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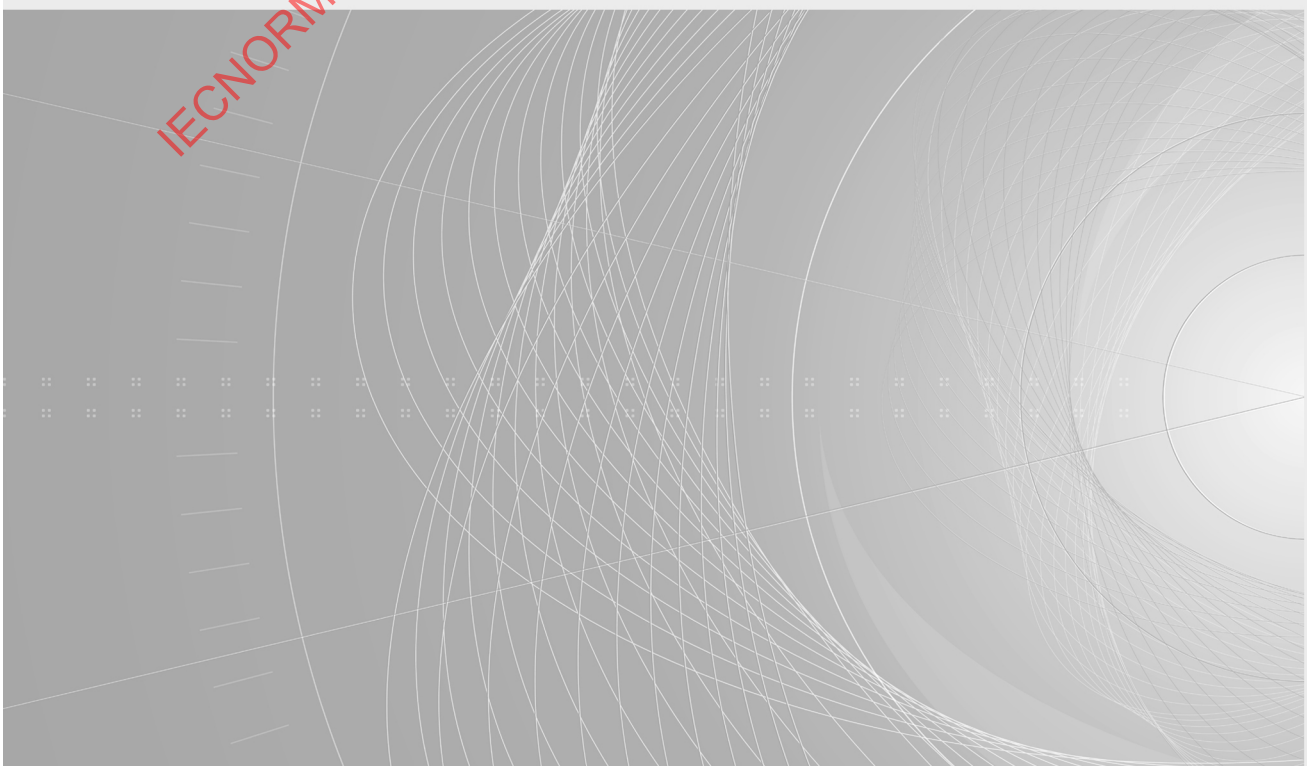
TECHNICAL REPORT

On-line analyser systems – Guide to design and installation



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TECHNICAL REPORT

On-line analyser systems – Guide to design and installation

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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CONTENTS

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ON-LINE ANALYSER SYSTEMS – GUIDE TO DESIGN AND INSTALLATION

FOREWORD

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IEC 61831, which is a technical report, has been prepared by subcommittee 65B: Devices and integration in enterprise systems, of IEC technical committee 65: Industrial-process measurement, control and automation.

With the kind permission of the Engineering Equipment and Materials Users Association this report is based on and includes extracts from EEMUA Publication 138.

This second edition cancels and replaces the first edition published in 1999. This edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below.

- Updated references;

- Made consistent with current practices and regulations;
- Incorporating new technologies where applicable.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
65B/744/DTR	65B/793/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

This Technical Report provides guidance on the design and installation of on-line analyser systems. There are many International standards and documents which are referenced below relating to specific parts of the design and safety of on-line analyser systems. However, there is limited practical guidance available on the overall design concepts, approaches, tools and methodology for the design and installation of on-line analyser systems to ensure they perform with the required reliability and precision which this publication addresses.

The document is divided into eight clauses

1. General
2. Normative references
3. Terms and definitions
4. Remarks and considerations
5. Health, safety and environmental considerations
6. Housings
7. Sampling systems
8. Analyser communications

Individual users of on-line analysers have varying practices but the fundamental approach is generally similar. It is therefore hoped that this document will encourage standardisation within industry and lead to reduction in design and construction costs and to improved safety.

The word "analyser" has been used throughout this document to refer to instruments variously known as on-line analysers, process stream analysers, quality analysers, quality measuring instruments and process quality monitors.

Where reference is made to International standards it should be noted that National authorities may have statutory requirements that are mandatory.

ON-LINE ANALYSER SYSTEMS – GUIDE TO DESIGN AND INSTALLATION

1 Scope

This technical report is a guide applicable to on-line analyser systems. It provides the necessary guidance for the system supplier and user to specify or design a complete analyser system from sample point in the process to the final output for display or control purposes.

2 Normative references

IEC 61285:2004, *Industrial-process control – Safety of analyzer houses*

ISO/IEC 8802-3:2000, *Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*

BS 5925:1991, *Code of practice for ventilation principles and designing for natural ventilation*

API (ANSI/ASTM D4177), *Manual of Petroleum Measurement Standards – Part 8: Chapter 8.2 Automatic Sampling of Petroleum Products ()*

EEMUA 175, *Code of Practice for Calibration and Checking Process Analysers (Formerly IP 340)*

3 Terms and definitions

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

3.1
analyser housing
general term including any of the following terms:

3.2
analyser case
enclosure forming part of the instrument

3.3
analyser cabinet
small simple housing in which analysers are installed singly or grouped together. Maintenance is carried out from outside the cabinet

3.4
analyser shelter
structure with one or more sides open and free from obstruction to the natural passage of air, in which are installed one or more analysers. The maintenance of the analyser is normally carried out from within the shelter

3.5
analyser house
enclosed structure in which are installed one or more analysers. Either natural or forced ventilation is used. The maintenance of the analyser is always carried out from within the house

4 Remarks and considerations

4.1 General remarks

The petrochemical, chemical, pharmaceutical and food industries need to be able to control their processes to ensure safety and environmental compliance and to optimise operations for maximum profitability. The use of on-line process analysers is a valuable tool in helping to achieve these objectives. This is because analysers provide frequent (continuous or cyclic) analytical information on key process properties to allow continuous on-line optimisation of the plant and rapid identification and correction of off-spec or undesirable operating conditions. Analyser repeatability is also usually better than a laboratory reference method which allows closer control and targeting to product specification.

However, the correct design and installation of on-line analysers which are addressed in this publication are essential to achieve the full benefits from the analyser systems. Analysers are expensive to install and maintain and should only be installed when there is a clearly defined and quantified benefit. On-line process analysers are usually justified for one or more of the following reasons:

a) Personnel and plant safety
b) Pollution measurement, prevention and control
c) Optimising plant operations for yield and throughput
d) Control of final products as closely as possible to maintain specification and minimise product quality give-away
e) Minimising product degradation and reprocessing costs in cases of plant upsets, change in mode of operation and start-ups
f) Improving energy efficiency of boilers, furnaces, distillation columns and reactors
g) Corrosion control

4.2 Further considerations

The following considerations are also important in the application of on-line analyser systems:

a) Analysers and associated sampling systems are often complex installations demanding attention from specialist personnel responsible for their maintenance. Therefore, it is essential that the end user has the appropriate, correctly trained manpower resources and spare parts available to ensure the analysers operate at the required level of performance to capture the anticipated benefits
b) The justification for analysers is not usually based on the reduction in the cost of laboratory testing as this saving is often offset by the associated increase in analyser maintenance costs. To promote the effective use of analysers by operators it is often beneficial to discontinue the duplication of analyses by laboratory testing. Laboratory facilities are still required for validating and calibrating the on-line analyser systems and for any statutory requirements
c) Single stream analysers are preferred and are usually essential for continuous automatic control
d) On-line analysers usually require environmental protection in the form of housings to ensure reliable operation

4.3 Reliability

The following points are important considerations in the design and installation of analyser systems:

a) Correct location and orientation of sample point
b) Proper design of the sample transport and sample conditioning systems
c) Availability of reliable and clean utilities
d) Environmental protection against heat/cold, humidity, solar radiation, rain, dust and corrosion
e) Ease of accessibility for maintenance of all the analyser system components
f) Proper design of validation and calibration facilities
g) Adequate preventive maintenance

4.4 Design

The design should permit maintenance, adjustments and repairs to be carried out quickly and preferably whilst the analyser is in operation. Components likely to require attention should be accessible without the aid of portable ladders or other temporary means and shall have mountings/fixings located such they are also accessible from the front. The overall design should eliminate or keep to a minimum the emission of hazardous or noxious gases and vapours and the possibility of liquid spillage.

4.5 Centralisation

The grouping together of a number of analysers where practical in a shared analyser house or shelter has a number of advantages:

a) Single housing
b) Common multi-core signal cables to control system
c) Common location for power, water, steam and compressed air supplies. Common drain, vent and purge lines
d) More efficient for maintenance
e) Common heating, ventilation and air conditioning (HVAC) systems

4.6 Local mounting

There are, however, cases where local mounting is desirable for the following reasons:

a) When the cost of centralisation would be disproportionate to the expected benefit
b) When centralisation would result in excessive sample transport time lags
c) When sample handling problems are to be expected e.g. waxy samples, trace components

4.7 Pre-assembled systems

Pre-assembled analyser systems supplied by specialist analyser systems contractors or the analyser vendors are generally the most convenient and economical approach to install new analyser systems in the plant. They may include one or more analysers with their associated sample conditioning system and common utility connections mounted together in the appropriate housing(s). There are many advantages to this approach:

a) Systems designed and factory constructed by a specialist supplier are generally superior to those produced in the field by a contractor on site
b) Detailed design and field construction by site contractor are reduced
c) Factory construction is independent of weather and labour conditions at site
d) Manpower at site is not usually skilled and experienced in this type of work

e) Systems can be fully tested under simulated operating conditions and major design, equipment and construction faults corrected before delivery to site

f) Proven designs can be used with consequent savings in costs and improved reliability

g) All relevant documentation can be incorporated into a single design and operating manual by the specialist supplier

5 Health, safety and environmental considerations

5.1 Overview

Analyser systems shall be designed, installed and operated in such a manner that they are non-hazardous to personnel, to the process plant and to the environment.

The principle hazards are ignition of flammable substances, contact with toxic substances, asphyxiation in enclosed spaces and release of harmful or polluting materials to the environment. It is also important that personnel coming into contact with analyser systems do not suffer injury from additional hazards such as burns, electric shock and cuts from exposed sharp edges.

A number of statutory requirements pertaining to safe design and practices are in force in many countries e.g. the ATEX and PED Directives in Europe. There are also specific standards relating to the safety of analyser systems e.g. IEC 61825. (See Clause 2 for normative references and bibliography for other references.).

5.2 Prevention of explosions and fires

The same conditions apply to the installation of analysers as with installation of any other electrical equipment in electrically classified hazardous areas and the appropriate relevant legal regulations and standards should be followed for the country in which the equipment is being installed.

The extent to which the measures need to be applied can be minimised by restricting the likely size of an internal release in the housing by:

a) Minimising and restricting the quantity of potentially dangerous materials entering the housing

b) Reducing the number of joints in sample lines

c) Using the lowest possible operating pressures

d) Reducing the power dissipation of the electrical equipment installed within the main enclosure of the equipment

e) Ensuring that the design does not produce surface temperatures above the ignition temperature of the gases or vapours that may be present

5.3 Prevention of toxic and asphyxiant hazards

When a system is designed, the toxicity of the substances should be considered so that under the worst fault conditions, the legal short-term exposure limits of the substances in the atmosphere are not exceeded. The design shall also ensure that, under the worst fault conditions, the atmosphere inside enclosed spaces which personnel may also enter, cannot reach asphyxiating levels. It should be noted that many substances will reach the short-term exposure limit or asphyxiant levels long before the lower flammable limit value.

Analysers handling toxic substances may need to be separately housed and clearly identified.

Sampling systems containing toxic or otherwise dangerous substances should be purged with air or an inert material prior to disassembly. Warning signs shall be provided to alert personnel to possible toxic and asphyxiate hazards.

Certain analysers contain toxic components and care is needed during maintenance e.g. reagents in wet chemical analysers and certain materials of construction. Toxic calibration samples shall be stored and piped from outside analyser housings.

5.4 Radiation hazards

Apparatus and enclosures containing radioactive sources shall be clearly identified and handled in accordance with the relevant statutory regulations.

5.5 Safety facilities

Gas monitoring and alarm systems for flammable, toxic and asphyxiant substances should be installed in enclosed analyser houses and cabinets as necessary. Fire extinguishers and/or fire blankets should be made readily available at housings containing flammable substances. Fire detection and automatic suppression equipment may also be appropriate. Escape facilities should also be provided as necessary.

Housings containing toxic, acid or alkaline materials should have eye baths and showers in a readily accessible nearby location.

5.6 Manual shut-down facilities

Manual shut-down devices for the incoming power, sample, carrier gas and other potentially hazardous utilities should be fitted close to the analysers. In the case of analyser cabinets, shelters or houses, these devices should be clearly identified and located outside the housing.

A separate shut-down device should be fitted for any associated house ventilation fans.

5.7 Noise

Attention should be paid to noise levels within analyser housings to ensure maximum short term and long term noise exposure limits are not exceeded. The most likely sources of noise are from heating air conditioning and ventilation systems, water chiller units, air vortex coolers, purge systems, pneumatic valve switching and sample pumps.

6 Housings

6.1 Overview

Analysers and analyser sampling systems require varying degrees of protection, depending on the type of analyser, importance of application and the environment in which it has to operate. Where the instrument case itself is not suitable for the working environment, additional protection should be provided. This additional protection is to ensure satisfactory performance of the instrument and to facilitate maintenance.

