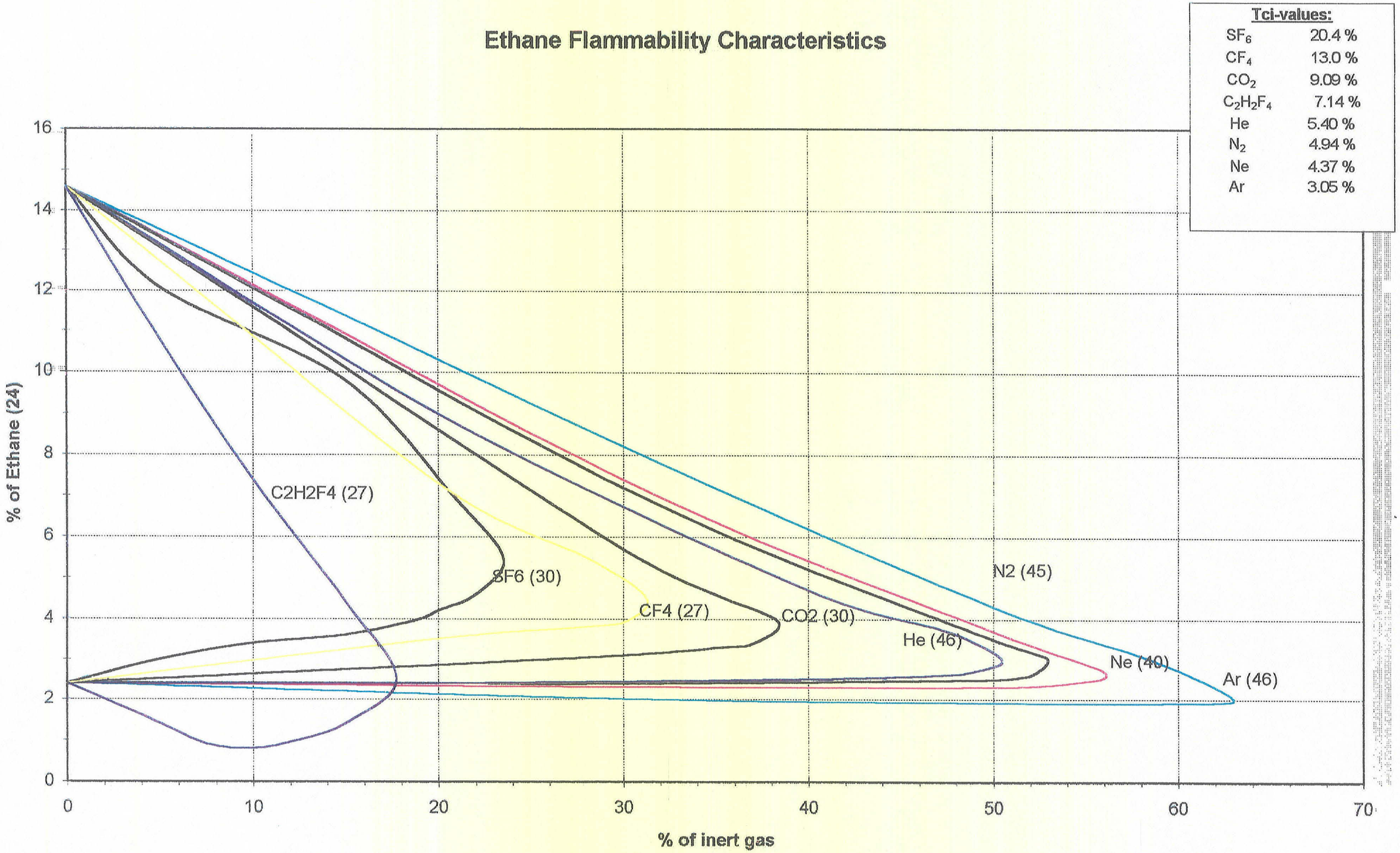
Appendix M


Methane Flammability