




Instruction Manual: UK Smoke and Sulphur Dioxide Network

April 2002

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Contents

1	Introduction	1
1.1	PURPOSE OF THIS MANUAL	1
1.2	BACKGROUND	1
1.3	NETWORK OPERATION AND ADMINISTRATION	2
1.4	AIR QUALITY STANDARDS AND GUIDELINES	2
1.4.1	EC Directive 80/779: the Smoke and SO ₂ Directive	2
1.4.2	The Daughter Directive	3
1.4.3	The National Air Quality Strategy	4
2	Methods of Measurement	6
2.1	BLACK SMOKE	6
2.2	SULPHUR DIOXIDE	7
3	The 8-Port Sampler	8
3.1	APPARATUS	8
3.2	COMPONENTS OF THE SAMPLING INSTRUMENT	8
3.3	REAGENTS AND ACCESSORIES	10
3.3.1	For the assessment of smoke stains	10
3.3.2	For sulphur dioxide measurement	10
4	Siting and Installation of Sampling Equipment	23
4.1	SELECTION OF SAMPLING SITE	23
4.2	LOCATION OF THE SAMPLER	23
4.3	SAMPLING INLET	24
4.4	NETWORK SITE DATA RECORDS	25
5	Routine Operation of the Sampler	28
5.1	THE SAMPLER IN USE	28
5.1.1	Labelling of Components	28
5.1.2	Weekly Procedure	29
5.1.3	Interruptions to Power Supply	30
5.1.4	Containers for Transporting Peroxide Samples	30
5.2	OBTAINING GOOD SMOKE STAINS	31
5.3	BUBBLER (DRESCHER) BOTTLES	32
5.3.1	Use and Care of Bubblers	32
5.3.2	Conditioning of new Dreschel Bottles	32
5.3.3	Evaporation	33
5.3.4	Freezing	33

5.4	THE 8-PORT VALVE	33
5.5	READING THE GAS METER	35
5.6	CARE AND MAINTENANCE OF THE PUMP	35
5.6.1	The CAPEX Pump	35
5.6.2	The Dymax Pump	36
5.7	CHECKING FLOWRATES	37
5.8	WHAT TO DO ABOUT HIGH FLOWRATES	38
5.9	WHAT TO DO ABOUT LOW FLOWRATES	39
6	The Assessment of Sulphur Dioxide	42
6.1	PRINCIPLES OF THE METHOD	42
6.2	STRENGTH OF SOLUTIONS	42
6.2.1	Sulphuric acid and di-Sodium Tetraborate	42
6.2.2	Hydrogen Peroxide	43
6.3	USE AND CARE OF LABORATORY GLASSWARE	43
6.3.1	Cleaning and Rinsing	43
6.3.2	Filling Volumetric Containers	44
6.3.3	Use and Care of the Burettes	44
6.3.4	Reading the Burette	44
6.4	TITRATION OF EXPOSED SAMPLES	45
6.5	PREPARATION OF SOLUTIONS	47
6.5.1	di-Sodium tetraborate Solution $0.002 \text{ mol dm}^{-3}$ (0.002 M , $\text{N}/250$)	47
6.5.2	Sulphuric Acid $0.002 \text{ mol dm}^{-3}$ (0.002 M or $\text{N}/250$)	48
6.5.3	Preparation of pH 4.5 dilute hydrogen peroxide solution (1 vol)	48
6.6	TESTING ACID AND BORATE STRENGTH	50
6.7	PREPARATION OF A NEW COLOUR CONTROL	51
6.8	CALCULATION OF SULPHUR DIOXIDE CONCENTRATIONS	53
6.9	PREPARATION OF NEW STORAGE CONTAINERS	53
6.9.1	Glass	53
6.9.2	Plastic Containers	54
6.10	DETERIORATION OF THE INDICATOR	54
7	Assessment of Smoke Stains	57
7.1	THE REFLECTOMETER	57
7.2	SET-UP AND USE OF REFLECTOMETER	57
7.2.1	Setting up the <i>Analogue</i> Reflectometer	58
7.2.2	Setting up the <i>Digital (43D)</i> Reflectometer	60
7.2.3	Setting up the <i>Kemtronix (Digital conversion)</i> Reflectometer	62
7.2.4	Measurement of smoke stains	64
7.3	CALCULATION OF SMOKE CONCENTRATIONS	65
7.3.1	Use of "Look-up Tables"	65
7.3.2	Formulae used in Calculating Concentrations	65

8 Network Data Return 67

8.1	POLLUTION YEAR CALENDAR	67
8.2	DATA RETURN FORM	67
8.3	POINTS TO NOTE	67
8.4	COMMON ERRORS	69
8.5	DATA REQUIRED FOR CALCULATIONS	69
8.6	CONTINUITY OF MONITORING: BREAKDOWN OF EQUIPMENT	70

9 Regular Checks 73

9.1	WEEKLY CHECKS	73
9.2	TWO-MONTHLY CHECKS:	73
9.3	SIX-MONTHLY CHECKS	74
9.4	CHECKING FOR LEAKAGE	74

Appendices

APPENDIX 1	READING THE GAS METER
APPENDIX 2	SETTING THE 8-PORT TIMER
APPENDIX 3	LOOK-UP TABLES

1 Introduction

1.1 PURPOSE OF THIS MANUAL

This Instruction Manual has been written for the guidance of participants in the UK Smoke and Sulphur Dioxide Monitoring Network. It is intended as an update to “National Survey of Smoke and Sulphur Dioxide: Instruction Manual”, issued in 1966. This updated version covers the operation and components of the 8-port sampler now used at all Network sites, with advice on its installation, operation, and maintenance. It also covers assessment of smoke and sulphur dioxide concentrations from the measurements obtained. However, if you have a copy of the old Manual, please keep it, as it provides useful background information.

Please note that any references to product or manufacturer names do not imply recommendation or endorsement by AEA Technology or the Department for Environment, Food and Rural Affairs (DEFRA).

1.2 BACKGROUND

The UK Smoke and SO₂ Monitoring Network, and its predecessor the National Survey of Air Pollution, date back to the early 1960s, and provide the longest running series of air quality measurements in the UK. The National Survey was set up to monitor the progress of the Clean Air Act; this Act was introduced, following the smogs of the 1950s, to control urban smoke and sulphur dioxide pollution resulting from domestic coal burning. The 8-port sampler was used, an instrument which provides daily mean concentrations of sulphur dioxide and fine suspended particulate (as black smoke). The National Survey was run by Warren Spring Laboratory (WSL), on behalf of the Department of the Environment (now the Department for Environment, Food and Rural Affairs). Monitoring was carried out by participating organisations, mostly Local Authorities, and data from the Survey processed at WSL.

Over the first twenty years of the National Survey's operation, smoke and sulphur dioxide emissions decreased substantially, reducing ambient concentrations of these pollutants. In 1981, the National Survey was reduced in size, and is now known as the UK Smoke and Sulphur Dioxide Network. The Network now serves two purposes. Firstly, to monitor compliance with the relevant EC Directives on sulphur dioxide and suspended particulate matter. Secondly, to provide a long-term database of smoke and SO₂ measurements to assess trends in concentration and spatial distribution. For this purpose, a “core” subset of sites is used to provide a representative sample of monitoring locations in major population centres throughout the UK, with a wide spatial coverage of the whole country.

Warren Spring Laboratory operated the UK Smoke and Sulphur Dioxide Monitoring Network until their merger with AEA Technology in 1994. Since then, **netcen** (an operating division of AEA Technology) has operated the Network on behalf of DEFRA and data from the whole period of operation is archived at **netcen**.

1.3 NETWORK OPERATION AND ADMINISTRATION

Monitoring is currently carried out at approximately 180 sites in the UK. The sampling equipment is operated by co-operating organisations. These are mostly Local Authority Environmental Health departments, although some other organisations such as colleges also participate. These participants maintain and operate the sampling equipment used, carry out analysis of samples, and send the raw data to **netcen** on a monthly basis, using a standard format (discussed in more detail in Sections 5 and 8).

The data are processed at **netcen**, again on a monthly batch basis. Specialised computer software is used to validate the data and calculate ambient concentrations of black smoke and SO₂. A printout of the month's results is sent to the Local Authority. The daily mean concentrations of black smoke and SO₂, are retained on **netcen**'s own air quality database. From here, the data are available to the Department for Environment, Food and Rural Affairs, and on request to other Government Departments, the public, industry, research organisations, schools and colleges. The Annual Summary Report, published each year, has provided one of the main routes for public dissemination of data from the Network. Also, a comprehensive archive of air quality measurements, including those from the Network, is available via the World Wide Web, at web site <http://www.aeat.co.uk/netcen/aqarchive/archome.html>

1.4 AIR QUALITY STANDARDS AND GUIDELINES

Since the original instruction manual was produced in 1966, there have been substantial developments in legislation and standards covering ambient smoke and SO₂ concentrations.

1.4.1 EC Directive 80/779: the Smoke and SO₂ Directive

The European Council Directive 80/779/EEC of 1980 set air quality limit values and guide values for sulphur dioxide and suspended particulates. The limit values were mandatory in most parts of the UK from 1 April 1993. This Directive has been superseded, but the limits for black smoke will remain in force until it is fully repealed in 2005. The limits for both pollutants are presented in Table 1.1, along with the non-mandatory guide values for reference purposes.

For many years, the Network has fulfilled the statutory monitoring requirements of the EC Directive on Sulphur Dioxide and Suspended Particulates. Each year an analysis of all the previous pollution year's data is carried out, with respect to the requirements of the Directive. This is supplied to the Department for Environment, Food and Rural Affairs (and in previous years to its predecessors) for formal submission to the European Commission.

In the UK, smoke concentrations are calculated according to the British Standard smoke stain calibration. However, the Directive quotes smoke concentrations in terms of the OECD (Organisation for Economic Cooperation and Development) Smoke Calibration Curve (OECD Publication no. 17913: 1964). The relationship between concentration determined using OECD and BS calibration is:

$$\text{OECD concentration} = \text{BS concentration divided by } 0.85$$

Table 1.1 EC Directive 80/779/EEC Limits

EC Directive Limit Values For Smoke And Sulphur Dioxide In Microgrammes Per Cubic Metre		
Reference Period	Smoke: BS	Limit Values for Sulphur Dioxide
YEAR (median of daily values)	68	If smoke \leq 34: 120 if smoke $>$ 34: 80
WINTER (median of daily values October-March)	111	If smoke \leq 51: 180 if smoke $>$ 51: 130
YEAR (Peak) (98 Percentile of daily values)	213	If smoke \leq 128: 350 if smoke $>$ 128: 250
EC Directive Guide Values For Smoke And Sulphur Dioxide In Microgrammes Per Cubic Metre		
Reference Period	Smoke	Guide Values for Sulphur Dioxide
YEAR (arithmetic mean of daily values)	34 to 51	40 to 60
24 HOURS (daily mean value)	85 to 128	100 to 150

1.4.2 The Daughter Directive

As explained above, Directive 80/779/EEC^{1,1} has been superseded; the European Commission have issued a Directive on the Assessment and Management of Ambient Air Quality^{1,2} - the so-called "Framework Directive". "Daughter Directives" for pollutants including SO₂ and suspended particulate matter are being developed under the "Framework Directive". The first proposed Daughter Directive on SO₂, NO₂, PM₁₀ and lead^{1,3} was published in April 1999 and came into force in July 2001. This Directive contains limit values for these pollutants, aimed at protection of human health and, in some cases, of ecosystems.

The Daughter Directive limits relating to SO₂ are given in Table 1.2 below.

Table 1.2 EC 1st Daughter Directive (1999/30/EEC) Limits for SO₂

	Averaging period	Limit value	Date by which limit is to be met
1. Hourly limit value for protection of human health	1 hour	350 $\mu\text{g m}^{-3}$ not to be exceeded more than 24 times per calendar year	1 January 2005
2. Daily limit value for protection of human health	24 hours	125 $\mu\text{g m}^{-3}$ not to be exceeded more than 3 times per calendar year	1 January 2005
3. Limit value for the protection of ecosystems	Calendar year and winter (1 Oct - 31 Mar)	20 $\mu\text{g m}^{-3}$	2 yrs from entry into force of Directive

There is also an “alert threshold” for SO_2 of $500 \mu\text{g m}^{-3}$, measured over three consecutive hours at representative sites over at least 100 km^2 or an entire zone or agglomeration, whichever is smaller. Public warnings and advice are to be issued if this threshold is exceeded.