The selection of the housing required for a particular analyser system depends on a number of factors, such as:

a) Hazardous area classification of the area in which the analyser is to be located

b) Special requirements specified by the relevant safety authority, vendor or user

c) Range of ambient conditions at site (e.g. temperature, rain, humidity, snow, wind, dust/ sand, direct sunlight, corrosive atmosphere)

d) Environment specified by the analyser vendor for reliable, accurate and/or safe operation

e) Protection required for equipment and personnel during maintenance operations

f) Maintenance and accessibility requirements of the system components

g) The initial installed cost

This section primarily describes analyser housings located in hazardous areas and/or into which hazardous samples are introduced. Analyser housings located in a non-hazardous area and into which no flammable, asphyxiate or toxic samples, services, calibration mixtures, or air from a hazardous area is introduced are only required to provide the necessary environment for accurate and reliable operation without any special conditions for ventilation.

Four types of housing, as defined in Clause 3 are considered:

a) Analyser case
b) Analyser cabinet
c) Analyser shelter
d) Analyser house

6.2 Selection of housing

6.2.1 Analyser case

Analysers such as pH meters, electrolytic conductivity meters etc. may be installed directly in the open (enclosed only in the case) provided they comply with the specification of hazardous area classification and environment.

The advantages of this method are that the area around the case is naturally ventilated so there is no risk of accumulating an explosive atmosphere outside the casing. This is the lowest cost method of installation. The disadvantages are that there is no weather protection for equipment or maintenance personnel. Equipment shall be carefully specified to minimize corrosion attack and it may not have as long an operational life as equipment which is installed in a cabinet, shelter or house. This method of housing is not suitable when analysers require heating or extensive maintenance.

6.2.2 Analyser cabinet

Analysers can be installed singly or grouped in cabinets provided that the equipment is installed in accordance with the hazardous area classification. Analyser cabinets provide a low cost means of improving environmental protection for analysers and can help make the equipment more easily accessible for maintenance.

The analyser manufacturers environmental specifications can be met by e.g. including heater in the cabinet if required. Ventilation where necessary is normally achieved by natural means. The advantage of a naturally ventilated method is that ventilation is permanent and independent of mechanical failure.

However, natural ventilation does not change the hazardous area classification inside the cabinet and where a non-certified analyser with cabinet is to be installed in a hazardous area a certified air purge system will be required. The disadvantages of cabinets are that there is a practical limit on the size of analyser installed and no protection is provided for maintenance personnel.

6.2.3 Analyser shelter

This construction can be used when the analysers comply with the hazardous area classification of the location and the ambient environmental conditions comply with the analyser manufacturers specification. A shelter may be conveniently used for equipment requiring minimal protection.

A shelter is advantageous where highly toxic materials are handled. The advantages are that it facilitates the grouping of analysers and affords some protection for maintenance personnel, as well as affording permanent natural ventilation. Its disadvantage is that it does not give the

facility to change the hazardous area classification and affords only minimum environmental protection.

6.2.4 Analyser house

The analyser house is the highest cost installation but is usually justified for analysers, which require a high degree of protection, which are expected to require regular attention and from which a high service factor is required. These analysers may be installed in an analyser house which affords a controlled environment for operations and maintenance, and should reduce long term maintenance costs.

This type of protection is essential where extreme ambient conditions are encountered. The two alternatives for the ventilation system are either the natural ventilation system or the forced ventilation system.

The natural ventilation system provides limited control of the environment and the area classification within the house will always be the same as the surrounding atmosphere.

The advantages are a simpler and cheaper installation, since natural ventilation is permanent and independent of mechanical failure. The forced ventilation system can closely control the environment within the structure and the area classification within the house can be chosen depending on the source of the ventilation air. An advantage is that uncertified equipment can be used in the house provided ventilation air is drawn from a safe area and safety interlocks are included to isolate the equipment when the ventilation system is not operating.

6.3 Area classification and toxic danger

6.3.1 Electrical area classification

The area within the above house, shelter or cabinet should be classified in accordance with the appropriate local regulations. These documents will lay down the type of equipment which is necessary and the precautions which must be taken to achieve the required level of safety within the housings. All equipment used in these housings should be suitable for use in accordance with the area classification.

6.3.2 Toxic and asphyxiate danger

Ventilation requirements for an analyser housing into which toxic materials are introduced should ensure that the relevant occupational exposure limit for those materials is not exceeded under normal or any likely fault condition. Entry into a housing where toxic materials can be present above the occupational exposure limit should be prohibited without supervision and appropriate means of detection and protection. A warning sign of the possible presence of a highly toxic gas within the housing should be given on doors or case.

Ventilation requirements for an analyser housing into which asphyxiate materials are introduced should ensure that dangerous asphyxiate levels are not exceeded under normal or any likely fault condition. A warning sign of the possible presence of an asphyxiate gas within the housing should be given on doors or case.

6.4 Construction and mounting

6.4.1 General

The preference for the type of construction within the options below should be specified by the user.

6.4.2 Analyser housings

The following guidelines are applicable to all types of analyser housing: Materials of construction should be of fire-resisting material and be resistant to attack from oil and chemicals. Other environmental factors such as high humidity, frost, solar radiation, etc. should also be considered. When used as a support for equipment the enclosure should have sufficient rigidity to minimise vibration.

Where necessary, anti-vibration mountings and flexible pipe connections should be used to isolate vibration-sensitive analysers from pipework or structural vibration. Lighting should be provided to give adequate illumination for operations and maintenance. Lighting shall remain operational at all times and shall be suitable for Zone 1 hazardous areas.

Heating and air conditioning should be considered when extreme temperature and/or high-humidity conditions are expected. Heater surface temperature should not exceed the temperature allowed by the area classification and the heater element should be shielded against accidental contact by personnel.

Where ambient conditions or heat release within the analyser house results in unacceptably high temperatures air conditioning should be considered.

Where any form of environmental temperature control is considered within the housing, the wall and roofing materials and construction should be designed to minimise heat loss. This also applies to minimizing heat gain within the housing due to solar radiation. Where cavity walls are used care shall be taken to ensure gas or liquid cannot build up within the cavity.

6.4.3 Analyser houses

The following points are applicable to analyser houses:

a) Construction is typically of brick, concrete, stainless steel sheet or glass reinforced plastic/marine ply sandwich.

b) Outward-opening doors should be provided at both ends of the housing to permit easy escape in an emergency. The position and size of doors and the access to them should be arranged to permit removal of equipment housed. Lockable doors should be avoided. Where these are considered essential, the doors must be capable of being opened from the inside in the locked condition and crash bars shall be provided on all doors.

c) Safety-type windows of a suitable material should be provided in each door unless specifically excluded by the user or safety authority.

There should be unobstructed internal headroom of at least 2 m. Dead corners and trenches that may collect gas should be avoided. Equipment such as, sample conditioning units, gas cylinders, calibration sample containers, and laboratory sampling points shall be located outside the housing with appropriate weather protection, unless otherwise specified by the user.

Roofs shall be inclined to prevent accumulation of water. Suitable vents shall be installed at the highest and lowest points to prevent the accumulation of gas pockets. Where the housing is to be mounted on a concrete base it should be impervious to hydrocarbons, raised at least 0,1 m above the surrounding area and sloped to a suitable point outside the housing for draining of any spillage and cleaning.

6.4.4 Analyser shelters

The following points are applicable to an analyser shelter:

It should have a ventilated roof and the lower edge of the side sheeting terminated at a minimum height of 0,5 m above the ground. Consideration should be given to mounting equipment above the lower edge of the side sheeting.

6.5 Analyser housings with natural ventilation

6.5.1 General

Natural ventilation is defined as ventilation induced by external wind forces and/or thermal gradients between inside the house and outside. Natural ventilation does not rely on mechanical means.

The following subclauses 6.5.2 and 6.5.3 apply only to houses and cabinets.

6.5.2 Ventilation requirements

The ventilation rates should be designed to dilute and dissipate any dangerous release (flammable, toxic or asphyxiate) within the house or cabinet.

By its very nature, the mechanism of natural ventilation does not give close control over ventilation rates. Statistical data is required on wind speeds, directions and frequencies at the proposed location of the house. From this data and knowledge of heat dissipated within the house from equipment (excluding environmental heaters) ventilation areas can be calculated.

The mode of ventilation (wind induced or thermally induced) which gives the smaller area requirements should be used. Wind calculations should use the minimum average wind speed exceeded for 90 % of the year. Wind or thermally induced calculations should use as a basis, a minimum of 10 changes/hour or the number of changes necessary to:

a) dilute escaping vapours from the rupture or failure of the most hazardous sample or service line to less than 20 % Lower Explosive Limit (LEL) around any potential means of ignition. Particular attention shall be paid to those liquids which vapourise at ambient temperatures. Dilute to below the occupational exposure limit any toxic gases/vapours introduced into the house by accidental rupture of any one sample or service line within the house:

b) dilute to below the asphyxiate level any asphyxiate vapour/gases introduced into the house by accidental rupture of any one sample or service line within the house. Wind induced ventilation rates should also be calculated for maximum average wind speeds using a gusting ratio of 1,6. If resulting ventilation rates exceed 50 changes/hour then comfort factors will deteriorate.

6.5.3 Heating requirements

With the above design procedure the temperatures in the house will essentially follow that of the outside ambient temperatures. To improve temperature control, thermo-statically controlled heating can be included. The heater banks should be sized to give a maximum exit air temperature of between 50 °C and 55 °C with the heater full on.

The air flow across the heater should not exceed the equivalent of 20 to 30 changes/hour in the house. With heating inputs as above it may be found that with a nominal temperature control setting on the thermostat of 20 °C a somewhat lower temperature will be achieved on the coldest days. This low value can be assessed by re-calculating the thermally induced ventilation rates. However, increased heat input is not recommended on the grounds that it would be wasteful.

Fan assistance can be included to aid distribution of the warm air. Warm air should be distributed in the lower half of the house as close to the lower vents as possible.

Annex D shows a worked example.

6.5.4 Analyser shelters

Shelters should be designed to prevent accumulation of gases and liquids.

6.5.5 Analyser cases

The manufacturers' installation requirements should be followed.

6.6 Analyser housings with forced ventilation

6.6.1 General

Forced ventilation is defined as ventilation achieved by mechanical means such as fans. The following paragraphs are applicable to analyser houses. Shelters by definition are naturally ventilated, cabinets and cases are not normally force ventilated.

6.6.2 Ventilation requirements

The house should be ventilated with air to keep flammable or toxic gases, either lighter or heavier than air out of the house, and to dissipate any leakage inside the house. Air should enter and leave the house by entry and exit ports as discussed in 6.6.5. The minimum differential pressure under operating conditions should be 25 pascals (0,25 mbar). It is normal practice to operate at an overpressure of 2 mbar to 5 mbar. The minimum air flow shall be 10 changes/hour (10 changes/hour is recommended but shall be at least 5 changes/hour according to IEC 61285) and sufficient to:

a) dilute escaping vapours from the rupture or failure of the most hazardous sample or service line to less than 20 % LEL around any potential means of ignition. Particular attention shall be paid to those liquids which vaporise at ambient temperatures;

b) dilute to below the occupational exposure limit any toxic gases/vapours introduced into the house by accidental rupture of any one sample or service line within the house;

c) dilute to below the asphyxiate level any asphyxiate gases/vapours introduced into the house by accidental rupture of any one sample or service line within the house;

d) assist in maintaining the temperature inside the house within limits specified by the user

6.6.3 Air intake system

The air intake should be through a stack provided with a weather protection cowl (rain hood). The air source should be from a non-hazardous area where corrosive or toxic gases do not occur. The design of the intake duct and the diameter of the stack should be sized to limit air velocity to a maximum of 15 m/s. Any ducting to the analyser house which passes through hazardous areas should be leak-tight. Ducting through Zone 1 hazardous areas should be avoided where possible.

In some instances distance to the safe area may be excessive and in these cases air may be drawn from a Zone 2 area in which case the following will apply:

a) Analyser house equipment shall be certified as suitable for Zone 2 as a minimum

b) Live maintenance should not be carried out except under a permit. Maintenance equipment should be isolated in the event of ventilation failure or gas detected.

6.6.4 Ventilation fan requirements

The forced ventilation equipment should be mounted outside the building and should be suitably protected. Ventilation should be by means of a centrifugal or axial fan. Motors positioned in the duct shall be suitable for Zone 2 operation. Dual ventilation fan systems should be considered to minimise trips of non-certified equipment on ventilation failure and to ensure continued dilution of leaks of flammable, toxic and asphyxiate materials in the event of failure of one fan. To facilitate maintenance, fans should be fitted in parallel with non-return

valves and have suitable means of mechanical isolation. Power supplies to the fan motor should be independent of each other.

A filter should be installed in the ducting and should be easily accessible for cleaning or replacement. The area of the filter should be sized to require cleaning/ replacement not more frequently than once per month under the worst dust conditions expected on site.

6.6.5 Airflow requirements

The direction of airflow within the housing should be such as to ensure a movement throughout the housing and around all equipment installed inside irrespective of wind direction and strength. The position and number of air entry and exit ports should be dependent on the nature of the hazardous materials handled inside the house (e.g. density heavier or lighter than or equal to that of air, toxicity and the concentration necessary to achieve the lower explosive limit). The air exit ports should be louvers or weight-balanced flaps. At least 50 % of the exit ports should be operable under all wind conditions. See IEC 60079-13 for typical ventilation rate calculations.

6.6.6 Heating requirements

The temperature inside the building should be controlled at a nominal 20 °C. However, any heating and/or cooling systems should be designed to maintain temperatures within the limits of 10 °C and 30 °C under extreme conditions dependent on equipment and/or maintenance restraints.

Under tropical conditions where high humidity may be a problem, the temperature inside should be a minimum of 5 °C above ambient to avoid condensation of moisture on the walls and equipment. If this is not practicable due to high ambient temperatures, consideration should be given to the provision of air conditioning or dehumidifying the air.

Due regard should be paid to heat given off by analysers, sample lines and trace heating as well as solar radiation on the walls and roof when calculating the base temperature inside the building. With the analysers shut down, the temperature shall not fall to less than 5 °C. Heating should be by the installation of electric or steam heaters. Electrical heaters should be of the metal-sheathed tubular type with the surface temperature below 200 °C under any condition of operation including fan failure. Where ventilating air is taken from a Zone 2 Area, then the surface temperature of the heater should not exceed the temperature classification of the gas groups present in the Zone 2 Area.

6.6.7 Safety monitors and alarms

6.6.7.1 Overview

The primary safeguard for the analyser house is the design of the equipment to the required standards, i.e. Zone 1 and 2 and/or their purge system. Flammable and toxic gas detectors should be fitted as an additional safeguard, the detecting heads being located at key points within the analyser house. The detector heads and associated electronics should be suitable for Zone 1 hazardous areas.