Characteristics

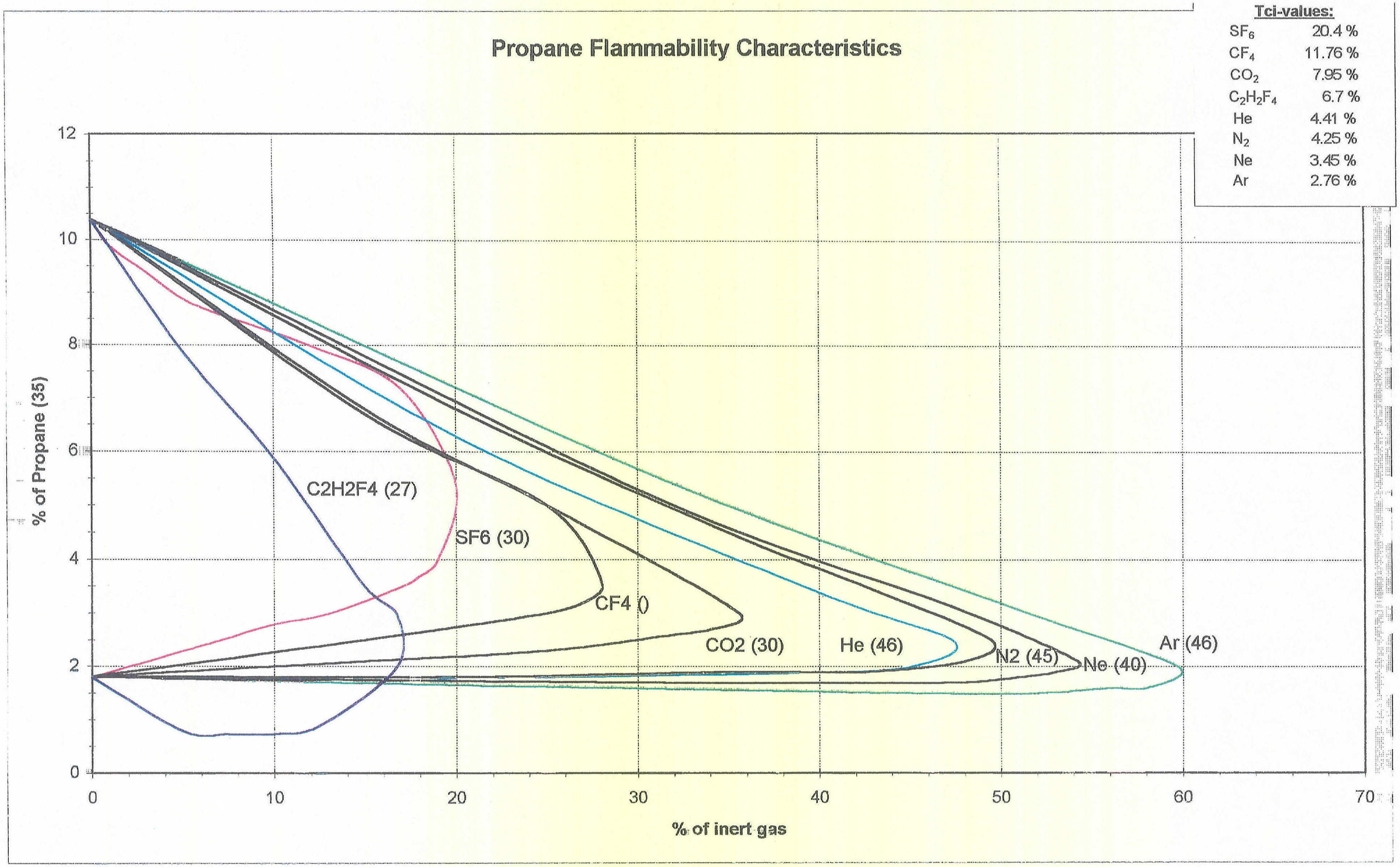
Tci-values:

SF_6	50.4 %
CF_4	33.43 %
CO_2	22.45 %
$C_2H_2F_4$	11.98 %
He	11.86 %
N_2	9.9 %
Ne	9.2 %
Ar	6.15 %

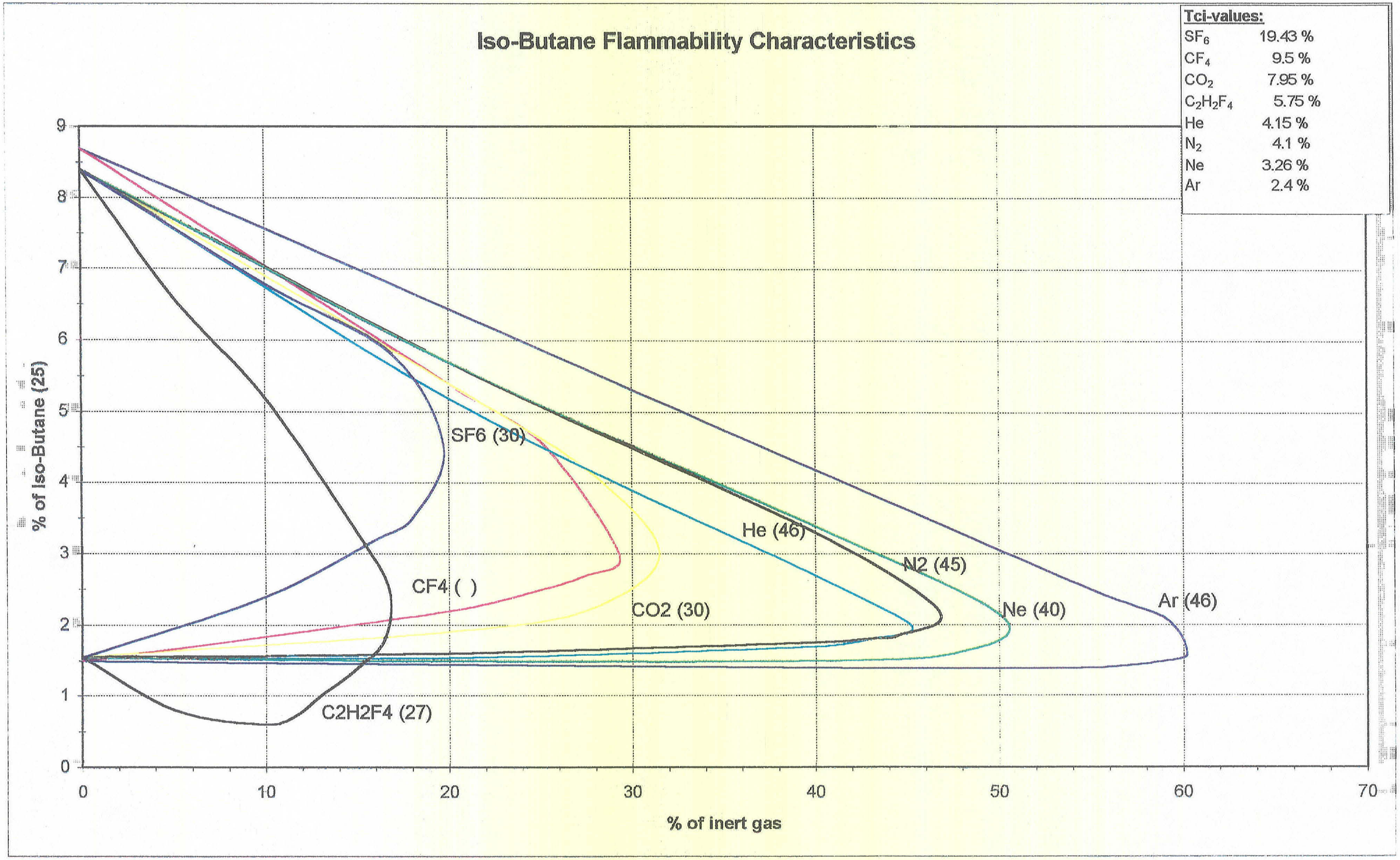
The tangent at 100% of inert gas gives the Tci-value(%) of Methane in the freon R134a.