It is clearly not possible to compare data from the Smoke and SO_2 Network with the hourly limit. Nor is it relevant to compare data from this urban network with the annual and winter limits for protection of ecosystems, which are intended for protection of rural areas. However, it is possible to compare the daily data from the Network with the proposed 24-hour limit, for protection of human health.

The Daughter Directive standards for suspended particulate relate to PM_{10} , not black smoke. Therefore, data from the UK Smoke and SO_2 Network are not directly comparable with this Directive. However, the Daughter Directive states that the existing monitoring requirements and standards for black smoke will remain in force until 2005.

1.4.3 The National Air Quality Strategy

The Air Quality Regulations (2000) for England^{1.4}, Wales^{1.5}, and Scotland^{1.6} include standards and objectives for SO_2 . These are explained in the Air Quality Strategy (January 2000)^{1.7}, and summarised below:

- $266 \mu\text{g m}^{-3}$ for the 15-minute mean, not to be exceeded more than 35 times per year, to be achieved by 31 December 2005.
- $350 \mu\text{g m}^{-3}$ for the 1-hour mean, not to be exceeded more than 24 times per year, to be achieved by 31 December 2004.
- $125 \mu\text{g m}^{-3}$ for the 24-hour mean, not to be exceeded more than 3 times per year, to be achieved by 31 December 2004.

Data from the Smoke and SO_2 Network, which provides daily mean data, can only be directly compared with the standard for the 24-hour. This is identical to the Daughter Directive 24-hour limit.

The Air Quality Strategy^{1.7} also provides objectives for suspended particulate matter. The particulate objectives specifically apply to PM_{10} , not black smoke, and the Strategy acknowledges that these two techniques are not the same. The Air Quality Regulations (2000) for England, Wales and Scotland contain objectives which are the same as those in the EC Daughter Directive for PM_{10} , and are as follows:

- $40 \mu\text{g m}^{-3}$ as the annual mean, to be achieved by 31 December 2004
- $50 \mu\text{g m}^{-3}$ as a fixed 24 hour mean, maximum of 35 exceedences per year (approximately equivalent to the 90th percentile), also to be achieved by 31 December 2004.

The above limits are based on European reference method for PM_{10} (a gravimetric technique), or equivalent.

Although the above standards and objectives pertain to PM_{10} , black smoke data can be of use to Local Authorities in their review and assessment of PM_{10} concentrations with respect to these limits.

References for Section 1

1. Council of European Communities Directive on Air Quality Limit Values and Guide Values for Sulphur Dioxide and Suspended Particulates (80/779/EEC)
2. Council Directive 96/62/EC on Ambient Air Quality Assessment and Management.
3. Council Directive 1999/30/EEC relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air. 22 April 1999.
4. The Air Quality (England) Regulations 2000 (Statutory Instrument 2000 No. 928), March 2000.
5. The Air Quality (Wales) Regulations 2000 (Statutory Instrument 2000 No. 1940 (W.138)), July 2000.
6. The Air Quality (Scotland) Regulations 2000 (Scottish Statutory Instrument 2000 No. 97), March 2000.
7. The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. Working Together for Clean Air. The Stationery Office, January 2000.

2 Methods of Measurement

This section describes the methods of measurement used in the UK Smoke and Sulphur Dioxide Network. Since the original Instruction Manual was written in 1966, these techniques have been standardised in several British Standard Specifications, and in some cases International Standards. These are:

- BS 1747 Part 2 1969 (1991) Determination of concentration of suspended matter^{2.1}
- BS 1747 Part 3 1969 (1991) Determination of sulphur dioxide^{2.2}
- BS 1747 Part 6 1983 (1990) = ISO 4219:1979 Sampling equipment used for the determination of gaseous sulphur compounds in ambient air^{2.3}
- BS 1747 Part 11: 1993 = ISO 9835: 1993 Determination of a black smoke index in ambient air^{2.4}

These Standards provide the definitive description of the techniques, and Network site operators may wish to obtain copies for reference. However, this manual is more concerned with the application of these methods to the Network. The current section gives an overview of the underlying principles; the apparatus and procedures are described in greater detail in subsequent sections.

2.1 BLACK SMOKE

The term “black smoke” refers to any fine dark suspended particulate which can be measured by this smoke stain technique, not necessarily particulate resulting from combustion sources. Black smoke is defined as “strongly light absorbing particulate material suspended in the ambient atmosphere..... The major contributor to black smoke is soot particles; i.e. particles containing carbon in its elemental form”^{2.4}. Such particles remain suspended in the air, as they are too small to fall under their own weight. In this important respect, the black smoke method differs from deposit gauge techniques, which measure deposited particulate.

The British Standard technique for monitoring fine suspended particulate matter as “black smoke” is well established, and is also defined as a reference method for monitoring compliance with the old EC Directive 80/779/EEC^{2.5}. The principle of the method involves drawing air at a constant, measured flowrate through a paper filter. Suspended particulate matter is collected on the filter, forming a dark stain. An instrument known as a reflectometer is used to measure the darkness of the stain, and this reflectometer measurement is then used to calculate the concentration of particulate matter in the sampled air from a standard calibration (in the UK, the British Standard calibration).

2.2 SULPHUR DIOXIDE

The concentration of sulphur dioxide in the air is estimated by passing the same measured sample of filtered air through a dilute, acidified solution of hydrogen peroxide in a Dreschel bottle (bubbler). Sulphur dioxide in the sampled air reacts with the hydrogen peroxide to form sulphuric acid in solution. The solution is acidified to pH 4.5, so that strongly acidic compounds will be absorbed in preference to weakly acidic compounds (such as carbon dioxide). The amount of acid in the exposed sample is determined by titration with a standard alkaline solution. Other strong acids or alkalis in the air will affect the result, so **technically this method measures total gaseous acidity rather than SO₂**. However, in normal circumstances the concentration of such substances is very much less than that of sulphur dioxide. Therefore the result obtained is usually a good approximation to the concentration of sulphur dioxide.

References for Section 2

1. BS 1747 Part 2 1969 (1991) Determination of concentration of suspended matter
2. BS 1747 Part 3 1969 (1991) Determination of sulphur dioxide
3. BS 1747 Part 6 1983 (1990) = ISO 4219:1979 Sampling equipment used for the determination of gaseous sulphur compounds in ambient air
4. BS 1747 Part 11: 1993 = ISO 9835: 1993 Determination of a black smoke index in ambient air
5. Council of European Communities Directive on Air Quality Limit Values and Guide Values for Sulphur Dioxide and Suspended Particulates (80/779/EEC)

3 The 8-Port Sampler

The previous section described the *principles* of the black smoke and total acidity techniques. This section discusses the apparatus used to apply these techniques. Almost all Network sites use the 8-port sampler, a commercially available instrument used to measure daily mean concentrations of sulphur dioxide (as total acidity) and fine suspended particulate (as black smoke). Four examples of various types of 8-port samplers are shown in Fig. 3.1a, b, c, and d. It is also possible to make up an 8-port sampler from its component parts, and many such samplers are in use at Network sites. An example is shown in Fig. 3.1e.

3.1 APPARATUS

The sampler draws ambient air, at a controlled and metered rate, first through a filter paper on which suspended particulate is collected, then through a solution in which sulphur dioxide is absorbed. Most models require mains electricity, although battery powered samplers are available for use in rural areas.

An inlet funnel, positioned outdoors, is connected via flexible tubing to the sampler. This is connected to a manifold, having 8 branches. Each branch is connected to one of eight 'clamps', holding a filter papers, followed by one of eight bubblers (Dreschel bottles), containing a solution of dilute, acidified hydrogen peroxide. The outlet of each bubbler is connected to one of the 8 outer ports of an 8-port valve, a device which automatically switches the air flow once every 24 hours to pass through a fresh filter and bubbler. Each filter and bubbler is 'active' for one day only. The central port of the valve is connected to the inlet of a dry gas meter, the outlet of which is connected to the pump. Fig. 3.2 shows a schematic diagram.

The sampler can operate unattended for upto 8 consecutive 24-hour periods; in practice it is normally set to changeover at midnight and visited weekly, when the exposed filters and solutions are replaced.

The exposed filter papers, when removed from the sampler, will exhibit a dark, circular "smoke stain". The darkness of this stain is measured using a smoke stain reflectometer, which emits light onto the stain, and measures the reflectance. The darker the stain, the less light is reflected; this measurement is used to calculate the ambient concentration of black smoke.

The amount of acid absorbed in the exposed peroxide solutions is determined by titration with a standard alkaline solution of di-Sodium tetraborate. Section 3.3 gives details of the laboratory reagents and apparatus required for this; and the titration process itself (with details on making up and testing solutions) is given in Section 6.

3.2 COMPONENTS OF THE SAMPLING INSTRUMENT

All components of the 8-port sampler (with the exception of the funnel, and the tubing connecting it to the sampler) are contained in a box or case. There is a small hole in the side of the case, through which the inlet tube enters the box.

Manifold. The inlet tube is connected to the manifold, a metal tube with eight branches (Fig. 3.3). The branches must make an angle with the inlet stem of $135^{\circ} \pm 15^{\circ}$. This may be on the inside wall of the case, or on the floor of the box, under the bottles. Each branch is connected, via PVC tubing, to the lower section of one of eight filter clamps.

Filter clamps. These hold the filter papers on which the black smoke is collected. Various sizes are available: the size required will depend on the amount of smoke at the site, and its variability. The sizes available are 4 inch, 2 inch, 1 inch and $\frac{1}{2}$ inch diameter (10, 5, 2.5 and 1.25 cm respectively). Nowadays, 1 inch clamps are used at almost all urban sites; however, larger sizes were frequently needed in the past when smoke concentrations were higher. If there is any doubt as to the appropriate clamp size for the type of district concerned, please contact **netcen**. Fig. 3.4 shows a set of filter clamps, removed from the sampler for clarity.

Clamp holder. The two sections of the clamp are most commonly held in place by a screw-down holder. When this is tightened, the paper is firmly sandwiched between them. Some commercially available samplers have other means of securing the clamps, for example in the Airstest models the clamps are secured by operation of a lever. Most commercial sampler designs incorporate a means of ensuring that the upper and lower filter clamps are exactly aligned.

8 Bubbler (Dreschel) bottles with bubbler heads. The bottles are of 125 ml capacity and made of clear **hard** (borosilicate) glass (soda glass is unsuitable as its alkali content interferes with the total acidity method). The Dreschel bottle heads must be connected so that air enters the bottle through the central tube, passing down into the bottle through the top of the head and leaves through the arm inserted into the side of the head.

PVC tubing. PVC tubing (internal diameter $\frac{1}{4}$ inch (6.5 mm) nominal) connects the various parts of the apparatus. A medical grade, e.g. Portex, is recommended, but not essential. The tubing must, however, be PVC. Rubber tubing must not be used as it absorbs sulphur dioxide; neither polythene or PTFE tubing must be used as they attract smoke particles electrostatically. The tubing used is normally described as "semi-hard"; it must be rigid enough to resist kinking and crushing.

8-port valve. The eight tubes leading from the bubblers connect to the back of the 8-port valve. This component incorporates a timing device, and is set to change ports each 24 hours, thus allowing the sampled air to be drawn through a fresh filter paper and bubbler each day. The single outlet from the 8-port valve leads to the inlet of the meter. Various designs are available; for example the AGL sampler incorporates a box-shaped version, with a timing disc on the front, and a light which comes on when a port-change is in operation. Fig. 3.5a and 3.5b show two widely used designs.

Dry gas meter. The meter must be readable to 0.01 m^3 or 0.1 ft^3 , and accurate to $\pm 3\%$ at a flow rate of approximately 2 m^3 per day. A wide variety of meters have been, and still are, in use. Metric meters are preferred, but some which read in cubic feet are still in use. Fig. 3.6 shows the popular Remus type. This is no longer commercially available, but is still in use at many sites. An alternative is the similar Kimmon meter.

Electric suction pump. The pump must be capable of providing a constant flowrate of 2 m^3 per day ($70 \text{ ft}^3/\text{day}$ or 1.5 l/min), $\pm 10\%$. Most samplers now incorporate the Capex 2LNS

pump, which is made by Charles Austen Pumps Ltd, but older designs, e.g. the Dymax pump, are still in use. The Capex 2LNS pump uses a flow-limiting critical orifice to provide the required flowrate. This is preceded by a “safety filter”, which traps any fine particulate remaining in the air, which would otherwise accumulate on the flow-limiting orifice and gradually block it. These components are housed in a small black plastic cylinder, connected to the pump inlet by a length of reinforced tubing. The Capex pump is also supplied with a silencer on its outlet (Fig. 3.7). Older designs, e.g. the Dymax pump (Fig. 3.8), are still in use at some sites.