Analysers should preferably be certified for use as a minimum in a Zone 2 hazardous area. (This is to allow continued operation even when ventilation and combustible alarms exist.

Any shutdown/alarm logic is usually contained within the analyser house and incorporates all logic indicators, key operated alarm/shutdown override switches and equipment reset switches.

To allow continued operation during ventilation failure and/or gas detection, the analyser house lighting, and equipment associated with the shutdown/alarm system including all initiators, logic and alarm indicators should be certified for use in Zone 1 hazardous areas.

Uninterrupted Power Supplies (UPS) should be used for all of the shutdown system, including gas detectors.

The following alarms/shutdowns should be provided as appropriate.

6.6.7.2 Ventilation failure

A low flow switch positioned to unambiguously detect failure of airflow through the house should be used. Care should be taken to ensure any air flows due to leaks in filtration units, parallel fan re-circulation routes etc. are not monitored. The switch should be set to indicate flow failure when flow falls below the equivalent of 60 % of design flow. A time delay of up to 1 minute may be used to prevent spurious operation during short term disturbances.

Low flow detection should initiate visible and audible alarms in the house and at a manned location elsewhere.

Where equipment other than that suitable for Zone 1 or Zone 2 operation i.e. general purpose is used, the low flow detection shall initiate the following trip functions.

a) Immediately isolate non certified equipment
b) Immediately isolate wall sockets
c) In the absence of flammable gas detection isolate Zone 2 certified equipment after an optional time delay up to a maximum of 24 hours
d) For Zone 2 purged equipment, purge failure coincident with ventilation failure should initiate isolation of the purged equipment after an optional time delay up to a maximum of 24 hours

Upon restoration of ventilation, power shall not be permitted to be restored to isolated equipment until at least 10 analyser house volumes of air have been exchanged. This should be automatically controlled via a delay-on timer initiated when ventilation airflow is established. Activation of a local manual reset facility will then be allowed to restore power.

Ventilation fans shall have local start/stop switches.

A visual indication of the pressure differential between the analyser house and the external atmosphere should be provided within the analyser house.

6.6.7.3 Flammable gas or vapour detection

If flammable gas detectors are used they should be calibrated and positioned according to the nature of the gases expected to be released within the house either from the analyser systems or via the ventilation system.

Gas detection shall initiate visible and audible alarms in the house and at a manned location elsewhere.

Gas detection should initiate a visual alarm on the outside of the house, normally a yellow flashing beacon.

Gas detectors should give two levels of alarm with trip functions as follows:

a) Immediately isolate non-certified equipment on 20 % LEL detection.
b) Immediately isolate wall sockets on 20 % LEL detection.
c) For Zone 2 purged equipment, purge failure coincident with 60 % LEL detection should initiate isolation of the purged equipment.

The above trip functions should operate independently of ventilation failure trip functions.

Gas detection is an added safeguard and is not a substitute for ventilation failure trips other than allowing for the optional requirement for the time delay on tripping Zone 2 and purged equipment to be removed.

On removal of the hazardous conditions as indicated by the gas detection equipment (below 20 % LEL), power shall not be restored to isolated equipment until at least 10 analyser house volumes of air have been exchanged. This should be automatically controlled via a delay-on timer initiated when flow is established/confirmed and the LEL falls below 20 %. Activation of a local manual reset facility will then be allowed to restore power.

6.6.7.4 Purged equipment

Purging of non-certified equipment with no internal source of release of flammable material is necessary for Zone 2 or Zone 1 hazardous areas. If the analyser house is designated Zone 2, tripping of equipment on purge failure is not required other than trips associated with ventilation failure and/or flammable gas detection as described in paragraphs 6.6.7.2 and 6.6.7.3 .

Purging of equipment with an internal source of release of flammable material has the added function of preventing a build-up, from an internal leak, of a flammable atmosphere within the equipment by dilution or inerting.

All purged equipment should be certified Ex'p'. Purge failure in any circumstances shall initiate visible and audible alarm.

6.6.7.5 Toxic and asphyxiate gas detection

If toxic and asphyxiate gases are handled inside the house, toxic gas and oxygen deficiency detection should be provided. Detection of toxic gas above preset alarm of oxygen below preset limits should initiate a visual and audible alarm in the house and at a manned location elsewhere.

Toxic and low oxygen gas detection should initiate a visual alarm on the outside of the house, normally common with flammable gas using a yellow flashing beacon.

6.6.7.6 Fire detection and protection

Manual call points should be provided on the outside of the house next to the doors. Fire detection may be provided in the form of smoke or heat detectors. They are normally only installed where there is general purpose equipment using large volumes of sample e.g. octane engine comparators or where there are open flame type analysers e.g. Wobbe Index.

Fire suppression may be provided which can be automatically or manually initiated on detection of fire.

Where automatic release is required, initiation should be controlled by smoke detectors, but an independent manual release facility shall be provided. For automatic release, voting systems are preferred to prevent spurious operation of extinguishing.

Fire detection shall initiate a visual and audible alarm in the house and at a manned location elsewhere.

Fire detection should initiate a visual alarm on the outside of the house normally a red flashing beacon.

In the event of fire detection, consideration should be given to automatically initiate the isolation of:

a) Any pipework entering the house that contains flammable materials

b) Ventilation fans

c) All electrical supplies to the house

Where fire suppression systems are fitted, it is necessary that ventilation air is shut off, all ventilation inlet and outlet louvers are automatically isolated and analyser house doors are of the self-closing type.

Extinguishing system status should be indicated over the house door. e.g. Blue - locked off, Green - manual, Amber - automatic, Red - discharged. States other than Red for discharged are optional depending on degree to which the personnel are to be informed.

6.6.7.7 Alarms

The following analyser house related local alarms/indicators should be generated and displayed:

a) Ventilation flow low *

b) Combustibles present (more than 20 % LEL) *

c) Fan 1 not in operation

d) Fan 2 not in operation

e) Common alarm for failure of any individual analyser air purge system failure *

f) Toxic gas present (no more than the long term Occupational Exposure Limit (OEL)) - if applicable *

g) Low oxygen levels detected*

h) Fire detected - if applicable *

i) Extinguishant released - if applicable *

j) 24 hour timer in operation

k) 10 air changes completed after restoration of normal conditions

l) Common shutdown/alarm bypass in operation *

The alarms marked * should also be transmitted to a permanently manned control room, either individually or as a common alarm.

7 Sampling systems

7.1 Overview

Where an analyser is not installed with its sensing element directly into a process line, a sample system will be necessary. A sample system includes all components from, and including, the sample probe up to the analyser inlet inclusive of the sample transport system (sample line).

The purpose of the sample system is to ensure that the analyser receives a sample representative of the process stream with the minimum of delay and in a state (temperature, pressure, cleanliness, flow-rate) such that the analyser will operate within its specification. The system shall include all components necessary for proper and safe operation. Probes, valves, filters, coolers, heaters, pressure regulators, pressure relief valves, space/trace heating, coalescers, piping/tubing, pumps, and all other necessary equipment should be included as required.

Sample systems should be designed to minimise product/material waste through the use of fast circulating systems (fast loops) and sample recovery techniques. A sample system may

have two separate conditioning systems, one located near to the tapping point (sample pre-conditioner) and one located near to the analyser (sample conditioner).

7.2 Sample system terminology

analyser response time	a) for continuous analysers: the time taken to reach 90 % of a step change at the analyser inlet i.e. T90 b) for cyclic analysers: the time taken to complete each cycle
analysis time lag	the sum of the 'sample system lag' and the 'analyser response time', i.e. the time between withdrawal of sample from the process and the analysis result
by-pass filter	a filter in which only the analyser offtake passes through the filter medium. The fast loop passes through the filter housing and may scour the filter element giving a self- cleaning effect
by-pass sample loop	a sample circulating system from the process and then back to the process or to a vent or drain
fast circulating loop	a sample circulating system from the process to the process, with sample usually taken to the analyser via a by-pass filter within the loop. (A fast loop will normally be shown as part of the process system on a process P&I drawing)
multi-stream systems	a system comprising one analyser shared between two or more sample streams
overall time lag	the sum of 'analysis time lag' and 'process lag'
probe	a device inserted into the line for extracting a sample for use with an analyser
process lag	the time between control action and the resulting change at the process analyser sample point
sample (tapping) point	the position from which a sample is taken
sampling system lag	the time between withdrawal of sample from the process and its delivery to the analyser

7.3 General requirements

The overall time lag of the analyser system, which includes process lag, sample system lag and analyser response time, should be consistent with the measurement and control requirements of the particular process.

Sample system lags may be kept to acceptable limits by locating the analyser close to the sample take-off point, or by increasing the velocity of the sample (e.g. fast circulation loop or by-pass to vent, drain or alternative disposal point).

Sample systems and their components shall be installed in such a manner that they can be readily maintained.

The physical or chemical properties which are to be measured shall not be changed in the sample system unless specifically required for the analysis.

Sample systems should be designed so that possible contamination of or damage to the analyser is prevented under plant upset conditions. Where, however, this is not possible, protective alarm and shutdown facilities should be provided.

Facilities for calibration and/or laboratory check sampling shall be provided. (See7.12).

7.4 Sample point location

The following should be observed in the selection of the correct location of a sample point on the main process line for the analyser. The optimum position may involve a compromise between several of the points below:

a) The sample point should be located at a point where the sample is expected to give the correct information on the properties or composition of the stream.

b) The sample point should be located at a point in the process which provides the most accurate representation of the process and where it is most appropriate for process control avoiding unnecessary time lags.

c) The sample point should be located in a position to utilise process differential pressures for any fast circulating or by-pass loops, (see.7.5).

d) The location should be chosen so that temperature, pressure, dryness or other conditions are already as close as possible to those required for the analyser in order to minimise the use of additional sampling system components such as sample coolers, pressure regulators, relief valves, etc.

e) The sample take-off points shall be readily accessible from grade or permanent platforms.

f) Analyser and laboratory process sample take-off points shall be kept separate, (see 7.12 paragraph 6).

Particular care should be taken to avoid locating sample take-off points where there is a possibility of contamination, or where pockets of gas/vapour/liquid/hydrocarbon/water/dirt/two phasing may occur in the plant stream.

Where samples are taken from horizontal lines, gas samples should be taken from the top and liquid samples from the side. Where samples are taken from vertical lines, liquid samples should only be taken when the flow is upwards.

When a representative sample is required from lines containing two-phase mixtures (e.g. liquid and vapour phases of material) or mixtures of immiscible fluids (e.g. oil in water or water in oil) care should be taken to ensure there is adequate mixing i.e. a homogenous sample flow must be present.

Samples should be withdrawn by probes, protruding into the process line to avoid wall effects. An example of such a probe is shown in Annex A. Special probes may be necessary to take a sample from a specific location within the process.

Design of sample probes should ensure failure cannot occur due to resonance (vibration) effects. Annex B covers the necessary procedures.

For samples taken from, and required to remain in a liquid phase, the pressure in any part of the sampling system shall always be higher than the vapour pressure of the sample to prevent flashing.

When reducing the pressure of hot liquid samples the need to prevent cavitation or flashing across the pressure reducing device should be noted. e.g. placing of coolers upstream of the pressure reducer.

When reducing the pressure of samples, particularly gas, consideration should be given to any Joule Thomson effects leading to cooling and icing problems, e.g. for moisture analysis, this could lead to degradation of the sample. Sample pre-heating and/or reducer body heating may be used.

Sample probes can be designed to minimize time lags. It is especially important to keep the liquid volume to a minimum where liquid samples are to be vapourised to reduce such lags.

7.5 Fast circulating systems (fast loops)

Fast circulating loops should be used to reduce sample system time lags with the minimum of product waste. The fast circulating loop should return to process wherever possible. Returning large volumes of process gas or liquid to vents or drains is not environmentally acceptable and may need the permission of the local government inspectorate. Annex C enables sample velocities and time lags to be determined from line size, viscosity and pressure drop.

Where possible, fast loops should take advantage of pressure differentials across the process. This negates the need for additional sample pumps, sample eductors etc. reducing installation and maintenance costs.

Fast loops across the following sources of differential pressure should be avoided:

a) Control valves: These usually create a variable differential pressure. Moreover the control function may be adversely affected.

b) Restriction Orifices: These normally create a relatively low differential pressure at high energy loss.

Fast loops should not be installed across orifice plates used for flow measurements, as it will affect the accuracy of the flow measurement.

When take-off and return points are widely separated, particular care should be taken to ensure no flow measurements or emergency isolation valves are by-passed.

The sample stream from the fast loop fed to the analyser should normally be filtered through a self-cleaning by-pass filter.

Specially installed pumps in fast loops should be avoided because of their extra maintenance requirements. If required the pump and its associated filter should not degrade the sample.

Facilities should be provided to indicate and regulate adequate flow in the loop usually by a flow meter located near to the analyser in or at the sample conditioning cabinet or panel.

7.6 By-pass systems

By-pass systems may be used to reduce sampling system lag e.g. when vapourising liquids for gas analysis.

By-pass systems may be used where they do not create environmental hazards and:

a) it is not practicable to return product to Process e.g. vapour and/or gas at low pressure;

b) it is not economic to return product to process because cost of recovery would exceed that of the product value;

c) return of the product to the process would cause contamination or degradation.

Particular attention shall be paid to the location of vent or drain when handling toxic and flammable substances. Flows shall be small to minimize risk and environmental impact.

7.7 Sample recovery systems

Sample recovery systems are used to return low pressure product by mechanical means back to the process. The low pressure product may be derived from the by-pass flow and/or the analyser discharge, (see.7.11.3).

Sample recovery systems are typically a collection vessel with a pump controlled from level/pressure switches within the collecting vessel, (see.7.11.3).

7.8 Special considerations

Where necessary, vapour phase samples should be heat traced and lagged to keep the sample at a temperature which will avoid condensation at any point within the sampling system and analyser. Analysers on vapour phase systems may also be heated to prevent liquid forming in the analysis chamber.

Liquid samples which are analysed in the vapour phase should either be:

a) completely vapourised as close as possible to the sample take-off point, and maintained in the vapour phase throughout the sampling system and analyser. The use of a reduced bore sampling probe (e.g. 3 mm to 6 mm bore) in the process line is required to reduce the sampling time lag; or

b) transported through a fast circulating loop and vapourised near or within the analyser.