Ethane Flammability Characteristics
Tci-values:
SF6 20.4 %
CF4 13.0 %
CO2 9.09 %
C2H2F4 7.14 %
He 5.40 %
N2 4.94 %
Ne 4.37 %
Ar 3.05 %
% of Ethane (24)
16
14
12
10
8
6
4
2
0
C2H2F4 (27)
SF6 (30)
CF4 (27)
CO2 (30)
He (46)
N2 (45)
Ne (40)
Ar (46)
0
10
20
30
40
50
60
70
% of inert gas

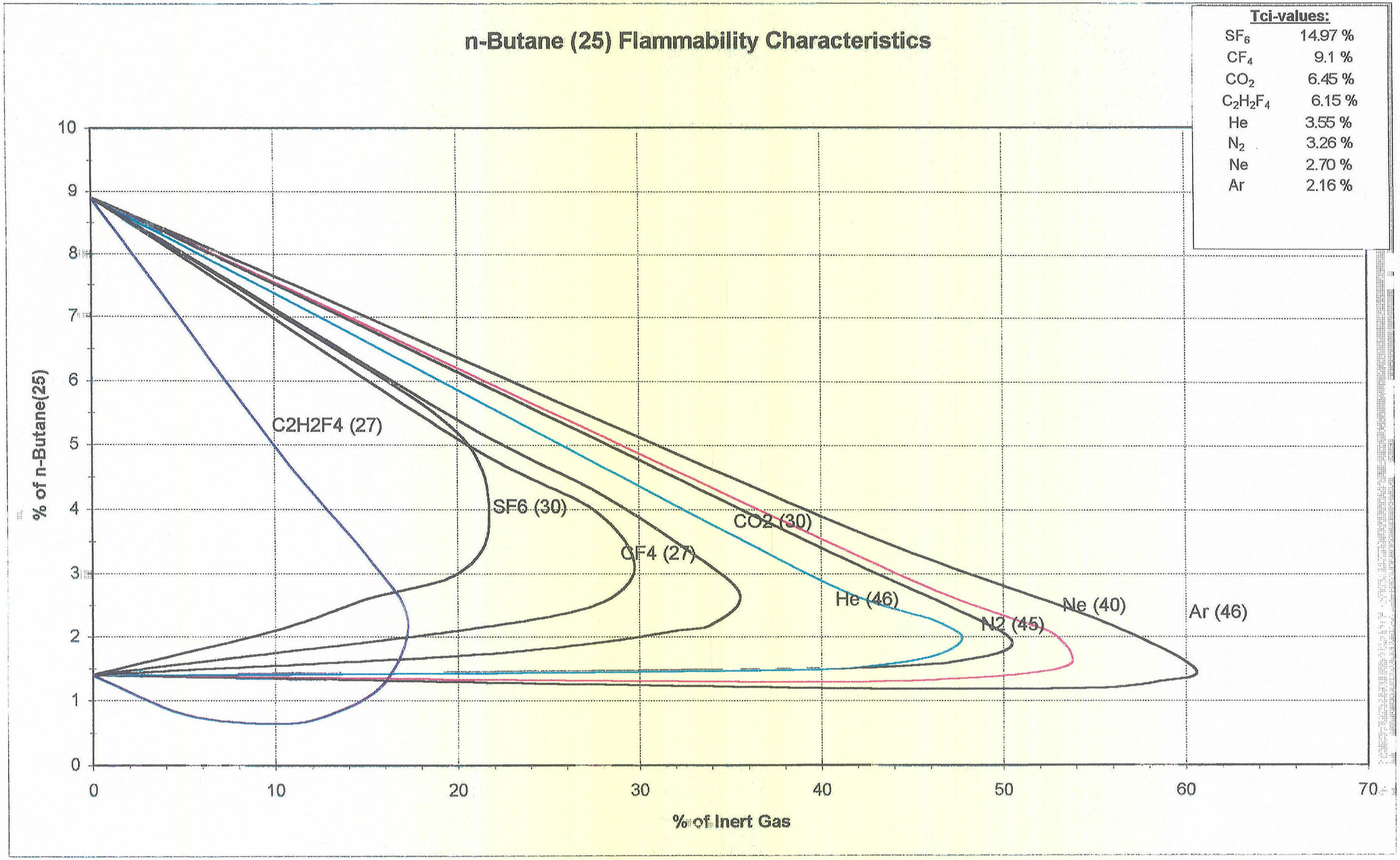
Appendix P


Propane Flammability Characteristics
Tci-values:
SF6 20.4 %
CF4 11.76 %
CO2 7.95 %
C2H2F4 6.7 %
He 4.41 %
N2 4.25 %
Ne 3.45 %
Ar 2.76 %
% of Propane (35)
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
% of inert gas
C2H2F4 (27)
SF6 (30)
CF4 ()
CO2 (30)
He (46)
N2 (45)
Ne (40)
Ar (46)