3.3 REAGENTS AND ACCESSORIES

One reflectometer and one set of chemical apparatus will serve a number of samplers.

3.3.1 For the assessment of smoke stains

Whatman No. 1 filter paper. The filter paper can be obtained conveniently in sheets 4 in x 3 in (10 x 7.5 cm) or in circles of 5.5 or 9 cm diameter, according to the size of the filter clamps being used.

Smoke Stain Reflectometer. (Suppliers: Diffusion Systems, Kemtronix).

3.3.2 For sulphur dioxide measurement

(i) Reagents

Hydrogen peroxide. This is bought in concentrated form (90–100 vol strength), and must be of analytical quality (e.g. ‘AnalaR’). It is diluted to ‘1 vol’ strength for use, in batches of 1000 ml or 2500 ml according to the number of samplers in use. 1000 ml of the dilute solution will be enough for one 8-port sampler. The concentrated peroxide is supplied in bottles of 250 and 500 ml. It is a strong oxidising agent: follow the safety instructions on the label.

BDH “pH 4.5” indicator. Supplied in 500 ml bottles. Smaller quantities can be transferred to a small dropping bottle. This indicator should be kept cool, ideally in a fridge, and because of its alcohol content is inflammable. It has a limited shelf life; refer to the packaging.

Ampoules of Concentrated Solution for preparation of 0.002 M di-Sodium

Tetraborate (this may also be sold as “sodium tetraborate” or “borax”). Supplied in boxes of six ampoules, each equivalent to 500 ml 0.002 M (N/250) solution when diluted with deionised water. These are a convenient way of making up this solution accurately.

Ampoules of Concentrated Solution for preparation of 0.002M (N/250) sulphuric

acid. *Note: ampoules are not available for 0.002M (N/250), only for 0.01M (N/50), which is five times the required strength. However, by extra dilution, these can be used to make up the 0.002 M (N/250) sulphuric acid required.* Each ampoule makes up 500 ml 0.01M solution, which is then diluted to give 2500 ml of 0.002M solution.

Deionised water. This should be obtained from an ion-exchange resin column, or from a supplier of chemicals. It need not be carbon-dioxide free. Tap water is **not** suitable; nor is

distilled water as obtained from garages, since it is often stored in containers contaminated with acid.

(ii) Chemical apparatus

It is not necessary to use Grade A glassware. Grade B is sufficiently accurate and often much cheaper. Inert plastic such as polypropylene is suitable for beakers, volumetric flasks and some storage bottles.

- **1 x 10 ml glass or plastic measuring cylinder.** To be used for measuring out small quantities of concentrated peroxide.
- **1 x small plastic bottle with pipette stopper.** Useful for extracting any excess concentrated peroxide from the above cylinder.
- **1 x 1000 or 2000 ml glass measuring cylinder.** For preparing dilute peroxide solution.
- **1 x plastic wash bottle.** With fine nozzle. Should be labelled "Deionised water". Used for rinsing, and for accurate topping up of the large measuring cylinder.
- **1 x 50 ml glass measuring cylinder.** For measuring out the prepared peroxide solution.
- **1 x burette graduated in 0.1 ml for 0.002M sulphuric acid.** A 25 ml capacity burette is the most generally useful size. Plastic stopper to fit.
- **1 x burette graduated in 0.1 ml for 0.002M di-Sodium tetraborate.** A 25 ml capacity burette is the most generally useful size. Plastic or rubber stopper to fit.
- **2 x 500 ml volumetric flasks.** For making up the di-Sodium tetraborate and sulphuric acid solutions.
- **1 x small glass or plastic funnel.** Optional.
- **1 x stand to hold 2 burettes.**
- **1 x tube of burette tap lubricant.**
- **2 x 100 ml beakers.** Used in filling burettes, one being kept for acid, one for borate.
- **5 x 150 ml conical (Erlenmeyer) flasks.** For carrying out titrations. Colourless glass.
- **1 x small (e.g. 20 ml) dark glass bottle with bulb pipette stopper.** For the pH indicator.
- **Storage bottles for reagents.** No two bottles should be alike, so that accidental mistakes are avoided. Plastic screw caps should be used for any storage bottles; do not use caps containing cork washers. The following bottles will be required.

For 1 vol hydrogen peroxide: dark glass, either 2500 ml or 1000 ml, depending on the quantity usually made up. Plastic (not metal) screw cap, or glass or plastic stopper, **not** rubber or cork.

For 0.002M di-Sodium tetraborate: clear glass or inert plastic 500 ml reagent bottle. Plastic screw cap, **not** glass stopper, to prevent "seizing" due to drying of alkali.

For 0.002M sulphuric acid: clear glass or inert plastic, 2500 ml. Glass stopper or plastic screw cap, **not** rubber or cork.

For deionised water: A large container, for example a 10 litre plastic aspirator bottle with a tap at its base is usually most convenient.

- **For transporting exposed peroxide samples:**
either: one spare set of Dreschel bottles per sampler, with glass or inert plastic stoppers
or: glass or inert plastic sample bottles, plastic screw caps, at least seven per sampler.

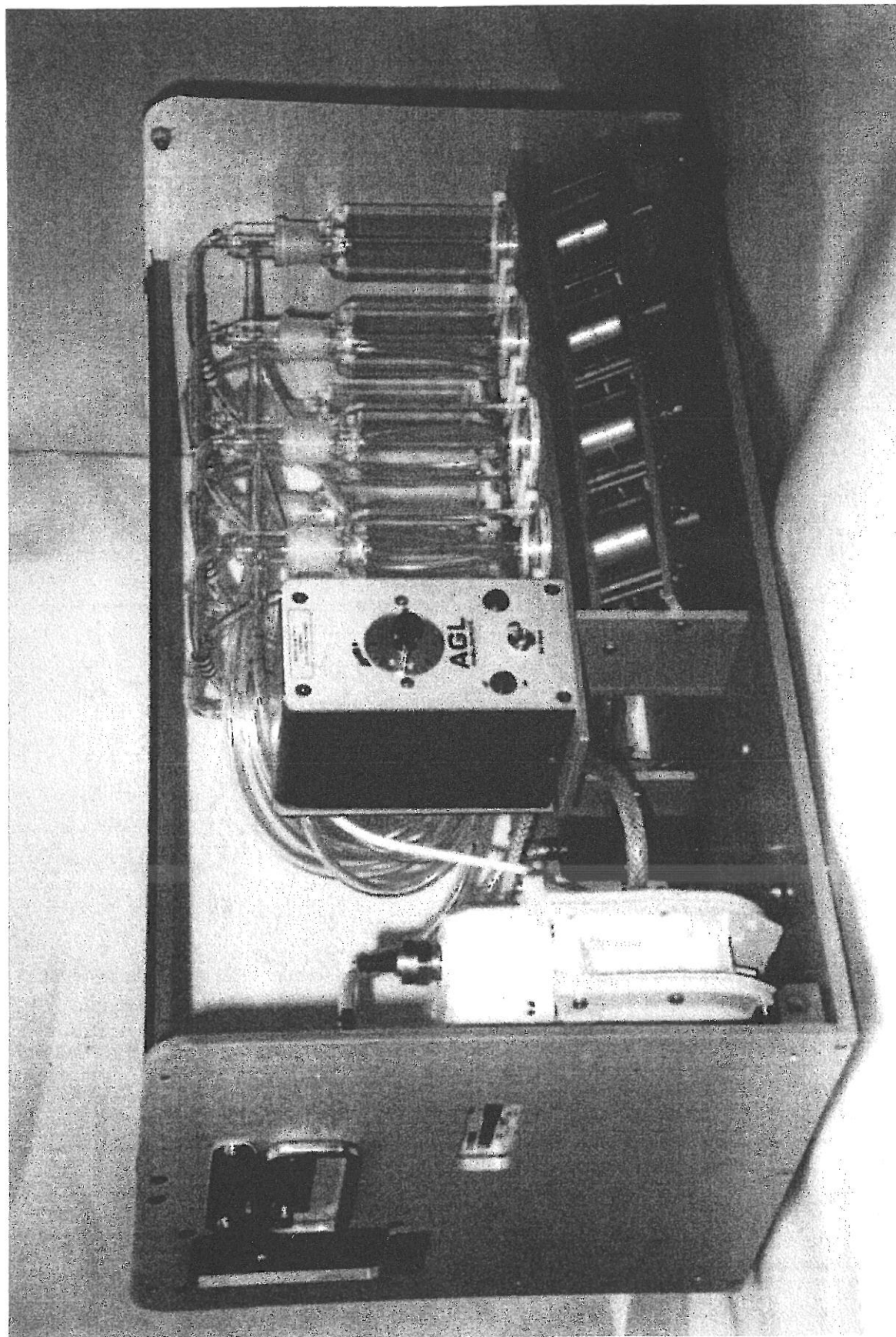


Fig. 3.1a AGL 8-Port Sampler
(Reproduced with permission of AGL Engineering)

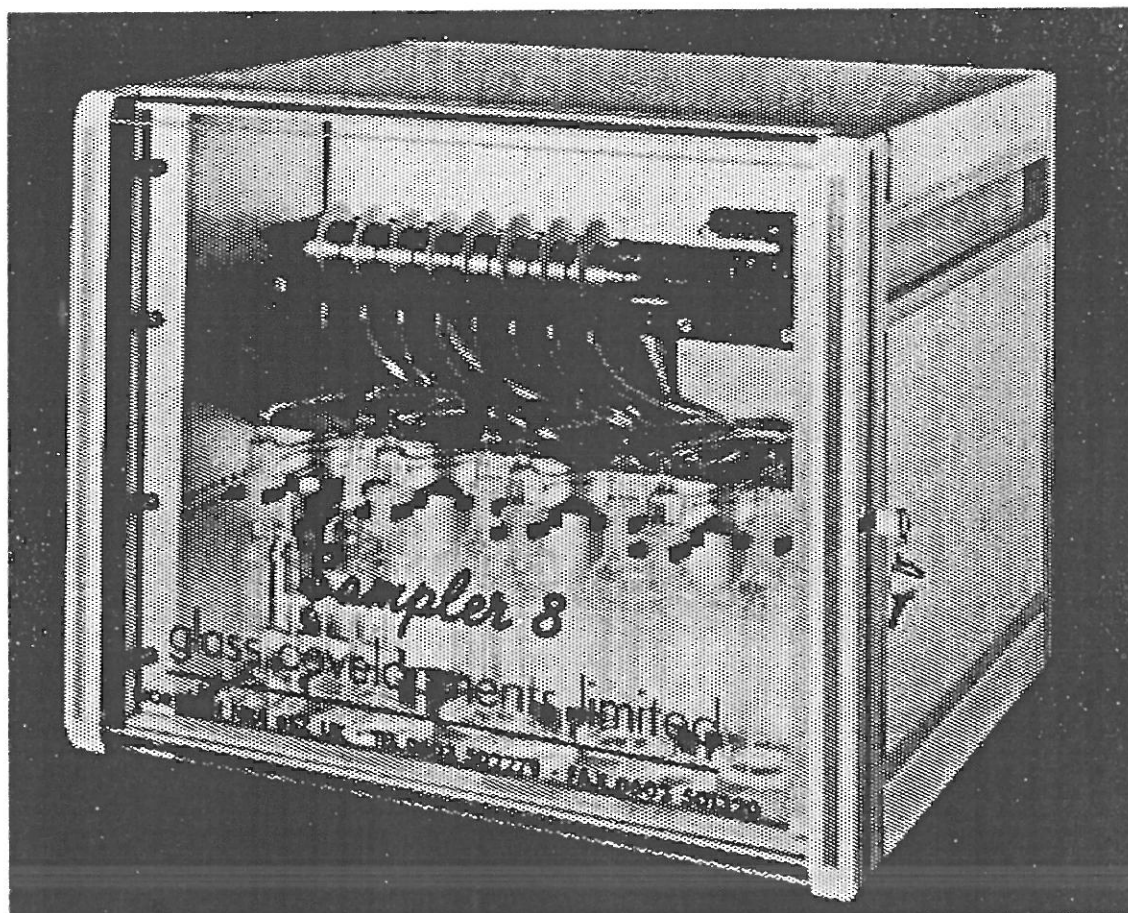


Fig. 3.1b Airtest "Sampler 8" 8-Port Sampler
(Reproduced with permission of Airtest, formerly Glass Developments Ltd)