The volume of liquid between the take-off point of the fast loop and the vapouriser should be minimized. (e.g. the volume of LPG increases approximately 300 times when vapourised at a pressure of 1 bar).

Heat tracing and lagging should be provided as necessary, particularly to replace heat absorbed at the vapouriser.

Gas samples should be pressure-reduced as close as possible to the sampling point or the fast loop to reduce time lags. Heat tracing and insulation may be necessary at the pressure reducer to replace heat lost by the Joule Thomson effect. Where necessary sample lines should be insulated and heat-traced to avoid condensation.

Sample from lines containing two-phase mixtures or mixtures of immiscible fluids require special consideration. Where analysis of the mixture is required the sample should be taken from a section of the line where the flow is turbulent. ISO 3171, while specifically relating to crude oil, offers further guidance on two phase sampling.

Facilities for flushing of sample lines and analyser should be provided:

a) on all streams where the sample has a viscosity greater than 500 cS at 38 °C;

b) where solidification is possible;

c) for corrosive and toxic services;

d) elsewhere when specified by the user;

e) due consideration should be given to the provision of pressure relief valves.

7.9 Multi-stream systems

Single-stream analysers are preferred and are usually essential for automatic control.

A multi-stream switching system may be used with some types of analyser. The cost of a number of single-stream analysers versus one on multi-stream service shall be assessed against the greater overall reliability of single-stream systems.

Disadvantages of multi-stream systems are:

a) Common mode failures i.e. Loss of information on all streams from the anlyser to the DCS/data-handling system in the case of analyser failure.

b) Possibility of contamination of one sample with another.

c) Possibility of cross contamination of process streams via the sample system.

d) Increased time delay between stream analyses.

e) Increased probability of failure due to complexity of the multi-stream sampling system with the switching arrangement, the sample selection unit and the data handling unit.

f) Increased maintenance problems of the sampling system due to greater complexity.

The possibility of contamination should be reduced by:

a) Designing the sampling system such that the entire stream switching valve header is flushed thoroughly with the sample to be measured.

b) Ensuring that no part of the line system contains a static sample from a previous analysis.

c) Fitting block-and-bleed systems to isolate and de-pressurize the unselected streams from the stream being analysed.

d) Ensuring that, where analyser design permits, the next sample to be analysed is flowing through the analyser while a former sample is being analysed (purging).

e) Making the common line from the stream selection system to the analyser as short and as small a diameter as possible.

7.10 Construction

7.10.1 General

The line size(s) of circulation loops can be determined from Annex C with due regard to the response time required. Piping up to and including the first isolation valve shall be to the process piping specifications.

Fast (main by-pass) circulating loops may be considered as part of the process system and as such, due regard should be paid to the relevant piping specifications where applicable.

For other sampling systems it is common practice to meet the process piping specification up to devices which will restrict the flow e.g. pressure regulators, restrictors or small bore tubing.

The number of joints in sample lines should be kept to a minimum. The method of jointing should conform to the relevant piping specifications.

Sample lines should be provided with drains and vents as necessary. Piping layouts which would create dead legs shall be avoided.

Provision should be made for depressurizing and safe disposal of the process fluid on plant or analyser shutdown.

Liquid phase sampling systems should be heat-traced and insulated as necessary to ensure that sample flow rates are maintained under all weather conditions.

7.10.2 Material selection

Sample lines and major components between the take-off filter and analyser shall be selected to ensure no further contamination of the sample can occur e.g. the use of stainless steel.

Materials for special or corrosive service (e.g. flue gas) should be agreed between supplier and user.

If special precautions are required for sample lines, i.e. steam tracing and lagging, then care should be taken to ensure that the material of construction is suitable for these new conditions. Typical problems which may be considered are Chloride and Sulphide stress corrosion of stainless steel. Detailed information on these problems may be found in NACE Standards (see Bibliography).

Samples where low concentrations of physically or chemically active components are being measured (e.g. moisture or HS at levels below 100 ppm) require special consideration.

Particular care should be taken in design and in the choice of materials used for sampling system construction to minimise the effects of adsorption and desorption on surfaces:

a) All internal surfaces should be smooth; generally AISI 316 stainless steel is the preferred material provided that it is not chemically reactive with a component of the sample stream.
b) Non-metallic components should be avoided unless their chemical or physical properties are superior and their use agreed with the user.
c) Sample line length and sampling system volume should be kept to a minimum.
d) The temperature of the sample line and all components should generally be kept constant and above ambient temperature by heat tracing and lagging.
e) Velocity in the sample line should be as high as practicable.

7.10.3 Flushing facilities

When using sample flushing facilities, the flushing medium should be injected immediately downstream of the sampling point. Consideration should be given to additional points to enable flushing of the system in individual sections.

Block-and-bleed valves shall be provided if there is a risk of cross-contamination.

7.10.4 Blockage removal

Facilities shall be provided for safe removal of blockages on applications where they are likely to occur, e.g. on streams containing catalyst. In these cases back purging systems (using steam or nitrogen) or specially designed rodding-through type of sample points may be installed.

7.10.5 Heat tracing and insulation

Heat tracing may be electric, steam or hot liquid.

Independent isolation and regulation should be provided for any trace heating required on analyser systems. In no circumstances should analyser system trace heating be combined with that for process equipment.

The design should ensure a reasonably uniform line temperature throughout the system, without excessive hot or cold spots.

Insulation should be readily removable for maintenance purposes - insulation blankets should be used where sample system components require regular maintenance. Preformed insulation pieces or pre-insulated / traced tubing should be used where possible. Alternatively, sections of the sample system may be housed in a heated, insulated box. Insulation of hot and cold surfaces should be taken into consideration for the protection of personnel.

Adequate spacing should be left between sample lines, including insulation and cladding, and cables or other services.

Each end of a heated line should be marked denoting source of energy supply and, in the case of steam, the location of condensate trap and blowdown valve.

Insulated lines should not enter sample conditioning cabinets or panels from below to prevent any leaks or drainings from maintenance work ingressing into the insulation material. Liquid ingress into traced / insulated lines may cause corrosion of heating element (both steam and electrical) and under lagging corrosion of sample line may also occur. Once liquid enters a

covered insulated line, the liquid will accumulate at the lowest point allowing corrosion to take place over a long period of time.

7.10.6 Minimising risks from leakage

To minimise risks arising from accidental leakages of sampled material, that portion of the sample system inside an analyser housing should be as simple as possible with the smallest contained volume and lowest number of joints practicable.

The tubing component of the sample system should be designed to limit the flow of sample into an analyser house to assist in meeting the requirements laid out in 6.6.2.

All cabinets containing sampling equipment should be fitted with drain holes and/or ventilation louvres. If containing high pressure liquids which vaporize at atmospheric pressure, bursting discs may be required. Use of electrical equipment inside cabinets may necessitate increased ventilation requirements.

7.10.7 Location of equipment

Installation and sample system design should ensure that components likely to require maintenance (e.g. filters, pressure reducing valves, flow meters) are readily accessible from grade or permanent platforms and can be removed with the minimum of dismantling. All components (including mounting brackets) should be accessible from the front - usually by means of a mounting bolt screwed into the backplate.

Ancillary equipment such as flow meters, valves, etc. should be conveniently grouped as near as possible to the analyser, but only a minimum of components for satisfactory operation should be located inside the housing.

A set of sample isolating valves should be located externally and adjacent to the housing. They should be easily accessible.

Open tundishes should not be located inside cabinets to prevent escape of any volatile materials within the cabinet and to prevent excessive condensation.

7.10.8 Instrumentation

The sample stream flow to each analyser and the by-pass stream flow, should be indicated locally. Any alarm sensor cabling should be run in such a way that any potential leaks will not drip onto signal cabling.

Glass tube variable area flow meters may be used with the approval of the user as local indicators for low risk service such as clean and non-corrosive samples under conditions of near-ambient temperature, low pressure and low flow. Where used, they should be mechanically protected. For high-risk service, generally stainless steel meters should be used or an alternative approved method (e.g. variable area orifice, turbine meter or dp cell).

The sample pressure and if necessary, the temperature should be indicated at the analyser inlet. Indication of internal cabinet temperature should also be provided on the outside of any temperature controlled cabinets.

Consideration should be given to remote shutdown in emergency.

7.10.9 Identification

Sample take-off and return points, isolating valves and sampling lines should be identified and permanently labeled. Any components featuring on a process P&I diagram should be labeled

clearly with the relevant tag number. All other components should have a unique identifying label to aid with reference to maintenance procedures.

7.11 Effluent disposal

7.11.1 General

Flammable and toxic materials should be disposed of in a safe manner and the area classification re-assessed in accordance with the IEC Publications and IP Electrical Safety Code.

7.11.2 Vapour

Vapour effluents, including gaseous sample and service discharges, should be disposed of to an atmospheric vent which is independent of any process vent. Vents from chromotograph columns, detectors and other systems where back pressure variations and/or back contamination may have a significant effect on operation should be completely independent.

The vent line should be sized to comply with manufacturer's limits for back pressure, preferably not smaller than 10 mm bore.

The tops of all vent lines should be arranged to prevent entry of rainwater and, where necessary, to prevent wind effects on the analyser - safety purge vents may be particularly susceptible to wind effects due to the very low pressure requirements of such systems. Each vent should have a water/condensate pot with a drain valve or alternative (e.g. goose neck) at the lowest point.

The use of flame arrestors should be considered.

7.11.3 Liquid

Liquid hydrocarbon samples should preferably be returned directly to the process or discharged to the plant slops system, the method of disposal being dependent on the value or difficult nature (e.g. waxy) of the sample and the quantities involved.

Disposal of hydrocarbon samples to oily water drain should be avoided.

Where direct return of the sample to the process is required, this may be achieved by either a pump associated with each analyser system or a common sample return system (SRS) with controlled pump-out.

SRS systems shall be provided with:

a) Automatic pump-out

b) High and low level alarms

c) Overflow to a suitable drain (via U-trap or similar seal)

d) Atmospheric vent

e) Drain valve

Analysers should be located such that their outlets are at a sufficient elevation in respect to drain headers. Drain lines from the analysers should be fixed directly to the drain header without valves.

Drain lines should be of sufficient size to prevent back-pressure on the analyser systems and should slope and be vented as necessary to prevent air locks.

When disposing of materials to drain, care shall be taken to ensure the drain system is suitable particularly where toxic, flammable, corrosive or waxy fluids are concerned.

7.12 Calibration facilities

The calibration of all analysers has to be proved on a routine basis. A general guide to the principles and methods used for calibrating and checking process analysers is given in EEMUA 175.

The frequency of calibration checking depends on the type of analyser, its duty and the operational importance placed upon its output.

An analyser check sampling point should be provided for the withdrawal of samples for each sampling stream. Sampling points should be located outside the analyser housing and at a height of not more than 1,5 m above ground or raised platform. A tundish, or trough, directly coupled to drain via a suitable seal, should be fitted approximately 0,5 m below each liquid sampling point. Consideration should be given to the change in area classification caused by the sampling point.

The analyser check sampling point should be downstream of all sample conditioning equipment and representative of the sample presented to the analyser.

Withdrawal of the check sample should not affect the operation of the analyser. The check sample point shall not be used as a process laboratory sample point.

NOTE Laboratory sample points should be completely separate from analyser sample points and sampling systems.

Facilities should be provided for the introduction of calibration samples into analysers. For samples which are toxic or potentially explosive containers should be located outside the analyser housing and be permanently piped from outside the house. The capacity should be sufficient for at least 10 calibrations.

Where necessary, calibration samples should be pressurized to comply with the normal analyser sample inlet conditions of pressure and flow rate. Any containers should be heated when using high-viscosity samples or when using samples that are liable to freeze at ambient temperatures.

Calibration sample containers should be easy to fill, empty and clean. Consideration should be given to transportable containers which may be removed to the laboratory for such operations.

Calibration gas cylinders should be installed in racks outside the analyser housing and protected from direct sunlight, and extremes of temperature. A cylinder pressure regulator is usually necesary (approved by cylinder supplier) to supply the analyser with gas under the required conditions. Cylinders shall be located to allow easy replacement. Access to cylinder racks shall remain clear at all times in case of an emergency.

Some standard gas mixtures can become non-homogeneous if stored outside of the range 10 °C to 40 °C. Advice should be sought from the gas mixture supplier. Cross contamination between calibration and process samples shall be avoided. e.g. physical disconnection or the installation of block and bleed valves.

7.13 Automatic calibration

Under this heading there are two distinct systems:

a) On a time based or manual initiation, a calibration sample is fed to the analyser which will self-calibrate (e.g. span and zero) and will re-adjust accordingly.

b) On a time based or manual initiation, a calibration sample is fed to the analyser and this result is compared against the calibration medium.

Method a) is a fully automatic calibration and is generally used in remote locations, or where analyser drift (for whatever reason) is a severe problem. It is usual to incorporate limits that set off an alarm when re-calibration is outside predetermined parameters.

Method b) is often termed “validation” and its prime purpose is to instill operator confidence in the analyser. When in the automatic mode there should be alarms to indicate if the analyser has drifted outside pre-determined limits.

In both cases adequate facilities shall be provided to:

- Prevent cross contamination of product and calibration medium.
- Ensure that during automatic calibration the plant control system is aware of the operation and any controller transfers to the default action.
- Ensure calibration sample is available at the analyser.

8 Analyser communications

8.1 Overview

This clause deals briefly with the signal transmission from the analyser.

8.2 Signal transmission

Signal data being transmitted from an analyser can be split in to three different types:

a) Analyser results
b) Alarms
c) Information flags

Typically, in basic analysers such as O2, pH, and Conductivity, analyser's result signals tend to be 4-20 mA signals with many manufacturers now utilising HART[1] additional serial protocols to receive information on the analyser's health. For more complex analysers which can have multiple results, as well as individual 4-20 mA current loops, digital transmission should be reviewed as a cost effective alternative. Digital transmission can come in a number of types, Ethernet (ISO/IEC 8802-3) using OPC[2] or Modbus[3] protocols, RS485/422, RS232 using Modbus, Foundation Fieldbus[4] or proprietary data highways.

The main advantage of using digital transmission is that it is possible to transmit all analyser data over a single link.

When using Ethernet transmission consideration must be given to distance limitations (100 m) using copper cabling, for greater distances the use of fibre optics with copper/fibre convertors would be required. The advantages of Ethernet are speed and compatibility to PC system, but for most analyser applications speed is not normally a problem.

When using RS485/422 distance is not normally a problem as distances may be up to 2 Km, but transmission speeds can be limited to 9 600 Bd. This is not normally a problem even with multiple analysers on a single system. Such systems are capable of being connected using standard screened twisted pair cables.