Appendix I

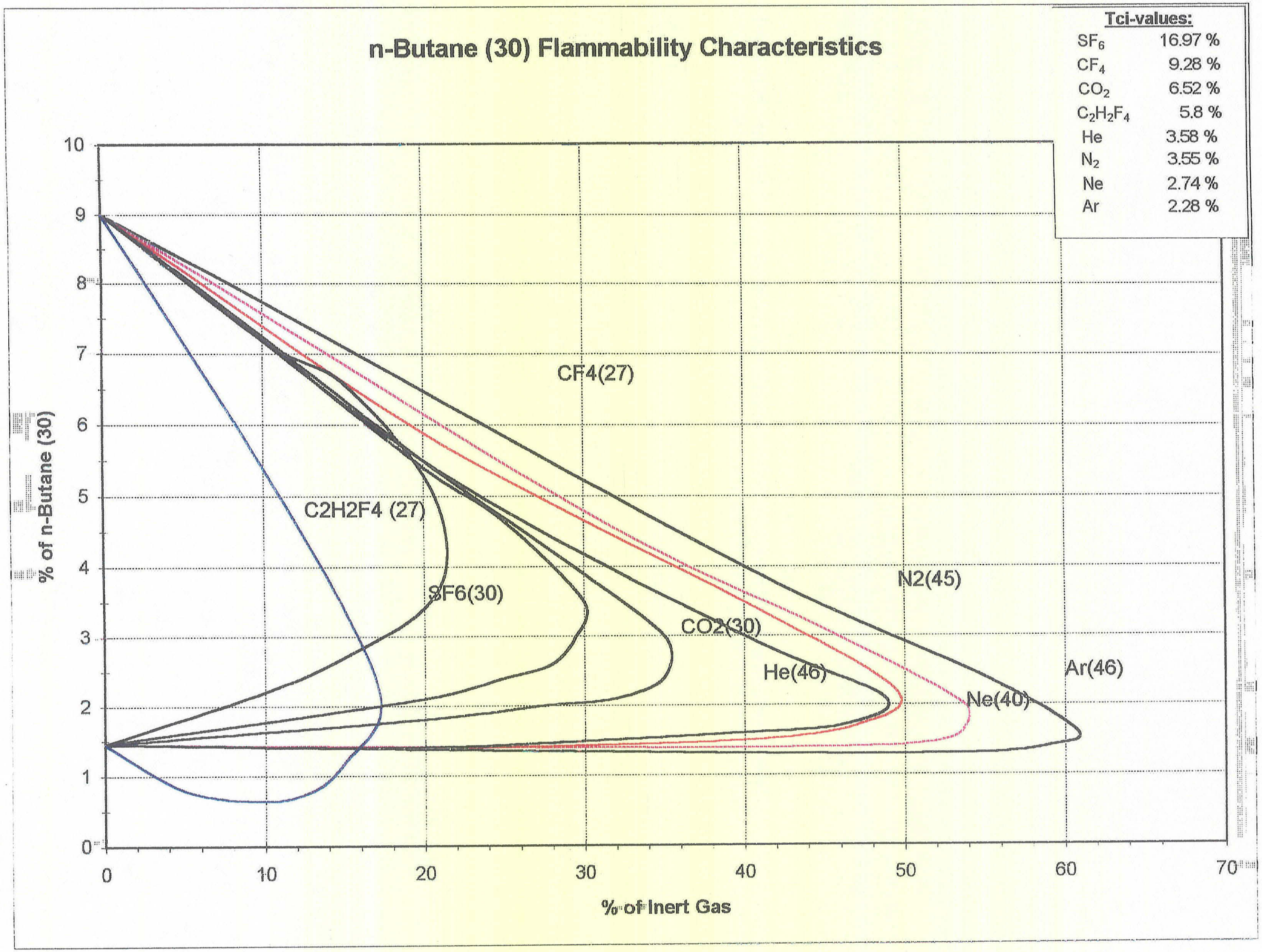

Iso-Butane Flammability Characteristics
Tci-values:
SF6 19.43 %
CF4 9.5 %
CO2 7.95 %
C2H2F4 5.75 %
He 4.15 %
N2 4.1 %
Ne 3.26 %
Ar 2.4 %
% of Iso-Butane (25)
0
1
2
3
4
5
6
7
8
9
% of inert gas
0
10
20
30
40
50
60
70
SF6 (30)
CF4 ( )
CO2 (30)
He (46)
N2 (45)
Ne (40)
Ar (46)
C2H2F4 (27)

Appendix N(25)



n-Butane (25) Flammability Characteristics

Appendix N(30)



Glossary

1 **Flammability** is a measure of how easily a gas, liquid or solid will ignite and how quickly the flame, once started, will spread. The more readily ignition occurs, the more flammable the material. Flammable liquids themselves are not flammable; rather, the vapour from the liquids are combustible. There are two physical properties of a material which indicate its flammability: Flash point and volatility.

2 **Flash point** of a material is the temperature at which a liquid (or volatile solid) gives off vapour in quantities significant enough to form an ignitable mixture with air.Given an external source of ignition (i.e. spark, flame), a material can ignite at temperature at or above its flash point. The flash point of ethyl ether, a highly flammable solvent, is -49° F; kerosene has a flash point between 100 and 150° F. Flammable gases have no flash point, since they are already in the vapour stage.

3 **Volatility** of a material is an indication of how easily the liquid or solid will pass into the vapour stage. Volatility is measured by the boiling point of the material -- the temperature at which the vapour pressure of the material is equal to the atmospheric pressure. The term volatility is often mistakenly used as a synonym for flammability. There are some materials that are volatile but not flammable, such as water, chloroform, and mercury.

4 **Autoignition Temperature (AIT)** of a substance is the minimum temperature required to initiate or cause self-combustion without ignition from an external source of energy.

5 **LEL** (in air) is the minimum content of a gas or gas mixture in air at which the gas or gas mixture will ignite. The limit is determined at atmospheric pressure and 20° C.

6 **UEL** (in air) is the maximum content of a gas or gas mixture in air at which the gas or the gas mixture will sustain combustion. The limit is determined at atmospheric pressure and 20° C.

7 **Tci-value** is the maximum content of flammable gas for which the flammable gas in an inert gas is not flammable in air.

8 **Sample**: A substance or a mixture of substances for which explosive limits are to be determined.

9 **Test substance:** The sample in the gaseous state of aggregation (liquid samples have to be completely evaporated).