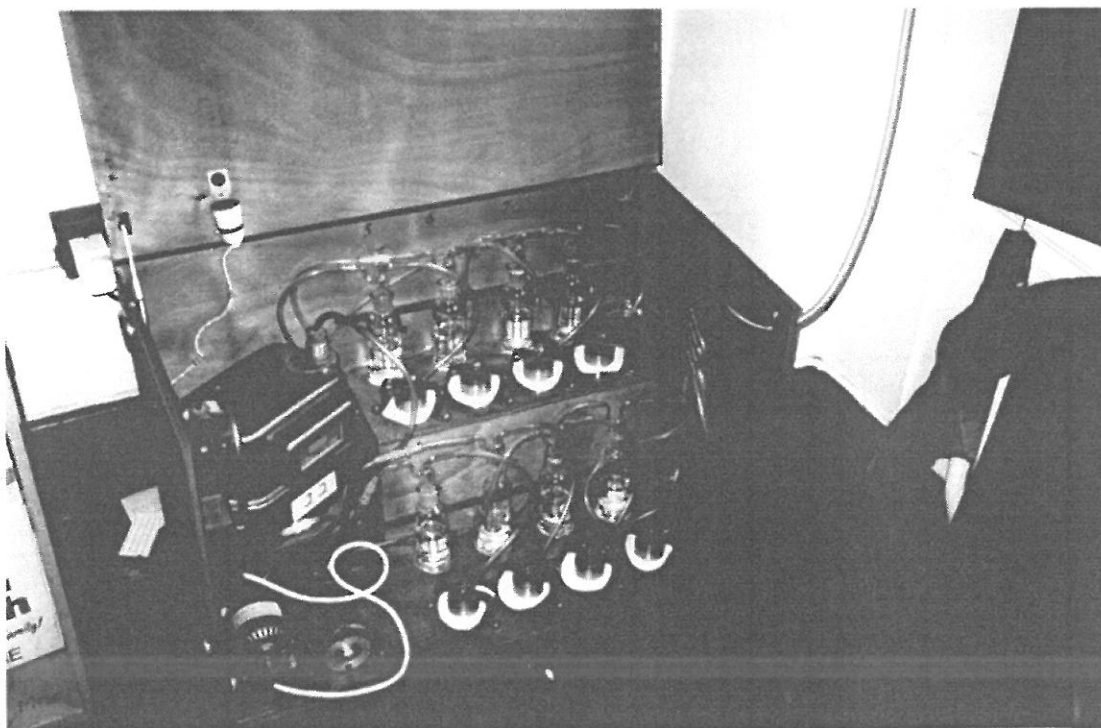


Fig. 3.1c Glass Developments Ltd 8-Port Sampler
(Reproduced with permission of Bolton MBC)

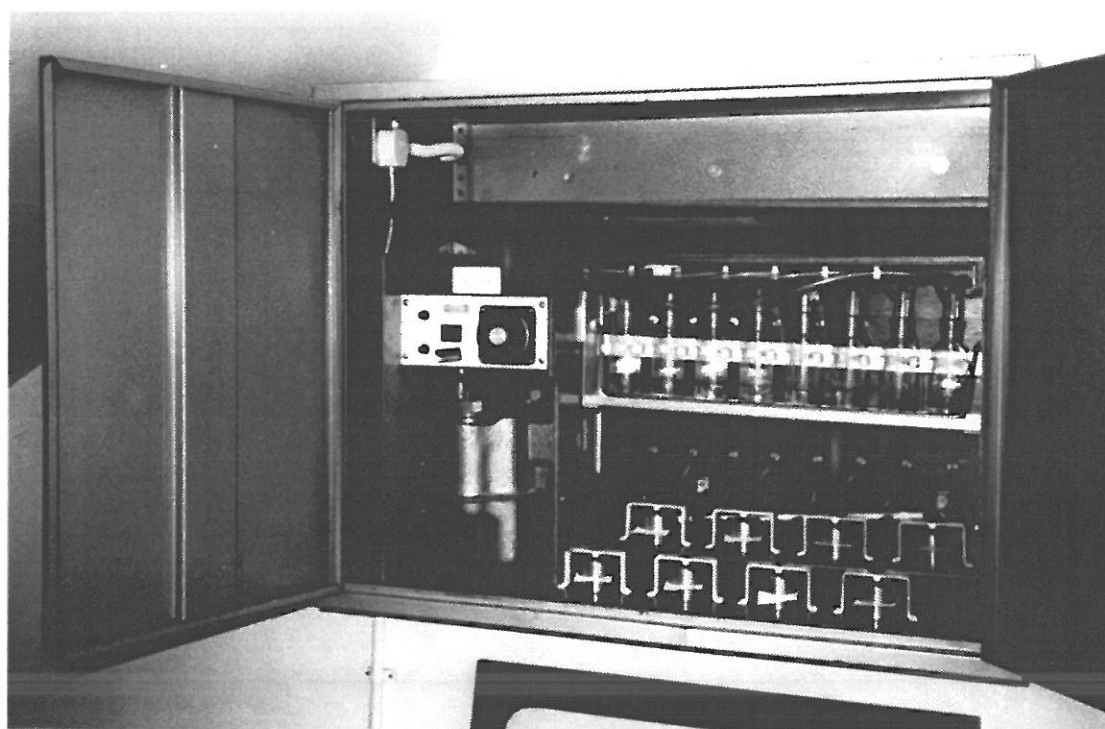
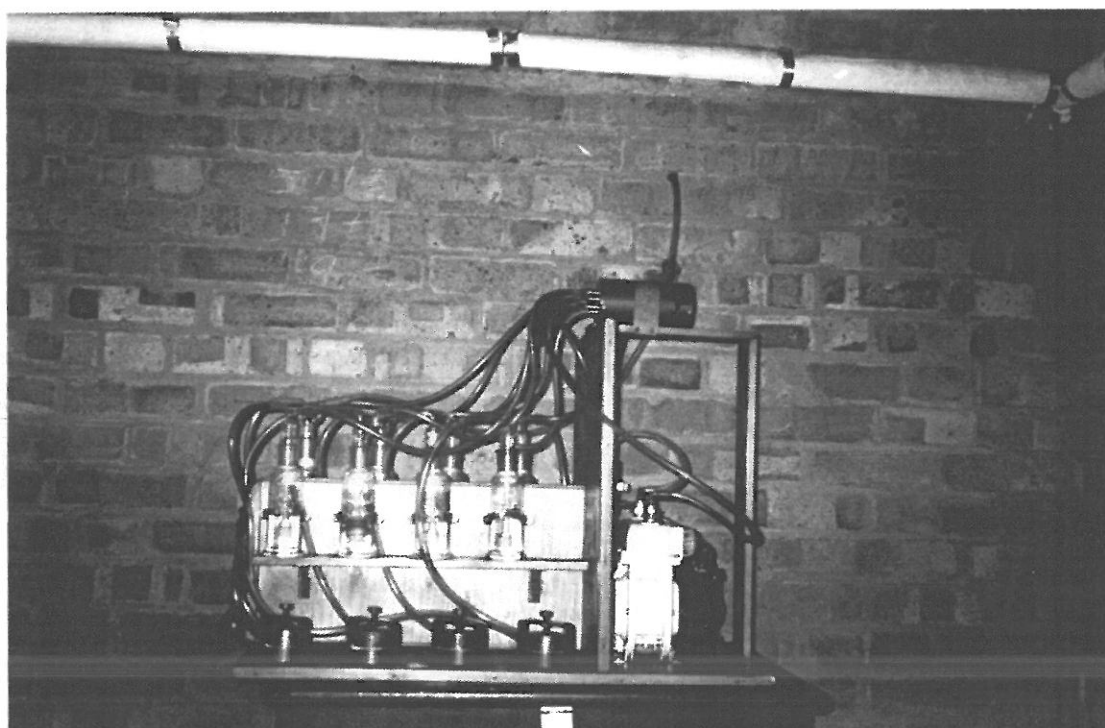


Fig. 3.1d Eccodata 8-Port Sampler
(Reproduced with permission of Kirklees MBC)