RS232 is only suitable for short transmission distances, for greater distances RS232/485 convertors should be used.

There are very few manufacturers offering Foundation Fieldbus data transmission.

Proprietary data highway systems are tending to be used less as manufacturers move towards open architecture systems. The main disadvantages to these systems are that they usually require specific cabling which can be expensive.

8.3 Safety

Particular attention has to be paid to the possible hazards associated with signal transmission. All analysers with the exception of the loop powered transmitter type should have isolated signal outputs. Analysers that are suitable to be used in hazardous areas shall be closely inspected to ensure that the cable and gland connections conform to the analyser certification. Analysers with purge systems should isolate the transmission as well as the power on loss of purge. Analysers made suitable for hazardous area operation by using purging methods are of particular concern e.g. On loss of the purge not only the mains power has to be isolated, but also the transmission lines.

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1 HART is a trade name of the HART Communications Foundation. This information is given for the convenience of users of this technical report and does not constitute an endorsement by IEC of the trademark holder or any of its products. Compliance does not require use of the trade name. Use of the trade name requires permission of the trade name holder.

2 OPC is a trade name of the OPC Foundation. This information is given for the convenience of users of this technical report and does not constitute an endorsement by IEC of the trademark holder or any of its products. Compliance does not require use of the trade name. Use of the trade name requires permission of the trade name holder.

3 Modbus is a trademark of Schneider Automation Inc., registered in the United States of America and other countries. This information is given for the convenience of users of this technical report and does not constitute an endorsement by IEC of the trademark holder or any of its products. Compliance does not require use of the trademark. Use of the trademark requires permission of the trademark holder.

4 FOUNDATION Fieldbus™ is the trade name of the non-profit consortium "Fieldbus Foundation". This information is given for the convenience of users of this technical report and does not constitute an endorsement by IEC of the trademark holder or any of its products. Compliance does not require use of the trade name. Use of the trade name requires permission of the trade name holder.

8.4 Cables

The routing of signal transmission lines shall be carefully considered, particularly inside analyser houses where segregation between IS signal, non-IS signal and power cables can be difficult. In case of explosion hazards, refer to IEC 60079-14 for further guidance.

8.5 Use of signal

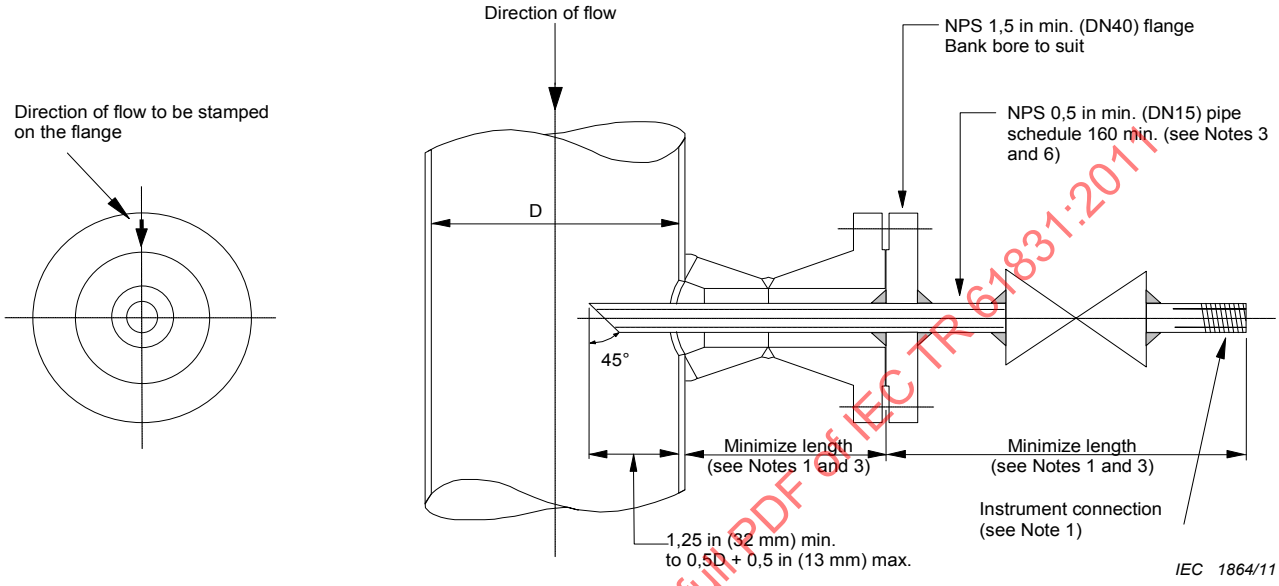
Analyser result signals are typically used for two main purposes, information or control. Any available diagnostics that an analyser may have should be used to validate the quality of the result. Environmental analysers are typical of analysers that are used for information purposes. Special consideration is needed for recording of the data from such analysers, data acquisition systems should be considered to ensure accurate logging of data. When analysers are used for control, consideration should be given to sample system resonance time and analyser cycle time to ensure the required control can be achieved.

8.6 Alarms

Individual analysers are often capable of generating alarms specific to their own condition, and with regard to their results. Depending on their criticality, consideration should be given to individually wire critical alarms rather than use flags within a digital link.

Annex A
(informative)

Typical analyser process line sampling probe for line sizes NPS 2" and above



NOTE 1 All materials, flange type, pipe fittings, valves, class rating, branch connection details, instrument details, instrument connection, welding details and heat treatment should comply with relevant piping specifications.

NOTE 2 The probe should not be installed in the bottom of process lines to avoid dirt and/or water entrainment in the sample.

NOTE 3 The contained volume of the probe should be minimised by limiting the dimensions shown in the figure. Where necessary, double valving should be provided. When the liquid sample is vaporised, double extra strong pipe and reduced bore valves should be used.

NOTE 4 The flange should be stamped with the probe tag number and flow direction.

NOTE 5 This probe is only recommended for single-phase process sampling.

NOTE 6 For fast loop service, the probe size and if necessary the branch connection, may be increased to meet loop flow requirements.

NOTE 7 Care should be taken with the design of the probe to ensure it will not fail due to resonance effects.

Figure A.1 – Typical analyser sample probe design

Annex B
(informative)

Determination of sample probe lengths

B.1 Overview

A probe in flowing fluid is subject to bending in the direction of flow caused by fluid drag and to vibration at right angles to the flow caused by vortex shedding.

Bending stress can be calculated from the probe dimensions, probe material properties, fluid velocity and density. In practice this calculation is not necessary, provided the probe is designed to accommodate the vortex shedding effect (see B.3.3 and B.3.4 below).

For all practical designs, the vibration effect due to vortex shedding is the dominant factor. Care has to be taken to ensure the probe is designed to avoid the possibility of failure due to resonance effects. If conditions allow the probe to oscillate at its natural frequency, it will be liable to snap off where the tube is welded into the flange.

All sample probes, therefore, shall be examined from this aspect and the length determined accordingly.

Reference is made to API Manual of Petroleum Measurement Standards – Chapter 8.2 Automatic Sampling of Petroleum Products (ANSI/ASTM D4177).

B.2 Vortex shedding theory

When a fluid flows past a cylindrical projection (sample probe) in a pipeline, vortices form at either side of the cylinder. As the fluid velocity and hence Reynolds number increases, the vortices grow in size, elongate and eventually detach, first from one side of the cylinder and then from the other. As soon as one vortex detaches another one is created. This phenomenon is called "vortex shedding" and the frequency at which this occurs is called the "shed frequency".

In developing these vortices the cylinder experiences drag forces in a direction transverse to the fluid flow. Since the alternate vortices are of opposite sign the cylinder is subject to a periodic transverse force. It has been found experimentally that the cylinder will start to oscillate when the "shed frequency" equals the natural frequency of the cylinder. Also the oscillations will continue at velocities beyond the one causing agreement of frequencies up to a maximum of twice the initiating velocity. This velocity depends on the mechanical damping and for increased damping the range of sensitive velocities becomes very small.

The following derivations assume a constant probe diameter with the probe weight uniformly distributed along its length. However, some probes may have their weight concentrated near the end and, in these cases, it is advised that a shorter probe length than that calculated is used.

It should also be noted that the calculated length of the probe from tip to support is always longer than the insertion length into the pipe. This will add a factor of safety for bending stress calculations as the entire length of the probe is not subject to the flowing fluid velocity but does not influence the vortex shedding calculations.

B.3 Calculations

B.3.1 Natural frequency

The natural frequency (f_n) of a cylinder in hertz (cycles per second = s^{-1}) is given by:

$$f_n = F_m \frac{A}{2\pi}\sqrt{\frac{EIg}{W_c L^4}} \quad \text{(B.1)}$$

where

E is the modulus of elasticity (kgf/cm^2);

I is the moment of Inertia about a diameter (cm^4);

g is the gravitational constant of conversion of kilogram-metre (kgm) to kilogram-force (kgf) (981 cm/s^2);

L is the length of cylinder (cm);

W_c is the mass per unit length (kgm/cm);

A is the constant for each mode of vibration as per the following table:

Table B.1 – Vibrational mode constants

Mode No.	1	2	3	4
A	3,52	22,4	61,7	121

F_m is the virtual mass factor – a constant to take account of the extra mass of the cylinder due to the fluid surrounding the cylinder and vibrating with it. For a gas F_m = 1, for water and other liquids F_m = 0,9.

For short probes usually only the first mode is of any significance.

The formula therefore becomes:

$$f_n = F_m \times \frac{0{,}56}{L^2}\sqrt{\frac{EIg}{W_c}} \quad \text{(B.2)}$$

Expressing probe diameters in mm and material density in kgm/m^3:

$$W_c = \frac{\rho V}{L} = \frac{\rho A_p L}{L} = \rho A_P = \frac{\rho\pi}{4} \times (d_o{}^2 - d_i{}^2) \times 10^{-8}\ \text{kg/cm}$$

and

$$I = \frac{\pi}{64} \times \left(d_o^4 - d_i^4\right) = \frac{\pi}{64} \times \left(d_o^2 - d_i^2\right) \times \left(d_o^2 + d_i^2\right) \times 10^{-4}\ \text{cm}^4$$

where

A_p is the cross-sectional area of probe (mm^2);

d_o is the outside diameter of probe (mm);

d_i is the inside diameter of probe (mm).

Expressing probe length, L, also in mm and substituting for I and W_c:

$$f_n = F_m \times \frac{0{,}56}{L^2} \times 10^2 \sqrt{\frac{E \times \frac{\pi}{64} \times (d_o{}^2 - d_i{}^2) \times (d_o{}^2 + d_i{}^2) \times g \times 10^{-4}}{\rho \times \frac{\pi}{4} \times (d_o{}^2 - d_i{}^2) \times 10^{-8}}}$$

$$= F_m \times \frac{0{,}56}{L^2} \times 10^4 \sqrt{\frac{E}{\rho} \times \frac{981}{16} \times (d_o{}^2 + d_i{}^2)}$$

$$= F_m \times \frac{4{,}38 \times 10^4}{L^2} \sqrt{\frac{E}{\rho} \times (d_o{}^2 + d_i{}^2)} \qquad \text{(B.3)}$$

where

E is the modulus of elasticity of probe material (kgf/cm^2);

ρ is the density of probe material (kgm/m^3);

d_o is the outside diameter of probe (mm);

d_i is the inside diameter of probe (mm);

L is the probe length (mm).

B.3.2 Shed frequency

The shed frequency (f_s) of a cylinder is given by:

$$f_s = \frac{S \times V}{D} \times 1\,000 \qquad \text{(B.4)}$$

where

V is the velocity of the fluid relative to the cylinder (m/s);

D is the projected depth of the cylinder in the direction of flow and may be taken as its diameter (mm);

S is the Strouhal number.

The Strouhal number is a none dimensional number defined by re-arrangement of Equation (B.4). It is dependent on the Reynolds number, shape of the cylinder and influence of end effects. Classical theory would indicate that the maximum Strouhal number is 0,198 for cylinders but practical values for the type of construction considered here can vary between 0,15 and 0,45. An acceptable number for sample probe applications can be taken as 0,2 as suggested by API chapter 8.2.

By equating these two formulae (B.3) and (B.4) and solving for (L_v) the permissible probe length to ensure the frequency induced by the vortex detachment from the probe does not exceed the natural frequency of the pocket may be determined from:

$$L_v^2 = \frac{F_m \times 4{,}38 \times d_o \times 10}{S \times V} \sqrt{\frac{E}{\rho} \times (d_o{}^2 + d_i{}^2)} \qquad \text{(B.5)}$$

where

L_v is the permissible probe length constrained by vortex shedding (mm);

d_o is the outside diameter of probe (mm);

d_i is the inside diameter of probe (mm);

V is the velocity of fluid (m/s);

E is the modulus of elasticity of probe material (kgf/cm^2);

ρ is the density of probe material (kgm/m^3).

Using the following assumptions:

a) a virtual mass factor of 0,9 which is the worst case, i.e. for liquid;

b) that the probes are "short" and vibrate in only the first mode;

c) a Strouhal number of 0,2;

d) using maximum design flow velocities (V_m) equating to a minimum of a 20 % factor of safety on the fluid velocity as suggested in API chapter 8,

the formula simplifies to:

$$L_v^2 = \frac{164 \times d_o}{V_m} \sqrt{\frac{E \times (d_o{}^2 + d_i{}^2)}{\rho}} \quad \text{(B.6)}$$

The resulting maximum permissible sample probe length using the above assumptions will be 10 % less (for liquid applications) and 15 % less (for gas applications) than the theoretical maximum. This gives an acceptable factor of safety whilst maintaining a practical design capability especially when considering retractable probe designs.

B.3.3 Bending stress (probe vertical)

Consider the probe as a uniform circular section tube mounted normal to the flow.

The flowing pipeline fluid striking the probe creates a pressure difference ΔP proportional to the density of the fluid (ρ_f) and the fluid velocity squared (V^2).

The constant of proportionality is effectively made up of a multiplier 0,5 and the drag coefficient (C_D). For Reynolds numbers above 2 000 up to 200 000, C_D varies between 0,6 and 0,8 for a finite cylinder of length to breadth ratio of 5 but as the length to breadth ratio increases the drag coefficient increases towards that of an infinite cylinder which varies between 0,9 and 1,5. The lower drag coefficient for a finite cylinder is due to end effects which tend to reduce the pressure on the upstream side and increase it on the downstream side.