10 **Test mixture:** The gas mixture of test substance and air.

11 **Explosion range:** The flammable range with concentrations of the test substance between the lower and the upper limits of flammability. Within the explosive range the combustion is self-propagating.

12 **Flame detachment:** The criterion of self-propagating combustion in this standard is the detachment of a flame from the spark gap used as ignition source. This so called *flame detachment* is visually observed (See figure 1).

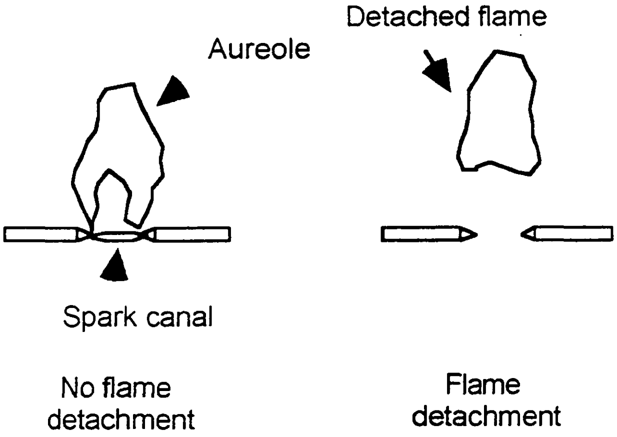


Figure 1. During the ignition spark, test mixtures whose test substance content lies slightly outside the explosion range exhibit a non-detaching luminous phenomenon (aureole) above the spark gap. In the case of certain test substances (e.g. halocarbons), the aureole occupies a large portion of the ignition chamber.

The criterion of ignition is the detachment of the aureole from the spark gap in the form of a flame propagating upwards. The flame does not necessarily have to propagate over the full height or the full diameter of the ignition chamber, but the detachment has to be clearly seen.

13 **Minimum Ignition Energy (MIE)** is the lowest energy of spark that can just ignite the most sensitive mixture of the material in air. Every concentration has its minimum ignition energy.

14 **Limiting Oxygen Content (LOC)** is the maximum amount of oxygen at which no explosion occurs at any gas concentration.

15 **Maximum Experimental Safe Gap (MESG)** is the standardized explosion index to describe the quenching of flames passing through narrow gaps. Fig 2 illustrates a MESG of a system as far as if volume V1 is iniated the propagation will not proceed in V2.

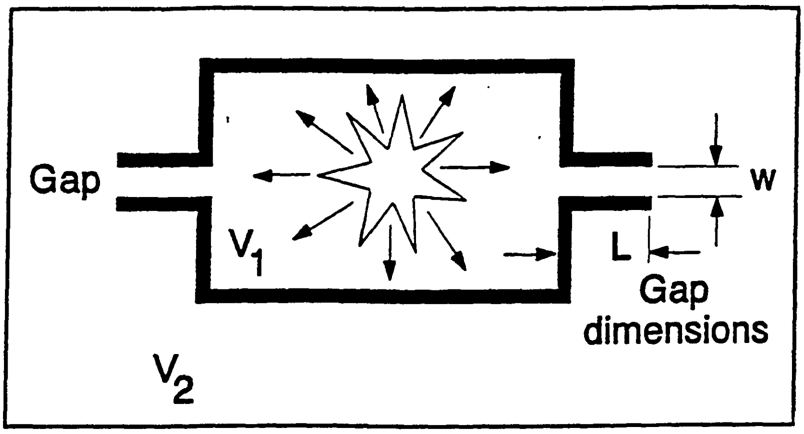


Figure 2. Schematic of a system illustrating the MESG of a system.

16 **FFT** for Full Flammability Test

17 **LHC** for the Large Hadron Collide

18 **Ki-values** are the coefficients of equivalency for inert gases relative to nitrogen. It gives an indication on the quenching power of a particular gas relative to nitrogen. These data are based on experience within the gas industry.