**Fig. 3.1e Example of an 8-Port Sampler Constructed from
Component Parts**
(Reproduced with permission of Walsall MBC)

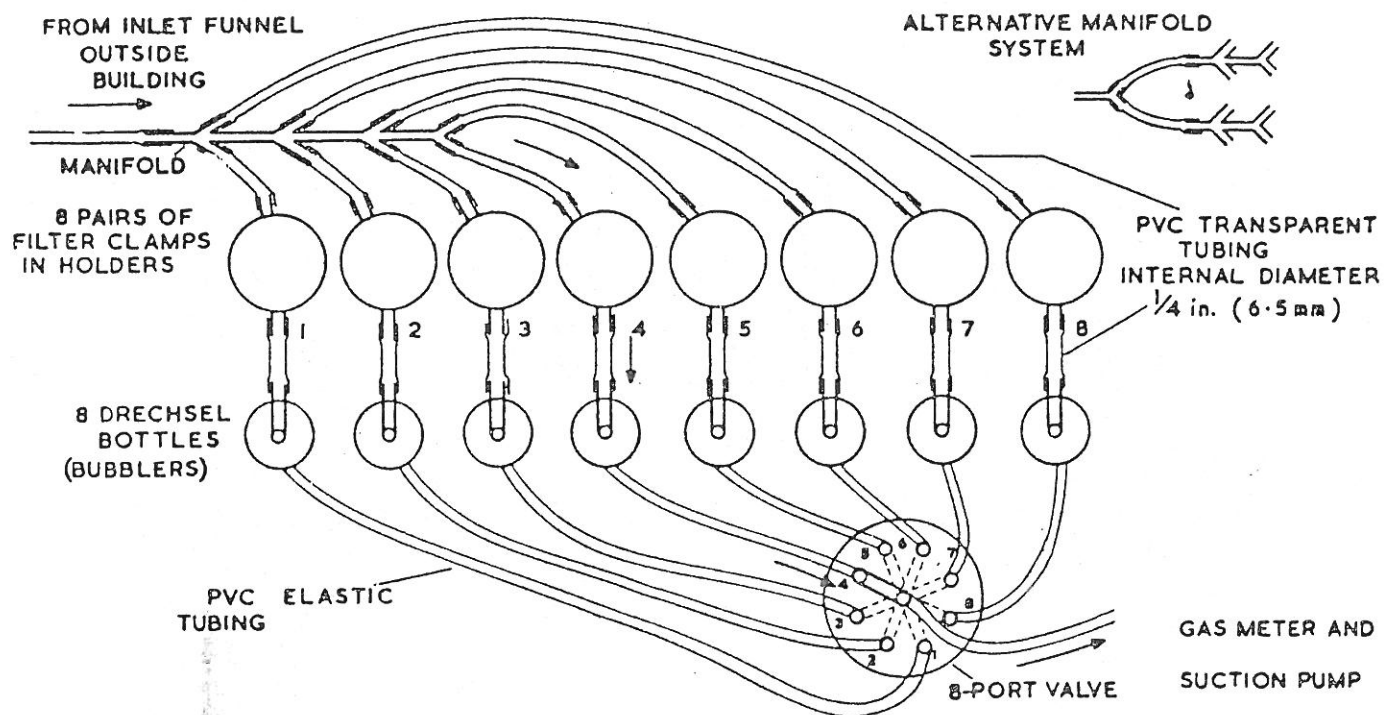


Fig. 3.2 Schematic Arrangement of 8-Port Sampler

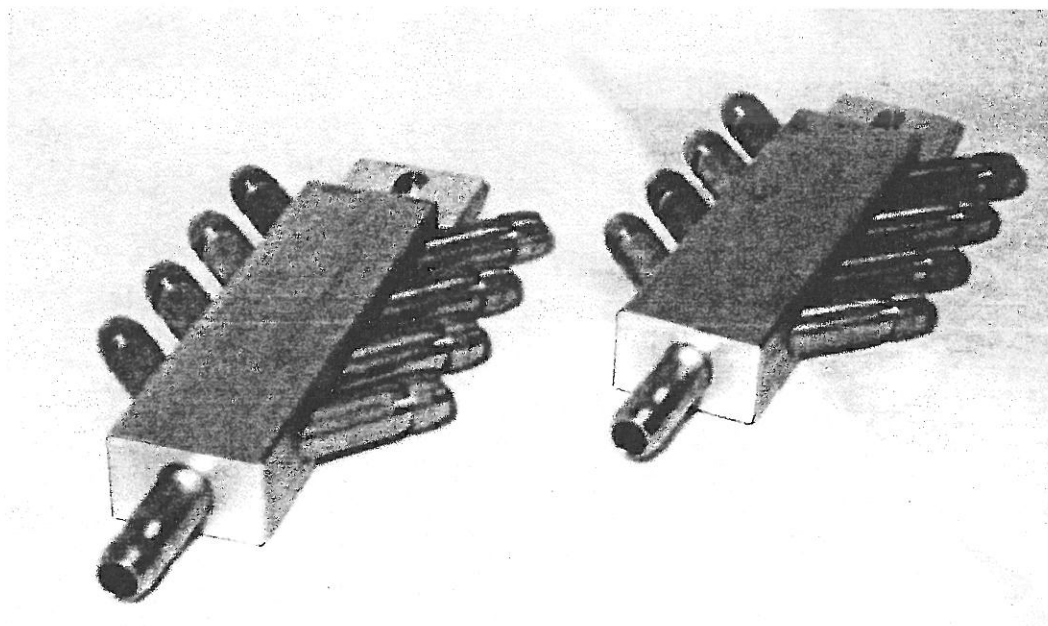


Fig. 3.3 Example of a Manifold

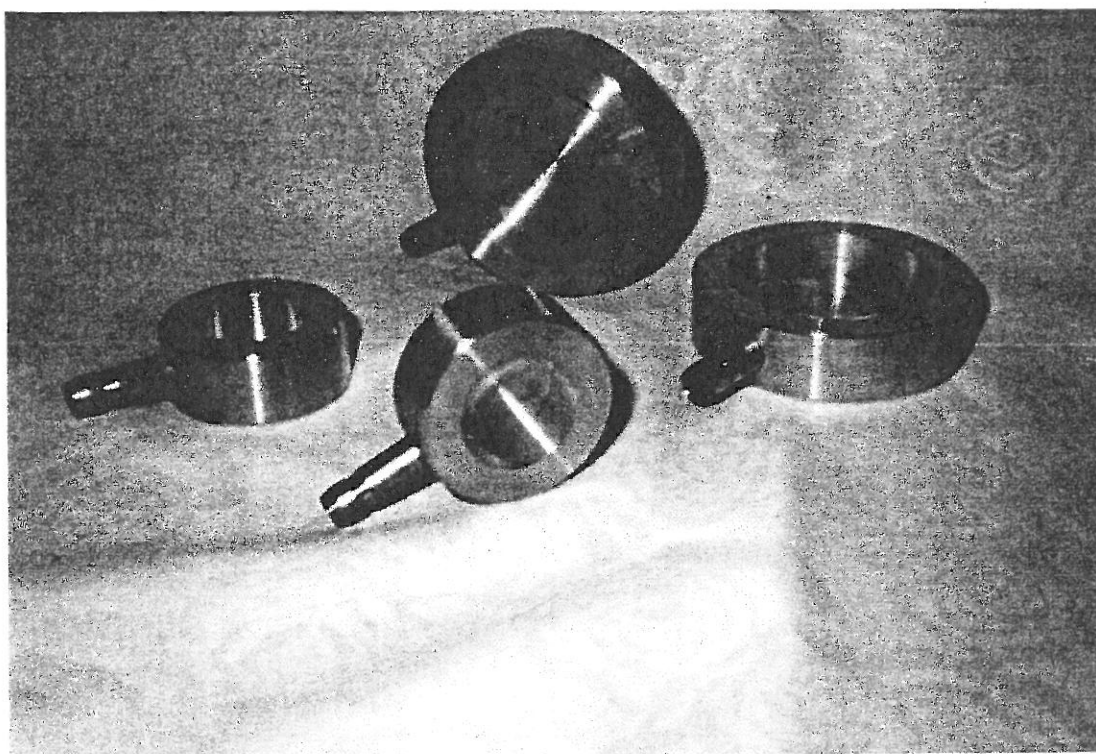
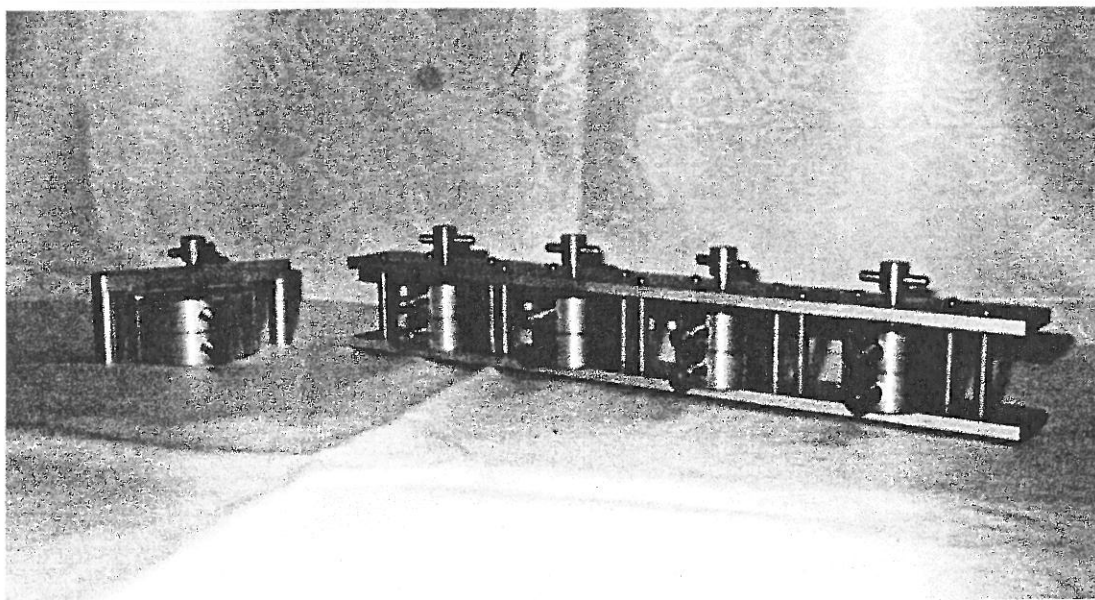


Fig. 3.4 Filter Clamps



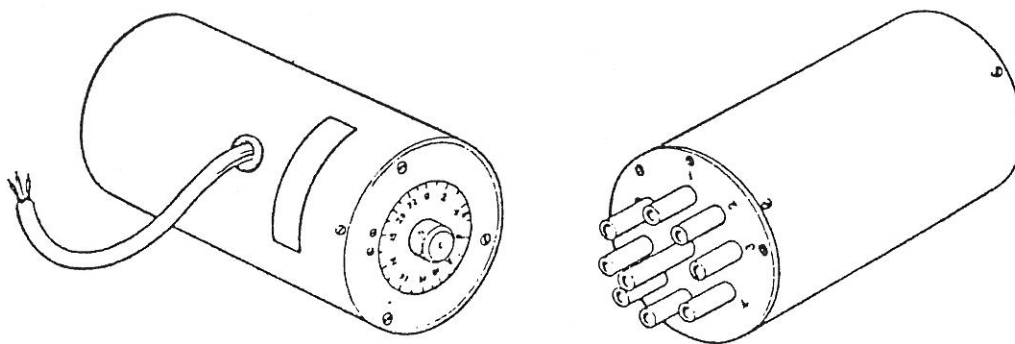


Fig. 3.5a GDL style 8 -Port Valve

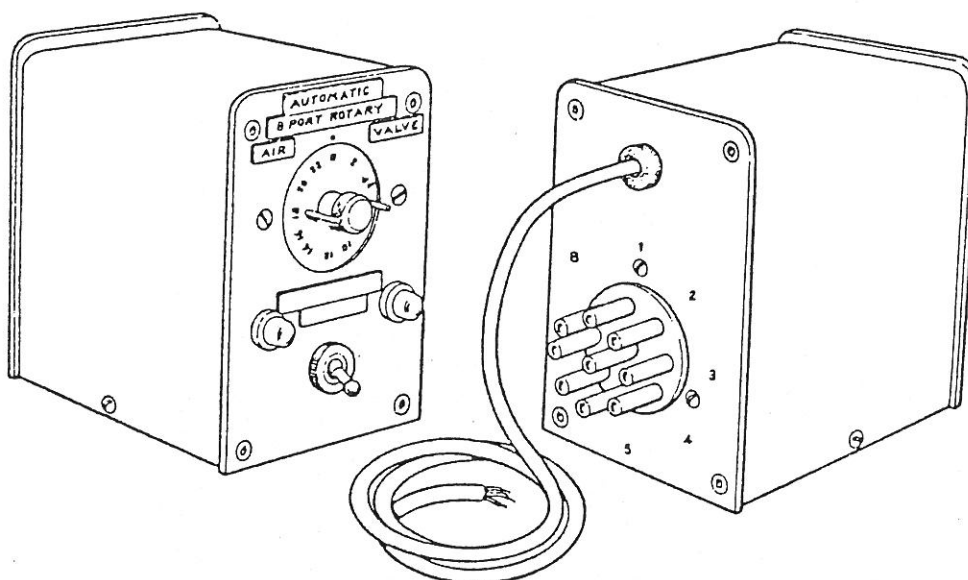


Fig. 3.5b AGL style 8 -Port Valve
(Reproduced with permission of AGL Engineering)