For the purposes of these calculations the worst case will be used, i.e. a drag coefficient of 1,5 which will give an adequate indication of bending stress calculations – even for long slender probes such as those that might be encountered in large diameter pipelines – at the fluid velocity V_f.

$$\Delta P = C_D \times \frac{0{,}5 \rho_f V_f^2}{g}$$

Substituting for C_D = 1,5

$$\Delta P = 7{,}5 \times \frac{\rho_f V_f{}^2}{g} \times 10^{-3} \quad \text{(B.7)}$$

where

ΔP is the differential pressure across the probe (kgf/cm^2);

ρ_f is the density of the fluid (kgm/m^3);

V_f is the fluid flow velocity (m/s);

g is the gravitational constant of conversion of kilogram-metre (kgm) to kilogram-force (kgf) (981 cm/s^2).

The drag force (F) acting on the probe is the product of this pressure and the area (A) exposed to the flow and is at right angles to the flow. The force (F) is distributed uniformly over the whole of the exposed area which can be defined as rLd_o where (r) is the decimal fraction of the exposed length to the total unsupported length of the probe, (d_o) is the outside diameter of the probe and (L) is the unsupported length of the probe.

To calculate the bending moment about the probe support, the distributed force can be taken as a point load acting at the midpoint of the exposed length (rL) of the probe. The bending moment (M) about the point of support of the probe due to the action of the fluid on the probe is given by:

$$M = 7{,}5 \times \frac{\rho_f V_f^2}{g} \times rLd_o \times (L - 0{,}5rL) \times 10^{-6} \quad \text{(B.8)}$$

where

M is the bending moment at probe support (kgf/cm);

d_o is the outside diameter of probe (mm);

L is the unsupported probe length (mm);

r is the decimal fraction of exposed section of probe to unsupported length.

The flow induced bending stress (σ_f) is calculated as the bending moment divided by the section modulus (Z) for the probe.

$$\sigma_f = \frac{M}{Z}$$

Substituting for M from Equation (B.7) and Z for a tubular section we get:

$$\sigma_f = \frac{7{,}5 \times \dfrac{\rho_f V_f^2}{g} \times rLd_o \times (L - 0{,}5rL)}{0{,}098\left(\dfrac{d_o^4 - d_i^4}{d_o}\right)} \times 10^{-3} \quad \text{(B.9)}$$

where

σ_f is the flow induced bending stress at probe support (kgf/cm^2);

d_i is the inside diameter of probe (mm).

To find the maximum unsupported probe length the bending stress which shall not be exceeded is the elastic (or proportional) limit of the material (σ_e). Re-arranging Equation (B.9) to find L_{bf} we get:

$$L_{bf} = \frac{113{,}22}{V_f \times d_o} \sqrt{\frac{\sigma_e \times (d_o^4 - d_i^4)}{\rho_f \times r(1 - 0{,}5r)}} \quad \text{(B.10)}$$

where

L_{bf} is the maximum unsupported probe length for flow induced bending (mm);

σ_e is the elastic limit of the probe material (kgf/cm^2).

To demonstrate that the vortex shedding design criteria dominates over the practical fluid velocity ranges the L_v and L_{bf} Equations (B.6) and (B.10) for both vortex shedding and bending can be compared in a worst case scenario to find at which theoretical maximum design fluid velocity bending stresses would start to exceed the probe material elastic limit.

The worst case giving the maximum length of probe allowable for bending stress criteria, by inspection of Equation (B.10), is with the whole of the probe exposed i.e. r = 1 and that the probe section is in fact solid i.e. d_i = 0.

The worst case giving the maximum length of probe allowable with vortex shedding criteria, by inspection of Equation (B.6), is when the internal diameter of the probe becomes equal to the external diameter i.e. $d_i = d_o$.

Replacing V_m by V_f in Equation (B.6) and using the above theoretical extremes with a probe material with a minimum elastic limit of 2 400 kgf/cm^2 (typical of carbon steels), a Young's modulus E of 2 × 10^6 kgf/cm^2 and a density of 7 500 kgm/m^3 gives the following examples with water (1 000 kgm/m^3), air at atmospheric pressure (1,29 kgm/m^3) and air at 200 bar (258 kgm/m^3).

Table B.2 – Example calculations for maximum fluid velocity

Maximum probe length	Water	Air at 1 bara	Air at 200 bara .
Vortex shedding (L_v)	$\frac{61{,}5 \times d_o}{\sqrt{V_f}}$	$\frac{61{,}5 \times d_o}{\sqrt{V_f}}$	$\frac{61{,}5 \times d_o}{\sqrt{V_f}}$
Bending (L_{bf})	$\frac{248{,}1 \times d_o}{V_f}$	$\frac{6{,}906 \times d_o}{V_f}$	$\frac{488{,}4 \times d_o}{V_f}$
V_f for $L_v/L_{bf} \geq 1$	16 m/s	12,610 m/s	63 m/s

It can be seen that fluid velocities exceed normal practical maximum pipeline flow design values well before bending stress equations start to dominate in sample probe design, even under extreme conditions. For maximum design flow velocities (V_m) below those shown in the table, the vortex shedding calculations limit the probe maximum length.

B.3.4 Bending stress (probe horizontal)

The above calculations can be applied to a horizontally mounted probe but account has to be made of the additional bending stress due to the weight of the probe itself. This will be most significant when the fluid flow is acting in the direction perpendicular to the weight of the probe.

The bending moment at the probe support due to weight of material will be:

$$M = \frac{\rho g L}{g} \times \frac{\pi\left(d_o^2 - d_i^2\right)}{4} \times \frac{L}{2} \times 10^{-10} \qquad \text{(B.11)}$$

where

M is the bending moment at probe support (kgf/cm);

ρ is the density of the probe material (kgm/m^3);

d_o is the outside diameter of probe (mm);

d_i is the inside diameter of probe (mm);

L is the unsupported probe length (mm);

g is the gravitational constant of conversion of kilogram-meter (kgm) to kilogram-force (kgf) (981 cm/s^2).

The weight induced bending stress at the probe support due to the weight of the probe material will be:

$$\sigma_w = \frac{\rho L \times \frac{\pi\left(d_o^2 - d_i^2\right)}{4} \times \frac{L}{2}}{0{,}098\left(\frac{d_o^4 - d_i^4}{d_o}\right)} \times 10^{-7} \qquad \text{(B.12)}$$

where σ_w is the weight induced bending stress at probe support (kgf/cm^2).

Assuming that the probe is designed for vortex shedding we can use the resulting probe dimensions to calculate the fluid velocity where the elastic limit of the material will be exceeded. This can be done by substituting the probe dimensions, material properties and fluid properties into Equations (B.9) and (B.12). To find the maximum fluid velocity that the probe can withstand when mounted horizontally we can equate the elastic limit stress of the material to the sum of the flow and weight induced stresses.

Therefore and, as before, assuming worst case conditions of a fully exposed solid probe for bending (d_i = 0), the total combined bending stress at the probe support for a fluid velocity V_f will be:

$$\sigma_t = \frac{L^2 \times 10^{-7}}{d_o^2}\left[(4{,}007 \times d_o \times \rho) + \left(390 \times \rho_f \times V_f^2\right)\right] \qquad \text{(B.13)}$$

where σ_t is the total bending stress at probe support (kgf/cm^2).

To solve this equation for the maximum allowable velocity the probe length needs to be known.

For a probe designed to the vortex shedding constraint the length of this probe is given by Equation (B.6). Using, for this example, a liquid flow with a typical maximum design fluid flow velocity V_m of around 5 m/s and, as before, taking Young's modulus as 2 × 10^6 kgf/cm^2, a material density of 7 500 kgm/m^3 and a worst case of the infinitely thin cylinder (d_i = d_o) this gives:

$$L_v = 27{,}5 \times d_o$$

Using water (density of 1 000 kgm/m^3) as the flowing fluid, substituting for L in Equation (B.13) and equating σ_t to the material elastic limit σ_e the fluid velocity at which the combined bending stress becomes critical, can be found:

$$V_f = \sqrt{81{,}37 - 0{,}0771 \times d_o}$$

This gives a maximum fluid velocity between 8,8 m/s and 9 m/s for probes up to 50 mm outside diameter.

Similarly for the air flow examples (density of 1, 29 kgm/m^3 at 1 bar absolute and 258 kgm/m^3 at 200 bar absolute) we could have typical maximum design velocities up to 100 m/s at atmospheric pressure (flare gas flow applications) and up to 30 m/s at high pressure giving corresponding maximum flow velocities, constrained by the combined bending stress, of 690 m/s and 43 m/s.

In all cases, if the probe length is designed to satisfy the vortex shedding criteria, the horizontal orientation results in lower maximum tolerable velocity but even so it will not be subject to failure by bending if fluid flow rates do not exceed their design maximum values.

Annex C
(informative)

Sample system calculations

C.1 Lag time and pressure drop in sampling lines

C.1.1 Overview

The nomograph (see Clause C.4) gives a graphical solution for finding lag time and pressure drop in sampling lines. The following basic formulae in SI units are used. See Table C.1 below for nomenclature used in the calculations.

C.1.2 Pressure drop

$$\Delta P = \lambda \times \frac{L}{d} \times \frac{\rho v^2}{2}$$

C.1.3 Flow velocity

for laminar flow

$$V = \frac{\Delta P}{L} \times \frac{1}{\rho} \times d \times \frac{2d}{64\upsilon}$$

for laminar flow

$$I = \frac{64}{Re}$$

or turbulent flow

$$V = \sqrt{\frac{\Delta P}{L} \times \frac{1}{\rho} \times d \times \frac{2}{\lambda}}$$

or turbulent flow

λ is a function of v, d, υ and the relative roughness of the pipe.

A practical value for λ = 0,032

C.1.4 Lag time

Lag time is the reciprocal of flow velocity.

C.1.5 Nomenclature

Table C.1 – Nomenclature used in calculations

Symbols	Quantity	Customary unit	To SI unit	Multiply by
ΔP	Pressure drop	mbar	N/m^2	10^2
L	Length	m	m	
d	Interior diameter	mm	m	10^{-3}
ρ	Density	kg/dm^3	kg/m^3	10^3
v	Flow velocity	m/s	m/s	
η	Absolute viscosity	cP	Ns/m^2	10^{-3}
ν	Kinetic viscosity	cSt	m^2/s	10^{-6}
λ	friction factor			
T	Lag time	s/m	s/m	
Q	Volume flow	m^3/h	m^3/s	$2{,}78 \times 10^{-4}$
Re	Reynolds number			
NOTE $kg/dm^3 = g/cm^3$; $N/m^2 = Pa$				

C.1.6 Graphical solution

Obtain the sample velocity and lag time in a sampling line for the following conditions (see Figure C.1 below and the Nomograph given in C.4):

I) $\Delta P/L$ = 33 mbar/m

ρ = 0,8 kg/dm^3

d = 13,8 mm (1/2 in line pipe schedule 80)

ν = 40 cSt

II) $\Delta P/L$ = 33 mbar/m

ρ = 0,8 kg/dm^3

d = 13,8 mm (1/2 in line pipe schedule 80)

ν = 10 cSt et 1,0 cSt respectively

1) Start at A for $\Delta P/L$ – 33 mbar/m.

2) Draw a straight line through B for ρ = 0,8 kg/dm^3 to C.

3) From C, draw a straight line through D1 for d = 13,8 mm to E.

4) From D2 project vertically for d = 13,8 mm to intersect the viscosity line for ν = 40 cSt.

5) From the intersection point with the viscosity line project horizontally to F1.

6) From E draw a straight line through F1 and if this line has no intersection with a value for Re > 2 000, draw the line further to V1.

7) V1 = 0,63 m/s.

8) The lag time is found opposite the flow velocity and is T = 1,6 s/m.

4) From D2 project vertically for d = 13,8 mm to intersect the viscosity line for ν = 10 cSt and ν = 1,0 cSt, respectively.

If there is no intersection with the viscosity line (in the example for ν = 1,0 cSt), flow is turbulent and proceed with 7.

5) From the intersection point with the viscosity line (in the example for ν = 10 cSt), project horizontally to F2.

6) From E draw a straight line through F2 and if this line intersects a value for Re > 2 000, flow is turbulent and proceed with 7.

7) Start anew from E and draw a straight line through λ = 0,032 to V2 = 2 m/s.

8) The lag time is found opposite the flow velocity and is T = 0,5 s/m.

9) To determine the volume flow start from T1 or T2 and draw a straight line through d = 13,8 mm to Q1 = 0,35 m^3/h and Q2 = 1,05 m^3/h, respectively.

C.2 Component equivalent lengths and pressure drops

C.2.1 Introduction

In order to estimate the sample line pressure drop per unit length ($\Delta P/L$), for use in the nomograph solutions of sample velocity and lag time (see Clause C.4), it is necessary to find an equivalent length of valves and fittings in terms of straight lengths of the sample loop pipework. This equivalent length is then added to the length of straight pipework and divided into the pressure drop (ΔP) available after account of pressure drops due to flow control valves, regulators, flow meters, changes in elevation, etc., have been made which cannot readily be given an equivalent length.

To aid this process Table C.2 gives equivalent lengths of valves and fittings commonly used in sample systems and Table C.3 gives guidance on pressure drop allowances that can be made for control valves, flow meters, filters, etc.

In compiling this data reference was made to:

a) CRANE, *Technical Paper No. 410 M Crane – Flow of Fluids through Valves, Fittings and Pipes*

b) PERRY's Chemical Engineers' Handbook

c) FISHER *Emerson Process Control – Control Valve Handbook, Fourth Edition*

Use of this data is applicable to both gases and liquids and should enable estimates to be made within ± 20 % of more rigorously calculated values.

When applying to gases care should be taken to ensure the correct densities are used for each section of the sample loop, for example upstream and downstream of a pressure regulator. Where there are large changes in fluid temperature, care should be taken to ensure correct densities and viscosities are used for each section of the sample loop, for example upstream and downstream of a heat exchanger.

C.2.2 Equivalent lengths

The most commonly used piping specification in sample systems is clean commercial steel schedule 40 pipe with Class 300 or lower fittings. Table C.2 is based on this specification using a pipe friction coefficient of λ = 0,032 which is fairly typical of analyser sample systems.

Equivalent lengths are given as multiples of pipe internal diameter (d) and are directly applicable to pipework, valves and fittings of corresponding nominal bores up to 25 mm.