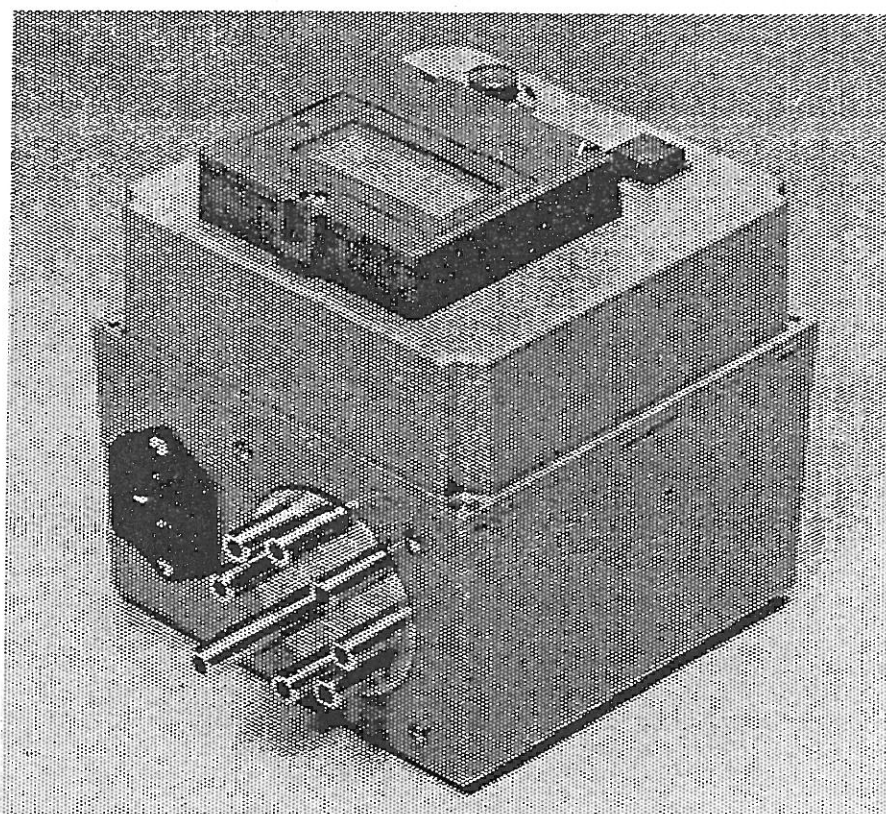


Fig. 3.5c Digital 8-Port Valve

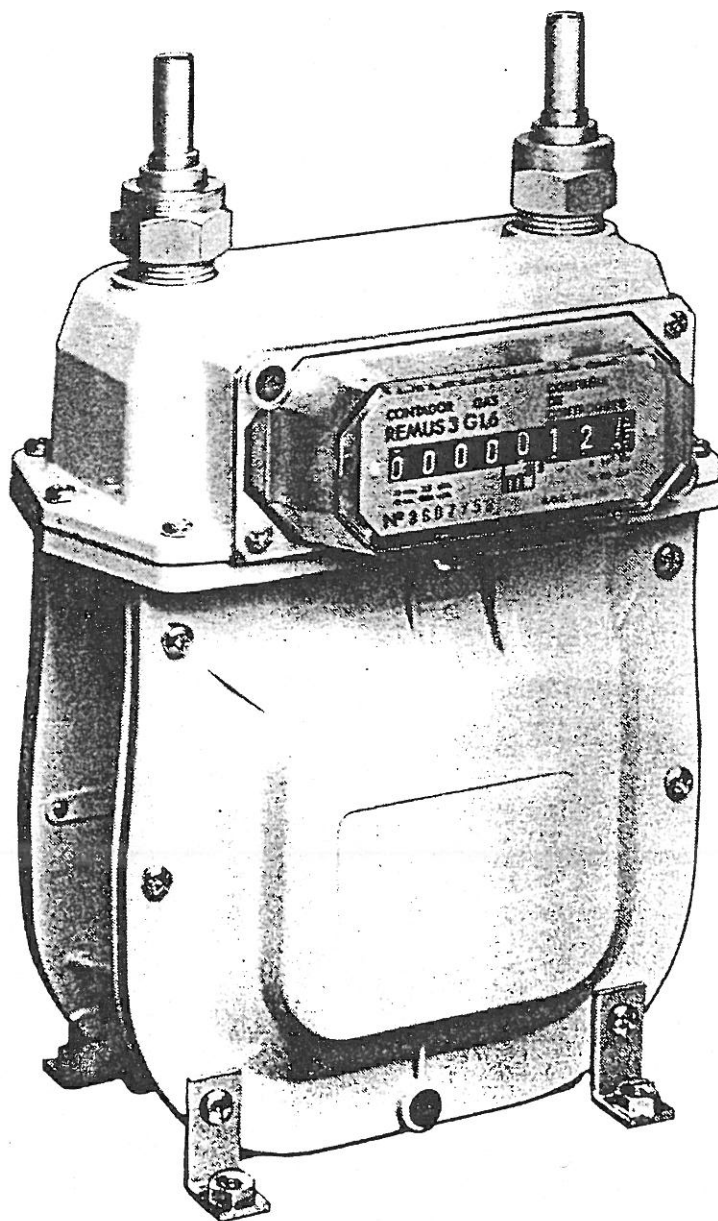


Fig. 3.6 Remus Dry Gas Meter

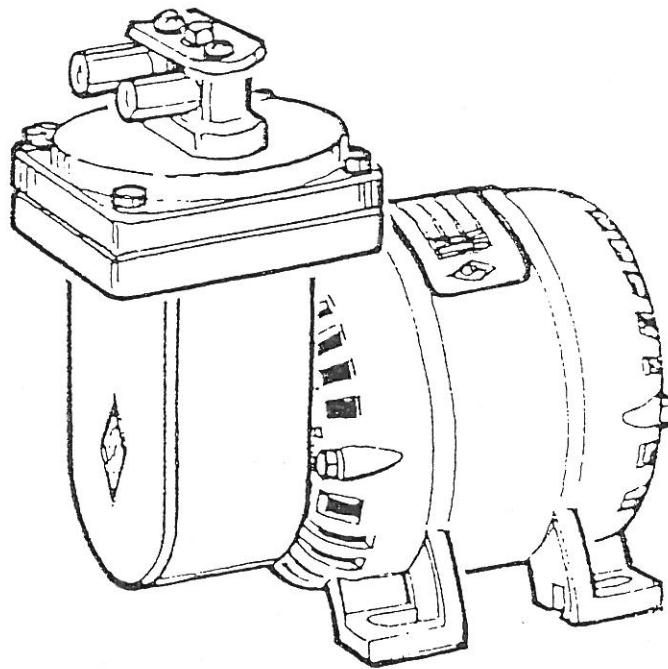


Fig. 3.7a Capex 2LNS Pump
(Reproduced with permission of Charles Austen Pumps)

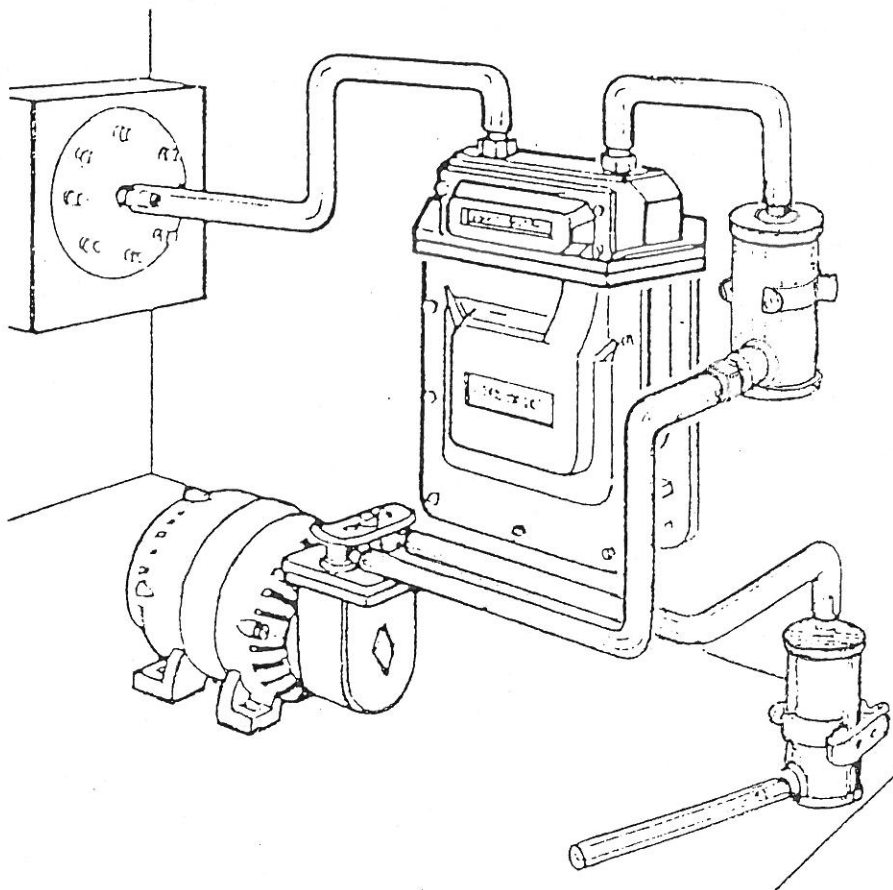


Fig. 3.7b Capex Pump "in situ"
(Reproduced with permission of Charles Austen Pumps)

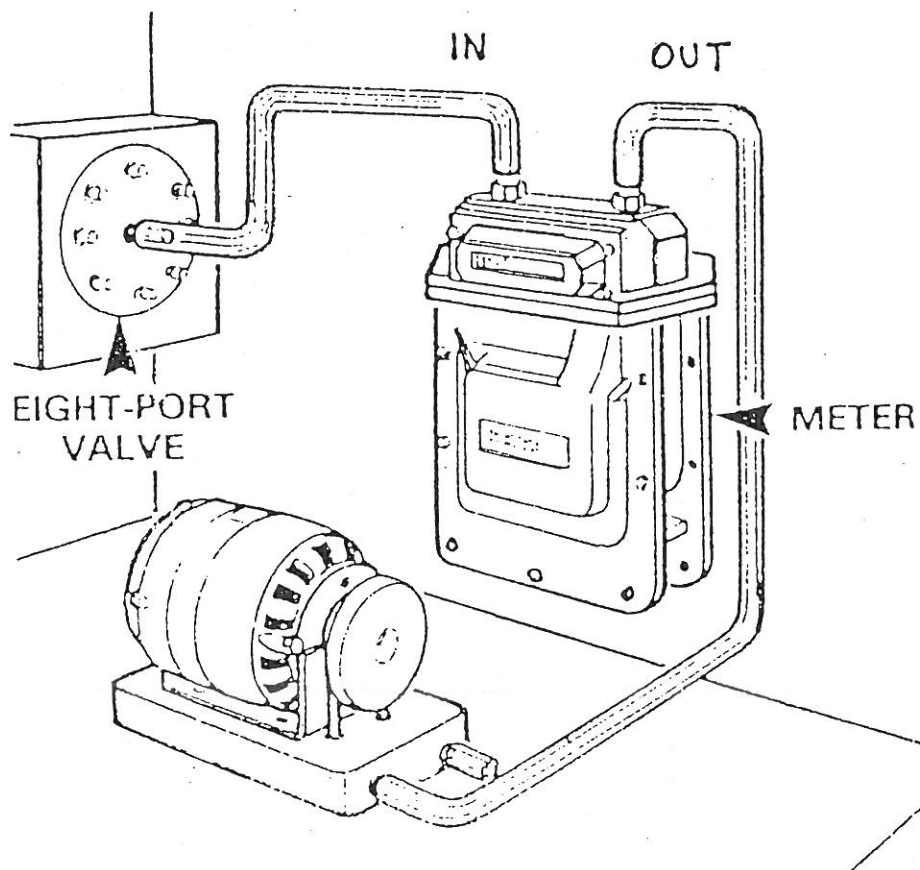


Fig. 3.8 Dymax Pump “in situ”
(Reproduced with permission of Charles Austen Pumps)

4 Siting and Installation of Sampling Equipment

4.1 SELECTION OF SAMPLING SITE

Since the intention is to monitor pollutant levels to which people may be exposed, the sampler should be placed where people spend long periods of time, such as residential areas. The method is not recommended for kerbside monitoring by busy roads. The monitoring site must be representative of the local area around it. Some points to bear in mind when selecting a site are listed here.

1. The sampler inlet funnel should be placed where it is exposed to a free flow of ambient air. Avoid situating the inlet funnel in a small enclosed yard, alcove, or corner.
2. The inlet should ideally be situated on whichever face of the building is exposed to the prevailing wind direction.
3. The funnel height should be at least 2.5m, and not more than 5m above the ground or other surface below (such as a flat roof).
4. The funnel should be a horizontal distance of at least 1m from any walls or other structures.
5. The site should not be anywhere near specific local sources of pollution, such as: *individual chimneys, industrial emissions, exhaust vents, areas where bonfires often occur, heavy traffic, vehicles waiting with engines running (for example at traffic lights), crematoria.*
6. The following can interfere with SO₂ measurement, and should therefore be avoided: *Toilets, fish shops, baby clinics, school chemistry labs, cleaning fluids, building or demolition work, drains, cattle markets, poultry, manure heaps, fertiliser, sewage works, chlorination plants for swimming pools, trees or foliage close by, any rotting vegetation, moss killing chemicals.*

In addition, other factors such as vulnerability to damage, and safe access for funnel installation and maintenance, will need to be taken into account. Also, for long-term monitoring, the future of the site should be considered; are any future changes likely to affect its suitability?

Finding a suitable site is not always easy: **netcen** will always give advice. The site should be given a unique identification name and number, which will need to be changed if it is moved.

4.2 LOCATION OF THE SAMPLER

The apparatus needs to be protected from the weather and from extreme temperatures or direct sunlight for long periods. Normally, it is kept inside a building, and the sampled air is drawn in from outside through flexible PVC tubing passing through a hole in a wall or window-frame. The length of tubing between the inlet and sampler should not be more than 6m. With sash windows it may be easier to put a board at the bottom on which the window can rest and through which the hole may be drilled. Alternatively, a glass pane may be replaced by one of Perspex, in which a hole can be drilled. A length of rigid conduit (metal or plastic) should be fixed so that it projects at least 1m from the building and more than 2.5 metres above the

nearest large area of horizontal surface such as the ground or a flat roof below. Fig. 4.1 shows the sampling inlet.

The apparatus is best placed in a store-room (although not one where chemicals are stored), or a room not in continuous occupation, as the noise of the pump, though not loud, can be distracting. The noise can be minimised by standing the apparatus on thick rubber or plastic foam sheeting. The sampler requires a mains supply, 240V AC, 50Hz. It is important that the apparatus should be protected from sunlight and from excessive heating by radiators or boilers; sunlight and warmth accelerate the decomposition of hydrogen peroxide, and excessive heating leads to evaporation of the liquid in the bubblers.

4.3 SAMPLING INLET

Inlet funnel. It is important that a funnel is used, and that its dimensions are as specified, as this affects the sampling of particulate. The funnel is usually made of plastic (glass was used in the past but is easily damaged). The diameter of the mouth must be $40 \text{ mm} \pm 10 \text{ mm}$, and the internal diameter of the stem about 6.5 mm. Most operators buy ordinary plastic laboratory funnels of a larger size, and cut them to the correct size. The mouth of the funnel can be cut carefully using a sharp knife, and any rough edges should be removed using a file or sandpaper. Any ribs on the stem must be filed off to ensure a close fit for tubing, and the stem will also need to be shortened. Fig. 4.2 shows the stages in cutting a plastic funnel to size.

Rigid metal or plastic conduit. This supports the PVC sampling tube, and carries it through the window or wall. At the outer end the funnel is connected, so that outdoor air is sampled. The tubing must extend the whole length from funnel to sampler, inside the conduit. The funnel should have its open end pointing vertically downwards: this can be achieved by bending the conduit itself; however, any bends should have a radius of at least 5 cm. The conduit should be positioned so that the funnel is at least 1m from the building wall, and between 2.5m and 5m from the ground.

Tubing. A supply of flexible PVC tubing will be needed to connect the funnel to the sampler. The tubing must be PVC, not rubber or polythene. It needs to be flexible, but rigid enough to resist kinking; the type sold as “semi-hard” is usually suitable. It may be necessary to select tubing with a slightly larger bore than the sampler’s internal tubing (perhaps 8mm) for this section, if 6.5mm will not fit the funnel or the manifold. A medical grade, such as Portex, is recommended, but not essential.

The sampler should be sited so that the run of tubing is as short as possible, and not longer than 6m. The run of the connecting tubing should be kept as straight as possible without kinks or hanging loops. Where the tubing has to change direction it is essential to keep the radius of the bend at least 5cm. A sharp bend causes turbulence in the air stream and deposition of some smoke particles on the walls of the tubing. Ensure that the tubing is protected from crushing (by furniture or being stepped on). Condensation occurs in tubing which has been chilled as soon as warmer air passes through, and this may reduce the air flow and may also absorb sulphur dioxide if the condensation can collect in any part of the tubing.

When attaching tubing to the funnel, manifold, or any component within the sampler, it is important to make a good seal. There are two methods of doing this.

1. The end of the tubing can be softened in very hot (not boiling) water for about a minute, and connected to the component while hot: it will contract on cooling, forming a good seal.
2. Alternatively, a *very* small amount of silicone lubricant can be applied to the end of the component inlet or outlet, and the tubing eased on gently.

All tubing should be examined regularly (e.g. every two or three months) and renewed when it becomes dirty, sticky, discoloured or loses its flexibility: usually after around two years.

4.4 NETWORK SITE DATA RECORDS

The details of all Network sites are recorded on **netcen**'s database. This includes:

- site name and number.
- The Local Authority responsible for its operation, with address and phone number.
- Its Ordnance Survey grid reference (or Irish Grid reference for sites in Northern Ireland).

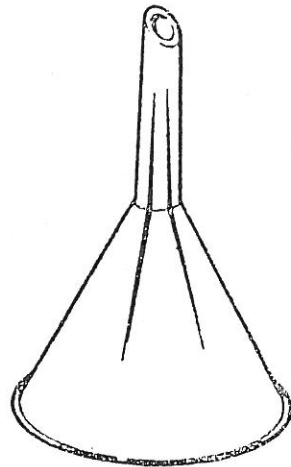
The site classification code; this describes the nature of the surrounding area. Site codes are as follows:

- A1 Residential area with high-density housing (probably terraced), or with medium-density housing in multiple occupation, in either case surrounded by other built-up areas.
- A2 Predominantly A1, but interspersed with some industrial undertakings.
- A3 Residential area with high-density housing or medium-density housing in multiple occupation surrounded by, or interspersed with, other areas with low potential air pollution output (parks, fields, coast).
- B1 Residential area with medium-density housing, typically an inner suburb or housing estate, surrounded by other built-up areas.
- B2 Predominantly B1, but interspersed with some industrial undertakings.
- B3 Residential area with medium-density housing surrounded by or interspersed with areas with low potential air pollution output (parks, fields, coast), or any residential area with low-density housing.
- C1 Industrial area without domestic premises.
- C2 Industrial area interspersed with domestic premises of high density or in multiple occupation.
- D1 Commercial area or one with predominantly central heating.
- D2 Town centre with limited commercial area, possibly mixed with old residential housing and/or minor industry.
- E Smoke control area or smokeless zone (the letter to be added to the primary classification).
- R Rural community.
- O1 Open country but not entirely without source(s) of pollution, e.g. airfields.
- O2 Completely open country; no sources within at least 400 metres.
- X Unclassified site, or mixed area.

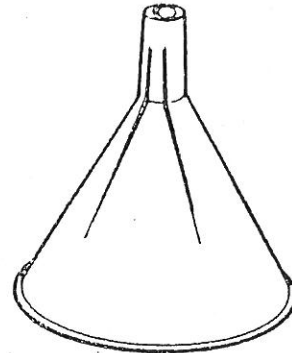
If any details change, such as Local Authority name or address, site classification or smoke control status, please inform **netcen** as soon as possible so that our records may be kept up to date. If it becomes necessary to move the sampler, please contact us beforehand for approval of the new site.



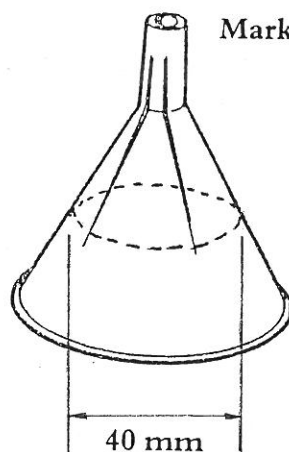
Fig. 4.1 Position of Sampling Inlet



1.

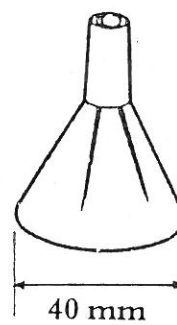


2.



3.

Mark using felt tip pen



4.

File off any ribs on the stem,
smooth cut edges using sandpaper

Fig. 4.2 Stages in Cutting A Plastic Funnel to the Correct Size

5 Routine Operation of the Sampler

This section describes the routine operation of the 8-port smoke and SO₂ sampler. Procedures for the weekly changeover of bottles and filter papers are outlined. This is followed by further details on specific aspects of the sampler's operation and routine maintenance, such as obtaining clear smoke stains, reading the gas meter and maintenance of the pump.

5.1 THE SAMPLER IN USE

The 8-port sampler is designed with eight pairs of clamps and bottles for weekly operation, providing daily means on a midnight to midnight basis. The timed eight-port valve should be set to switch over at midnight, to expose a fresh paper and bubbler each day. Weekly visits are made to change solutions and filter papers. The exposed solutions and papers are taken back to the laboratory for analysis and measurement.

The visits should ideally be made on the same day each week. If the sampler is left unattended for more than eight full days, filters and solutions will be exposed twice, invalidating two days' data for each day this happens. It is not necessary to ensure that the visit takes place at a particular time of day; the data processing programs used by **netcen** accommodate meter readings at varying times. The eight-port valve (if set correctly) ensures that the bubblers change over at midnight GMT exactly.

A standard data return form is used. These pre-printed forms are issued monthly to site operators by **netcen**. Section 8 gives full details of this form. Operators should take the data return form to the site when they visit, and record the meter reading and other details directly onto the form, adding titration and reflectometer results later. Recording directly onto the form in this way avoids transcription errors. If this is not possible, a logbook should be used to record meter readings, times, titration results, reflectometer readings and any notes. The logbook should be kept **for this purpose only**, and all entries should be clearly identified with the date, and site. *Do not use loose sheets of paper or rough notes; these are liable to get lost.*

5.1.1 Labelling of Components

Each pair of clamps and the corresponding Dreschel bottle **head** should be labelled with the number 1 to 8, in the order in which they operate. This should correspond to the number of the port on the 8-port valve to which it is attached (see back of 8-port valve). The Dreschel bottle heads and filter clamps can then be numbered to correspond. Suitable marking materials include wax "chinagraph" pencils, waterproof felt-tip pens or markers, or self-adhesive labels providing they stick firmly to glass or metal.

5.1.2 Weekly Procedure

A suggested weekly procedure is given below. It is expected that operators will adapt this to some extent; however, it is important the procedure remains consistent from week to week, to avoid errors.

It is useful to have a marker, e.g. a coloured clothes peg, which is placed each week on the *head* of the bottle which is active on the day of the visit (not on the tubing). This bottle and filter will be left undisturbed on this occasion, to be changed at the next visit; the marker should then be transferred to the active bottle. When changing solutions and papers, it is recommended to start with the bubbler and clamp which were active yesterday (for example, if bottle 5 is bubbling today, start with bottle 4), and work backwards round the circuit. The procedure will vary slightly depending on whether the operator uses a second set of Dreschel bottles to transport the exposed samples, or uses bottles of another type.

A card containing these instructions should be left with the apparatus so that, in an emergency, someone unfamiliar with the method could carry out the procedure.

1. There is no need to switch off electricity supply to pump in the case of the 8-port sampler, as the active bubbler will not be disturbed.
2. Ensure the timer is showing the correct time with respect to the next changeover. If a power cut has occurred, and the interruption was less than two hours, the timer should be re-set but the data need not be discarded. If the interruption was longer, inform **netcen** and make a note on data return form.
3. Read the meter. Enter figures **direct** on record form against today's date, ensuring that the pre-printed decimal point is in the correct place. Also enter size of filter clamp in use, and time of meter reading to the nearest minute. Do not make any corrections for British Summer Time.
4. Now check the flowrate: subtract previous meter reading from present one and calculate the volume of air passed since the last visit. If it is outside the required range of 2.0 cubic metres per day, $\pm 10\%$, this will need to be investigated and any possible fault corrected. **It is important that the flowrate is checked each time the site is visited. If the flowrate is outside the acceptable range, investigate the cause immediately.**
5. When changing the solutions and filters, work backwards in numerical order from today's active bubbler (which is left alone). The last bottle to be changed should carry the marker from last week's visit, and the date should fit into the sequence.
6. Ease the first bubbler out of its holder. Take the bubbler head firmly with one hand (without touching the glass tubes) and ease off the bottle with the other.
7. Either (i) replace with a second bubbler bottle containing fresh 1 vol hydrogen peroxide solution, seal the bottle containing the exposed solution, ensuring it is marked with the site name and date of exposure **or** (ii) pour contents into spare bottle or container for transport, and re-fill bottle with fresh solution to level marked on bubbler. See that container or spare bottle is named, dated and firmly sealed.
8. Do this for all seven non-active bottles. As you replace the bottle, ensure that the bubbler head makes a good seal. (If spare containers are used for transport, they must be conditioned before use as described in section 6). **When not in use they must be kept filled with fresh, pH 4.5 hydrogen peroxide solution** which is emptied out on the morning of the day they are used, several seconds being allowed for drainage).

9. Unscrew filter clamp and withdraw paper. Slip fresh sheet into place, making sure that smoother side is placed downwards, facing incoming air. After checking that the two halves of the clamp are absolutely in line, tighten screw down hard.
10. Carefully write the date of exposure, and the site name or number on the edge of the paper which was removed. Use a pencil or ball point pen which will not smudge. **Do not touch the stain itself, as this could affect the result.** Place paper in a self-sealing sample bag, box or envelope. Do not let the stain side of two exposed papers touch, as dirt may transfer from one to another. Note: some operators prefer to mark the date and site on the papers before inserting them in the clamps.
11. Do this for all seven non-active bottles and clamps.
12. Ensure that the sampler is bubbling normally before you leave. Note the rate of normal bubble formation; if subsequently the air flow is suspect, the bubble rate may help determine whether the pump or the meter is at fault.

The operator should now have seven exposed peroxide solutions, and seven smoke-stained filter papers.

5.1.3 Interruptions to Power Supply

If the timing disc is not in the expected position when a visit is made and/or bubbling is taking place in the wrong bottle, then a power cut has probably occurred. Provided that the interruption does not exceed 2 hours, no further action is necessary other than to re-set the timing disc. If the interruption exceeds 2 hours, then some of the results may have to be rejected. A note should be made on the data return form and/or in the log book of the time and duration of the interruption to the electricity supply, for quality control purposes and the timing disc will require re-setting. Should this persistently occur, the problem may not be power cuts, but a faulty timer.

5.1.4 Containers for Transporting Peroxide Samples

The exposed solutions must be carried back to the laboratory for titration in securely sealed containers.

The best option is to keep two sets of Dreschel bottles for the sampler; each week, the bottles containing the exposed samples can be marked with the exposure date, removed from the sampler and replaced with the other set filled with fresh hydrogen peroxide solution. They are strong, easily “conditioned” and can be fitted with a stopper of an inert material such as glass. The exposed solutions remain in the same Dreschel bottle until titrated, minimising the possibility of contamination. However, Dreschel bottles are comparatively expensive.