Table C.2 – Equivalent lengths of valves and fittings

Type of valve or fitting		Equivalent length (L_{eq})
Globe valve	Conventional	270 *d*
	Y pattern (45° stem)	115 *d*
	Y pattern (guided disc)	43 *d*
Angle valve	Conventional	120 *d*
	Guided disc	43 *d*
Gate valve	Conventional	6 *d*
	Reduced bore	40 *d*
Check valve	Swing type	80 *d*
	Lift type (wing guided disc)	480 *d*
	Lift type (45°)	43 *d*
	Ball type (in-line)	120 *d*
	Ball type (lift)	270 *d*
Ball valve	Full bore	3 *d*
	Reduced bore	50 *d*
Plug valve	Straight way	14 *d*
(Cock)	Three-way flow straight through	24 *d*
	Three-way flow through branch	72 *d*
Stop check valve	Globe type	315 *d*
	Angle type (conventional)	160 *d*
	Angle type (45° stem)	275 *d*
	Angle type (45° guided disc)	43 *d*
	Y pattern (45° stem)	235 *d*
	Y pattern (guided disc)	43 *d*
Standard elbow	90°	23 *d*
	45°	13 *d*
Standard tee	Flow straight through	15 *d*
	Flow through branch	46 *d*
Mitre bend	90°	46 *d*
	45°	12 *d*
Radius bend	*r* = 1 *d*	15 *d*
	r = 1,5 *d* to 4 *d*	10 *d*
	r = 5 *d* to 6 *d*	13 *d*
	r = 8 *d* to 10 *d*	21 *d*
	r = 12 *d* to 16 *d*	28 *d*

Table C.2 *(continued)*

Type of valve or fitting		Equivalent length (L_{eq})
Return bend	Close pattern	40 d
	r = 1 d	24 d
	r = 1,5 d to 4 d	18 d
	r = 5 d to 6 d	24 d
	r = 8 d to 10 d	37 d
	r = 12 d to 16 d	53 d
Sudden contraction (referred to smaller pipe)		$16[1 - (d/d_1)^2]d$
Sudden enlargement (referred to smaller pipe)		$32[1 - (d/d_1)^2]^2 d$
Entry		$24d$
Exit		$32d$
Valves with specified C_v (US gallons/min and inside diameter (δ) in inches)		$\frac{19{,}400 \times \delta^4}{C_v^{\,2}} \times d$
Valves with specified C_v (US gallons/min and inside diameter (δ) in inches)		$\frac{28{,}000 \times \delta^4}{C_v^{\,2}} \times d$
Valves with specified C_g (Convert to C_v (US))		$C_v = C_g/30$

Equivalent lengths can be modified to suit other pipework, valves and fittings using the following rules:

a) Using Class 400/600 with schedule 80 pipework, or Class 900 with schedule 120 pipework, or Class 1 500 with schedule 160 pipework, Table C.2 is directly applicable.

b) Using ANSI Class valves and fittings with pipework of nominal bores or schedules other than the matched nominal bores and schedules multiply by

$$(d_1/d_2)^4$$

where

d_1 is the internal diameter of actual pipework;

d_2 is the internal diameter of schedule pipework matched to the class of valve or fitting at its nominal size.

c) When the sample loop has more than one pipe diameter all pipework should be referred to one of the diameters by multiplying by

$$(d_1/d_3)^4$$

where

d_1 is the internal diameter of the reference pipe;

d_3 is the internal diameter of the pipe to be referred to.

In this case the pipe diameter (d_1) used in b) above should be the same as the reference diameter.

d) For tubing and associated compression fittings, equivalent lengths for fittings (elbows, tees, bends, contractions, enlargements, entries and exits) can be taken from the table along with those for ball valves. However, it is advisable to use manufacturers' data on C_v for estimating equivalent lengths of valves.

e) Tubing equivalent lengths should be taken to refer to the corresponding *o/d* tubing internal diameter.

C.2.3 Pressure drop allowances

In order to assign the pressure drop necessary to calculate $\Delta P/L$, the pressure drops associated with flow control valves, flow meters, filters, changes in elevation, etc. shall be taken away from the overall loop pressure differential available.

To assist in this, Table C.3 gives some pressure drop allowances which can be made in the absence of manufacturer's data.

Table C.3 – Sample system component pressure drop allowances

Feature	Allowance
Flow control valve	It is recommended that at least 30 % of the total pressure drop in the system is across this valve.
Variable area flow meter	For correctly sized meters 60 mbar at maximum flow is typical.
Flow indicators (ball type)	200 mbar.
Flow indicators (flapper type)	300 mbar.
Filters	Consult manufacturer's data. For correctly sized filter 100 mbar to 150 mbar is typical. If a C_v value is given refer to Table C.2.
Coolers	Consult manufacturer's data or establish pipe configuration and refer to Table C.2.
Elevation changes	For liquids, pressure change due to elevation variations is given by: $\Delta P_H = \frac{\Delta H(m) \times \rho_1}{10,2} bar$ where ρ_1 is the density of liquid at line conditions.
	For gases, elevation changes can be ignored.
Velocity changes	In most applications velocity head effects are negligible.

C.2.4 Large deviations in friction factor

From a knowledge of *Re* the true pipe friction factor can be found (for laminar flow $\lambda = 64/Re$ and for turbulent flow reference to Moody Charts (e.g. in CRANE's *Flow of Fluids Through Valves, Fittings and Pipes* will give λ).

If λ differs from 0,032 by more than +20 %, then the following can be done to improve the estimated values:

a) For laminar flow, with the *Re* below 1 600, the equivalent lengths of the valves and fittings should be modified by multiplying by 0,032 *Re*/64. Repeat the estimation.

b) For turbulent flow the following values of λ can be used:

***Re* range**	λ
2 000 to 3 000	0,046
3 000 to 6 000	0,041
6 000 to 10 000	0,037
10 000 to 50 000	0,032
greater than 50 000	0,025

The equivalent lengths of the valves and fittings should be modified by multiplying by 0,032/λ. Also this value of λ should be used in step 7 of the nomograph solution guide (see C.1.6). Repeat the estimation.

For smooth pipe (e.g. tubing), the pipe friction factor starts to deviate significantly from the above values at *Re*'s above 15 000. In this case, use the above commercial pipe friction factors for estimating equivalent lengths in Table C.2 but use the following values of λ in the nomograph solution:

***Re* range**	λ
15 000 to 20 000	0,027
20 000 to 100 000	0,021

Using the above data in conjunction with the nomograph, an estimate of line velocity, Reynolds number (*Re*), lag time, etc. can be made from a knowledge of the sample system piping and the pressure drop available to overcome the friction losses. Alternatively, knowledge of the required lag time and sample system piping can be used to calculate line velocity and *Re* and estimate the pressure drop necessary to overcome the friction losses by working through the nomograph in reverse.

C.3 Examples of sample system calculations

C.3.1 Example 1

C.3.1.1 Design basis

Figure C.1 below shows an analyser system. The analyser requires 1,0 l/min of sample taken from a fast loop system via a by-pass filter. The sampling system lag from the process sample point to the analyser is not to exceed 60 s. The lag time from the by-pass filter offtake to the analyser via its sample conditioning system is estimated to be 45 s.

Finding the flow velocity, pressure at the by-pass filter offtake and the necessary pressure drop across the fast loop flow regulating valve to meet the maximum lag time requirement for the following fast loop configuration and process data:

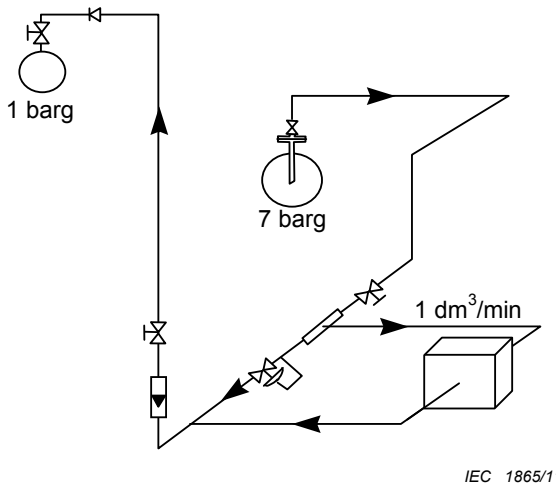


Figure C.1 – Sample system configuration

0,5 m sample probe in 1/2" schedule 160 pipe
1/2" class 600 gate valve
20 m of 1/2" schedule 40 pipe
4 × 90° elbows — Fast loop section from process to filter offtake
1/2" class 300 gate valve
By-pass filter (full bore element)

Regulating valve
VA flow meter
1/2" tee for analyser sample return
1/2" class 300 gate valve — Fast loop section returning to the process
30 m of 1/2" schedule 40 pipe
3 × 90° elbows
Check valve (lift type)
1/2" class 300 gate valve
Wall entry return to process

Pressure at sample point = 7,0 barg
Pressure at return point = 1,0 barg
By-pass filter elevation = 1,0 m above grade
Sample point elevation = 6,0 m above grade
Return point elevation = 9,0 m above grade
Fluid viscosity = 8,0 cSt
Fluid density = 0,8 kg/dm^3

C.3.1.2 Loop flow velocity

Required lag time from process to filter offtake = 60 s – 45 s = 15 s
Length 1/2" schedule 160 pipe = 0,5 m
Length 1/2" schedule 40 pipe = 20,0 m
Estimated length of valves and fittings = 0,3 m
$15 = 0{,}5/V_{160} + 20{,}3/V_{40}$
Schedule 160 pipe internal diameter = 11,84 mmo Schedule 40 pipe internal diameter = 15,8 mm

$$15 = \frac{1}{V_{40}}\left[0{,}5 \times \left[\frac{11{,}84}{15{,}8}\right]^2 + 20{,}3\right]$$

V_{40} = 1,37 m/s

Loop flow velocity = 1,37 m/s

Note that the flow through the regulating valve and the VA meter section of the fast loop is less than flow through the rest of the fast loop by 1,0 l/min. This represents a reduction of 6 % at a loop velocity of 1,37 m/s. Because this section of the system is short in comparison to the overall fast loop, the effect on the following calculations is negligible.

C.3.1.3 Pressure at by-pass filter offtake

Find equivalent length of valves and fittings up to and including the filter referred to 1/2" schedule 40 pipe (unless otherwise stated d = 15,8 mm). Using Table C.2

Probe entry loss	$= 24\,d \times \left[\frac{15{,}8}{d}\right]^4$	= 0,90 m
0,5 m 1/2" schedule 160 pipe	$= 0{,}5 \times \left[\frac{15{,}8}{d}\right]^4$	= 1,58 m
1/2" class 600 gate valve d = 13,87 mm ≡ schedule 80)	$= 6\,d \times \left[\frac{15{,}8}{d}\right]^4$	= 0,14 m
Sudden enlargement (d = 11,84 mm)	$= 32\left[1 - \left[\frac{d}{15{,}8}\right]^2\right]^2 \times d \times \left[\frac{15{,}8}{d}\right]^4$	= 0,23 m
90° elbows (4 off)	$= 23\,d \times 4$	= 1,45 m
1/2" class 300 gate valve	$= 6\,d$	= 0,10 m
By-pass filter – full bore treat as tee fitting)	$= 15\,d$	= 0,24 m
Total equivalent length of valves and fittings (L_{eq} process to filter)		= 4,64 m =======
Flow velocity V_{40}	= 1,37 m/s	
Viscosity	= 8,0 cSt	
Reynolds number (Re)	= (1 000 × 1,37 × 15,8) / 8,0 = 2 708	
For this Re a friction factor of λ = 0,046 is more appropriate and the equivalent lengths should be revised.		
Revised L_{eq}	= (4,64 × 0,032) / 0,046 = 3,23 m	

Referring to the nomograph in Clause C.4 and using λ = 0,046:

a) project from V = 1,37 m/s through λ = 0,046 to E;

b) project from E through D1 = 15,8 mm to C;

c) project from C through B = 0,8 kg/dm^3 to A;

d) read $\Delta P/L$ from A.

$\Delta P/L$ = 21,5 mbar/m

$L = L_{eq}$ + Length of straight pipe

L = 3,23 m+ 20 m = 23,23 m

Hence the pressure drop due to the pipe plus valves and fittings is given by:

ΔP = 23,23 mbar × 21,5 mbar = 499 mbar = 0,50 bar

Elevation change between sample point at process and the filter is given by:

Probe elevation – filter elevation = 6,0 m – 1,0 m = 5,0 m

From Table C.3: $\Delta P_H = (H \times 0{,}8 \text{ bar}) / 10{,}2 \text{ bar} = 0{,}39 \text{ bar}$

Pressure at the filter offtake is given by:

Process pressure – $\Delta P + \Delta P_H$ = 7,0 barg – 0,5 barg + 0,39 barg = 6,89 barg

Pressure at the by-pass filter offtake = 6,89 barg

C.3.1.4 Pressure drop across flow regulator

Find equivalent length of valves and fittings for complete fast loop referred to 1/2" schedule 40 pipe (unless otherwise stated d – 15,8 mm). Using table C.1:

From above valves and fittings up to and including the filter)		= 4,64 m
1/2" tee	= 15 d	= 0,24 m
1/2" class 300 gate valve	= 6 d	= 0,10 m
90° elbows (3 off)	= 23 d × 3	= 1,09 m
1/2" check valve (lift type)	= 480 d	= 7,58 m
1/2" class 300 gate valve	= 6 d	= 0,10 m
Sample return exit loss	= 32 d	= 0,51 m
Total equivalent length of valves and fittings (L_{eq}) (complete fast loop)		= 14,26 m ======

Allowing for more appropriate friction factor λ = 0,046 (see C.3.1.3 above):

Revised L_{eq} = 9,92 m

$\Delta P/L$ = 21,5 mbar/m

$L = L_{eq}$ + length of straight pipe

L = 9,92 + 20 + 30 = 59,92 m

Hence the pressure drop due to the pipe plus valves and fittings is given by:

ΔP = 59,92 mbar × 21,5 mbar = 1 288 mbar = 1,29 bar

Elevation change between the sample point at process and the sample return to process is given by:

Probe elevation – sample return elevation = 6,0 m – 9,0 m = –3,0 m

From Table C.3: ΔP_H = (–3,0 bar × 0,8 bar) / 10,2bar= –0,24 bar

Pressure drop allowance due to VA meter = 60 mbar = 0,06 bar

Pressure drop across the flow regulator is given by:

Sample point pressure – ΔP + ΔP_H – VA meter allowance – sample return pressure

ΔP_v – 7,0 bar – 1,29 bar – 0,24 bar – 0,06 bar – 1,0 bar = 4,41 bar

Pressure drop across the regulating valve = 4,41 bar

From a knowledge of the required ΔP_v and flow rate, C_v can be calculated to ensure correct sizing of the valve.

C.3.2 Example 2

C.3.2.1 Design basis

For the system described in C.3.1, it is found that the analyser plus conditioning system can operate with a minimum ΔP of 2,5 bar. Finding the maximum fast loop velocity and the associated lag time to the by-pass filter offtake.

C.3.2.2 Fast loop velocity

Considering pressure drops around the fast loop, the maximum ΔP due the fast loop pipework, valves and fittings can be estimated by:

ΔP = Sample point – VA meter allowance – ΔP_v + ΔP_H – sample return

ΔP_v + VA meter allowance = pressure drop required by the analyser (pressure drops in tee fittings are negligible 2,5 bar in this example).

From C.3.1.4: ΔP_H = –0,24 bar.

ΔP = 7,0 – 2,5 – 0,24 – 1,0 = 3,26 bar

From Table C.2 the valves and fittings equivalent length = 14,26 m (see C.3.1.3).

Friction factor is not known so assume λ = 0,032.

$L = L_{eq}$ + length of straight pipe

L = 14,26 m + 20 m + 30 m = 64,26 m

$\Delta P/L$ max = 3,26 bar × 1 000 ÷ 64,26 m = 50,7 mbar/m

Using the nomograph in Clause C.4 with λ = 0,032:

a) Project from A = 50,7 mbar/m through B = 0,8 kg/dm^3 to C
b) Project from C through D1 = 15,8 mm to E
c) Project vertical from D2 = 15,8 mm to intersect ν = 8,0 cSt. From this intersection project horizontal to F
d) Project from E through F to *Re*. If *Re* > 2 000 flow is turbulent. Start from E again and project through λ = 0,032 to V
e) Read velocity from V

V = 2,8 m/s

Check *Re* = (1 000 × 2,8 × 15,8) / 8,0 = 5 530

For this *Re* the appropriate friction factor λ = 0,041

Revised L_{eq} = (14,26 × 0,032) / 0,041 = 11,13 m

L = 61,13 m

$\Delta P/L$ = 53,3 mbar/m

Using the nomograph in Clause C.4 with λ = 0,041 repeat steps a) to e) above

V = 2,25 m/s.

Check *Re* = 4 448. For this value λ remains at 0,041

Fast loop velocity = 2,25 m/s

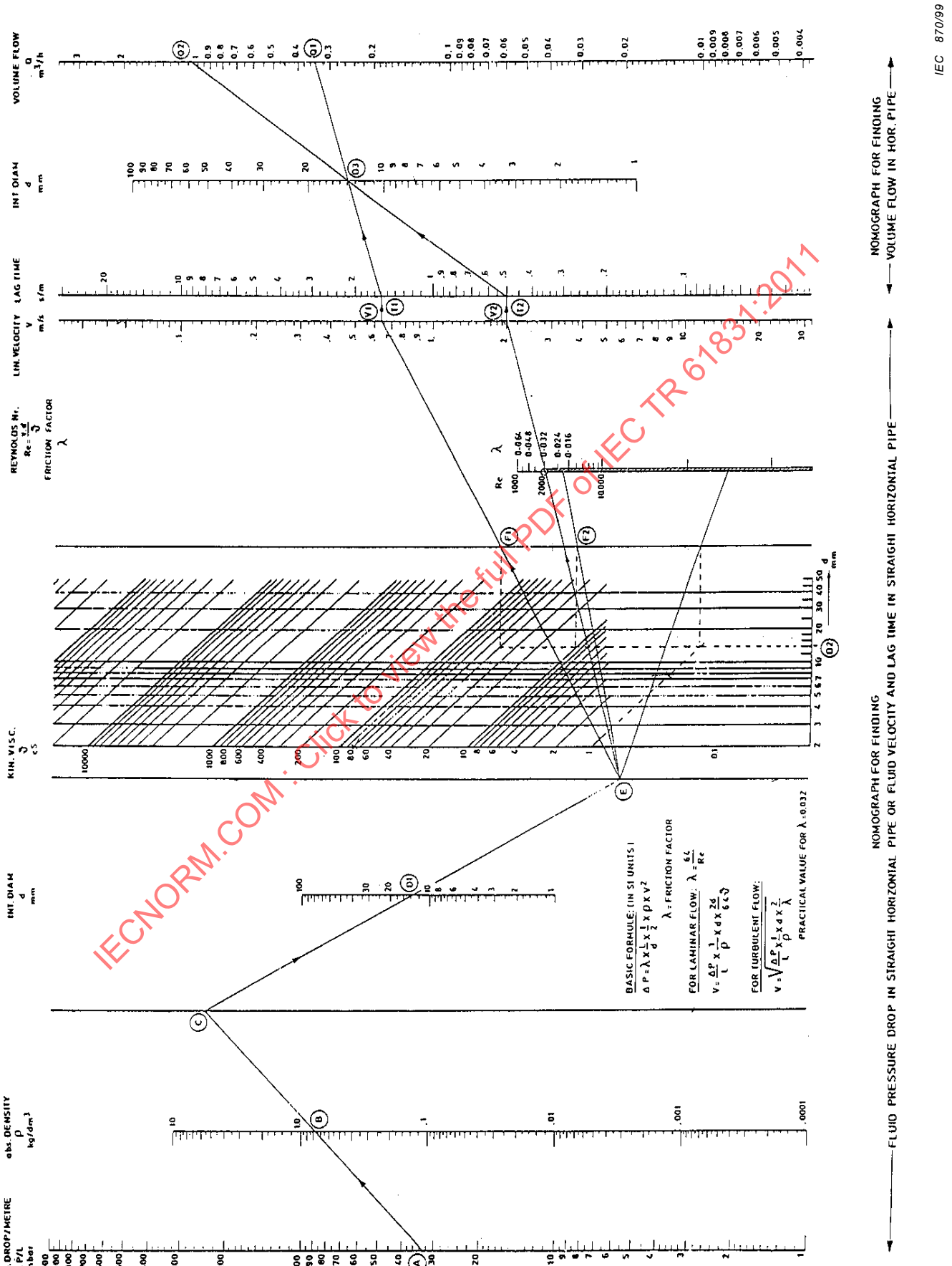
C.3.2.3 Lag time to filter

Referring to C.3.1.2:

$$t = \frac{1}{2{,}25} \times \left[0{,}5 \times \left[\frac{11{,}84}{15{,}8} \right]^2 + 20{,}3 \right]$$

Lag time in fast loop = 9,15 s.

C.4 Nomograph for sample time lags



Annex D
(informative)

Natural ventilation calculations

D.1 Overview

The following example illustrated in Figure D.1 is for a single skin steel analyser house with one distillation analyser. The house dimensions are 1,5 m × 2,0 m × 2,5 m high and the minimum heat input from analyser and services estimated at 200 W. The ventilation air exchange rate is required at a minimum of five changes per hour (see IEC 61285).

The object of the calculations to size louvres for natural ventilation purposes is to ensure that a minimum ventilation rate is achieved as called up in IEC 61285. In most circumstances ventilation rates will exceed the minimum values.

Reference is made to:

a) BS 5925, *Code of practice for ventilation principles and designing for natural ventilation*

b) KEMP'S *Engineering Year Book – Heating, Ventilation and Air Conditioning*

Assumptions that the house is located in a sheltered area and in city terrain are made to give worst case conditions. This gives a house wind pressure coefficient of ΔC_p = 0,1.

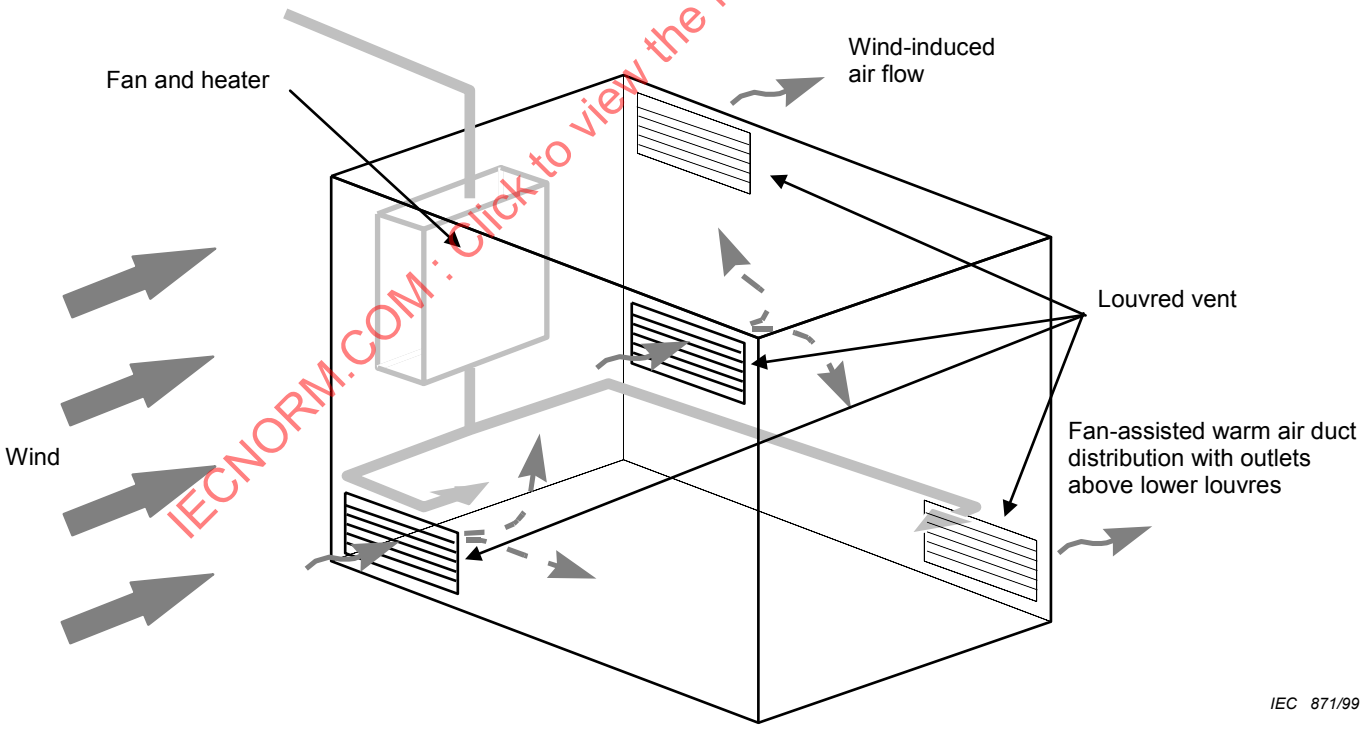


Figure D.1 – Schematic showing wind induced free ventilation principles with worked example ventilation louvre layout and suggested warm air distribution

D.2 Ventilation louvre sizing

D.2.1 Thermal ventilation

Heat input = fabric losses + air infiltration losses.

$$H_T = UA\ (T_1 - T_2) + 0{,}33\ NV\ (T_1 - T_2) \quad \text{(D.1)}$$

where

H_T is the heat input in watts (W);

U is the heat transfer coefficient (overall) for walls (W/m^2 °C);

A is the total surface area of house (m^2);

T_1 is the temperature inside house (°C);

T_2 is the temperature outside house (°C);

N is the number of air changes per hour;

V is the house volume (m^3).

U for steel under normal exposure with air velocities over surface up to 3 m/s, is 5,58 W/m^2 °C.

A = 20,5 m^2, V = 7,5 m^3, H_T = 200 W.

Hence for a minimum ventilation rate of 5 air changes per hour:

$(T_1 - T_2)$ = 1,57 °C = ΔT

Take ΔT = 1,0 °C for calculation purposes.

The ventilation area can now be calculated at nominal conditions of house temperature at 20 °C and 5 air changes per hour.

From Table 11, BS 5925:1991:

$$Q_b = C_d A_b \sqrt{\frac{2 \times \Delta T \times gH}{\theta}} \quad \text{(D.2)}$$

where

C_d is the discharge coefficient for the overall vent orifice = 0,61;

θ is the house temperature = 293 °K;

g is the gravitational constant = 9,81 m/s^2;

H is the height between upper and lower vents = 1,9 m;

Q_b is the design air flow rate required through the house equal to 5 changes per hour or 0,01042 m^3/s;

ΔT is the temperature difference between inside and outside of the house = 1,0 °C.

Hence

A_b = 0,048 m^2

Assume a total of four vents, two each in opposite walls, one upper and one lower in each wall and all of equal size with areas of A_v in m^2, then:

$$\frac{1}{A_b{}^2} = \frac{1}{(A_v + A_v)^2} + \frac{1}{(A_v + A_v)^2} = \frac{1}{4A_v{}^2} + \frac{1}{4A_v{}^2}$$

$$A_v = \frac{A_b}{\sqrt{2}}$$

Hence

Effective vent area/louvre = 0,034 m^2

D.2.2 Wind ventilation

In this example consultation of site meteorological data gives a minimum wind velocity which is exceeded 90 % of the time by 1,5 m/s whilst for 5 % of the time gusting up to 16 m/s can occur.

These are usually mean measured velocities at 10 m height and from this, estimates of the wind velocity at the analyser house roof level can be made. For the design purposes of meeting the minimum ventilation requirement the minimum wind velocity figure is used to calculate required ventilation louvre areas. The maximum wind velocity will give an indication of highest wind induced ventilation rates to be expected once the louvres have been sized.

This can be done using data from Table 8 and Equation 5 taken from BS 5925:1991.

$$\frac{U_r}{U_m} = Kz^a \qquad \text{(D.3)}$$

where

U_r is the mean wind velocity at the analyser house roof level;

U_m is the mean wind velocity at a height of 10 m = 1,5 m/s;

K is equal to 0,21;

z is the height of analyser house at roof level = 2,5 m;

a is equal to 0,33 for city terrain.

NOTE 1 For less sheltered locations different values of "K" and "a" can be used if required. Data given in Table 8 from BS 5925 relates to country and urban/city terrain and is summarised as follows:

–	Open flat country	K = 0,68	a = 0,17
–	Country with scattered wind breaks	K = 0,52	a = 0,2
–	Urban	K = 0,35	a = 0,25
–	City	K = 0,21	a = 0,33

Most analyser housings are located in relatively congested areas with high units/buildings (greater than 10 m) in close proximity and therefore city terrain figures have been chosen as most representative of a typical installation giving a worst case design scenario. In sites with low building unit/building heights (less than 10 m), urban terrain figures may be more applicable.

Hence

U_r = 0,43 m/s