A cheaper option is to use a set of screw capped inert plastic or glass bottles, for transport and storage of exposed solutions until they can be titrated. Suitable bottles can be obtained from a laboratory supplier. They should be tested as described in section 5.3.2. , to ensure they do not affect the pH of the solutions.

5.2 OBTAINING GOOD SMOKE STAINS

Always use Whatman Grade 1 filter paper. This is available from the major laboratory suppliers, and is not expensive. Several sizes are available:

- Whatman reference 1001 042 is a 42.5 mm diameter circle. The brass filter clamps in an AGL model 8-port sampler are also 42.5 mm diameter; however this can be awkward in use because once the paper is in the clamps, there are no protruding edges for handling or marking the paper.
- Whatman reference 1001 055 is a 55 mm diameter circle. Ideal for the Airtest (Glass Developments) and Eccodata samplers, there is plenty of gripping and writing space. However, this size does not fit the AGL model well, as the paper is too large to fit between the clamp alignment/centring posts, leaving a crescent shaped space in the clamping area, which may leak.
- Whatman reference 1001 824 is a rectangular paper 75 mm x 100 mm. This size would be wastefully large if used in one piece, but by guillotining through the long edge to give two 75 mm x 50 mm pieces it can be used in all 1 inch clamps. This is ideal in the AGL model when inserted diagonally.

The filter papers have a rough side and a smooth side. They are all the same way up in the pack or box. Determine which side is uppermost and write on the outside of the box for future reference. Take care when guillotining rectangular papers not to turn the pile over: keep them all the same way up.

When inserting into the clamps, the smooth side should face the incoming airflow, and collect the smoke stain. When reading the smoke stains, use the same side of a clean paper from the same batch to set the '100' reading. Use a fresh paper for this every measurement session.

Smoke stains should be perfectly circular, and have sharp edges with no blurring or rings around them. Fig. 5.1 shows examples of good and bad smoke stains. To obtain good smoke stains:

1. The lower part of the clamp must be correctly positioned. The means of positioning the clamp depends on the sampler design. In the AGL sampler this is done by pushing it back until it meets two 'centring posts'; some older designs have a small metal protrusion on the floor of the case, which fits into an indentation on the underside of the lower part of the clamp.
2. The upper and lower filter clamps must be exactly aligned, or the resulting stain will not be circular, the edges will be ill-defined, and the concentration of smoke obtained from it will be inaccurate, possibly by as much as 40%.
3. The clamps must be fully tightened, otherwise indoor air will leak in between them. This will produce stains with fuzzy edges, and dilute the sample, giving inaccurate results.
4. The paper should cover the whole area between the clamps; otherwise there may be leakage.
5. The filter paper must always be inserted with the smooth side facing the incoming air, normally downwards. To tell which is the smooth side of the sheet, the paper should be held with one edge towards the light, when the rough side can easily be seen as the light passes across the surface.

6. The filter papers which have been removed from the clamps should have the date and the name of the site written on them **without touching the stain**, and it should be placed in a clean sample bag or box until required. Alternatively, it may be helpful to mark the site identification and exposure date on the papers **before** they are inserted into the clamps.
7. One of the most common errors is reading the stains on the wrong side: it is therefore important that a consistent system is adopted, such as marking the paper on the same side as the stain.
8. If dark stains (reflectometer reading less than 70) are occurring frequently, it may be necessary to switch to a larger clamp size. However, 1-inch clamps are sufficient for most applications in the UK nowadays, so if this is a problem please consult **netcen** for advice.

The faces of the clamps may become worn after a long period of use. To improve the surfaces of **brass** clamps, place a sheet of carborundum paper on a perfectly flat surface such as a sheet of plate glass and rub the face of each clamp over it with a circular motion; carborundum paper grades 0, 00 and 000 should be used in succession as necessary. Test the clamps again and repeat until the seal is restored. The clamps must be carefully cleaned after this treatment. Alternatively, return them to the supplier for re-surfacing.

5.3 BUBBLER (DRESCHER) BOTTLES

5.3.1 Use and Care of Bubblers

The Dreschel bottle, or bubbler, is made in two parts: the body or bottle itself, and the head. To empty and re-fill, the bottle is disengaged from its head, which remains permanently in position. To do this, release the Dreschel bottle from any clips etc. holding it in place in the sampler. Then hold the Dreschel head firmly by the head itself (**not** by the glass tubing) with one hand while twisting the bottle downwards with the other. Any liquid remaining in the inlet tube is removed by touching it against the inside of the bottle, not the inside of the ground glass joint.

The ground glass joint between the Dreschel head and the bottle, under clean conditions, with careful use, will be airtight. A **very** small amount of tap lubricant, as used for burette taps, may be needed if the joint sticks.

5.3.2 Conditioning of new Dreschel Bottles

New Dreschel bottles may contain traces of alkali, which would interfere with the measurement of sulphur dioxide. They may therefore need to be "conditioned" before use, in order to remove this.

The new Dreschel bottle (or other glass container for transporting exposed samples if used) should be washed with deionised water, and rinsed well with 1 vol pH 4.5 hydrogen peroxide solution. Fill with the peroxide and seal with the stopper (or screw cap) provided. Leave until next day. Then pour around 50 ml of the peroxide from the bottle into a flask or beaker, and add 3 to 5 drops of BDH pH 4.5 indicator. Compare the colour with that of the same volume of fresh solution, in a similar beaker, to which indicator has also been added. If the colours of the two samples are identical, there has been no change in the solution left in the container

overnight, and the container is suitable for use. If the sample from the new bottle is at all blue, the bottle should be refilled with fresh dilute pH 4.5 peroxide, and left overnight again. This procedure should be repeated until there is no colour change.

5.3.3 Evaporation

Some water will evaporate from the bubblers while in use. This in itself is not a problem, as long as there is sufficient liquid to keep the end of the inlet tube submerged by 1 cm throughout the sampling period. The volume is not critical to the subsequent titration. In the UK, an initial volume of about 50 ml of peroxide per bottle is normally sufficient. However, in warm locations, the volume of hydrogen peroxide solution should be increased (though not to the extent that any liquid could be drawn into the outlet tubing). It may sometimes be possible to minimise the heating by leaving the box open, as the pump generates heat and the inside of the box can become quite warm.

5.3.4 Freezing

Freezing is much less likely in an 8-port than in the old single-day samplers, as the pump, which is a good source of heat, is enclosed within the box. However, if freezing does occur it will be necessary to insulate the entire sampler. The meter must be kept at least as warm as the bubbler or condensation will take place within it.

Under no circumstances should any form of "anti-freeze" be added to the solution as this would result in an incorrect answer being obtained on titration.

5.4 THE 8-PORT VALVE

The 8-port valve, by means of its timer, can be set to operate at any time of the day. However, for the purposes of the Network it should be set to change over at midnight GMT, throughout the year. Once the timer is set, it should run without adjustment for many weeks, assuming there are no power cuts or other problems. Instructions for setting the most commonly used 8-port valves (those found in the AGL, GDL, and Eccodata samplers) are given below. Instructions for the 8-port valves with the digital (Randall) timer are given in Appendix 2.

Usually, the only part of the valve to need adjustment is the timing disc. To move the disc, the locknut in the centre must be loosened first; forcing the timing disc round with the locknut tightened could cause damage. Hold the timing disc still with the fingers of one hand and loosen the locknut with the other hand. Rotate the timing disc to the new position, hold it in place and screw the locknut tight again – hand tight is sufficient. To test that the locknut is tight, try to **gently** move the timing disc by pressing with one finger. (The Eccodata model does not have this locking mechanism).

Avoid always moving the timing disc in one direction; constant rotation in one direction will either lock the disc, or wind it so far out that the microswitch inside is no longer operated by the cam on the timing disc. It should never be necessary to turn it through more than one revolution in either direction.

The direction of rotation of the timing disc has not been standardised. The hour markings on the timing disc may indicate either the time which has elapsed since the last change (in this case, the disc rotates past the timing mark in the direction 0-22-20-18...), or the time until the next change (in which case the disc rotates in the direction 0-2-4-6 ...). As in the twenty-four hour clock, 0 hours and 24 hours are at the same point on the disc, which for convenience is marked 0. If the valve is required to change from one port to the next at a specific time each day (usually midnight), the timing disc must be set correctly.

(i) If the timer shows hours until next change; check the time now (e.g. 2.30 pm). If it is British Summer Time (BST), subtract 1 hour (e.g. to 1.30 pm GMT). Calculate the hours remaining until midnight GMT (10 hours 30 minutes). Loosen the locknut, set the dial to show a time of 10.30 against the datum mark, and relock the disc.

(ii) If the timer shows hours since last change; the dial effectively shows the time of day. Check the time now (e.g. 10.00 am). Again, if it is British Summer Time (BST), subtract 1 hour (e.g. to 09.00 am GMT). Loosen the locknut, set the dial to show 9.00 against the datum mark, and relock the disc. *There is no need to alter the timer when British Summer Time begins or ends.*

If it is necessary to select a different sampling line from the one in use, the port-change motor can be operated manually as follows.

1. Have the sampler switched on and bubbling.
2. Hold the timing disc still by gentle pressure from the fingers, and loosen the knurled nut (locknut) by a few turns with the other hand.
3. Rotate the timing disc gently, in either direction, until the port-change light comes on, indicating that microswitch inside the valve is connected. This happens when the 0 on the disk is lined up with the mark on the body of the valve (in practice the two marks may not quite coincide at this point). The opening of the microswitch can be felt in the fingers rotating the timing disc - there is a distinct change in resistance to the turning of the disc. Now wait.
4. The bottle in use will stop bubbling. After a second or two, the bubbler next in line will start.
5. Wait until the light goes off.
6. If it is necessary to move on more than one port, repeat actions 3 to 5 above.
7. Set the changeover time to midnight GMT as described above, and re-tighten the locknut holding the timing disk in place.

It is also possible to set the changeover time by setting the dial so the datum mark is on zero, allowing the port change light to come on and bubbling to stop. Then switch off the sampler completely until midnight GMT. This method is more accurate, as it avoids error due to any 'backlash' in the valve's gears; however, it is of course very inconvenient, so in practice most site operators use the method above, which is perfectly adequate for the purposes of the Network.

Although the 8-port valve requires very little maintenance, it may leak if its internal components become worn. It is therefore recommended that it is serviced from time to time (and certainly if a leak is suspected). The current suppliers of samplers are able to provide this service, for any type of 8-port.

5.5 READING THE GAS METER

Mis-reading the meter, or mis-recording the reading, is a common source of error. Operators are advised to take their time and check their readings carefully.

Always note the time of the meter reading, correct to the nearest minute. The time should be recorded in 24 hour clock form, e.g. 9 am as 0900, 1.30 pm as 1330, and so on. Record the actual date on which the meter reading was taken: do not worry if the meter reading was not taken on the “normal” day of the week.

A variety of different types of gas meter are now in use. The more recent AGL and Airtest models use the metric Remus gas meter; this is a Spanish design, and uses a comma to represent the decimal point. Other types are in use, particularly in older samplers. Appendix 1 gives further guidance on reading various types of meters. The entry on the Data Return Form should be entered to the nearest 0.01 m^3 for a metric meter, or to the nearest 0.1 ft^3 for one reading in cubic feet: it is not necessary to round up the reading. Leading zeros must appear where appropriate, e.g. 02.34. You may find it helpful to cover part of the meter display window with masking tape, so that only the four required digits are visible. It may also be helpful to mark the position of the decimal point.

The accuracy of the meter should be within $\pm 3\%$. **netcen** can test your meter free of charge to determine whether or not it meets this specification. Meter suppliers may also offer this service. If there is any doubt about the accuracy of a meter, or if it has been in use for several years without checking, it is recommended that the meter should be tested.

Each time the meter is read, the volume of air passed since the last reading should be calculated. Please check air volume flow-rates are within the acceptable range of 1.8 to 2.2 m^3 per day (65 to 75 cubic feet per day). This is approximately 14 m^3 (500 cubic feet) per week. If this check is done while still at the site, mis-readings can be corrected, and faults identified quickly. Any unexpected variation should be checked; this way, any problems with the apparatus can often be remedied before they become serious and lead to loss of data. If a power cut is suspected, please indicate this on the Data Return Form: on which day and for how long, if known.

If someone other than the usual person has to do the meter reading, please make sure they are instructed, and given a copy of this manual. Instructions can also be kept near the sampler.

5.6 CARE AND MAINTENANCE OF THE PUMP

5.6.1 The CAPEX Pump

The type of pump now recommended for use in the 8-port sampler is the Capex 2LNS, manufactured by Charles Austen Pumps Ltd, a small diaphragm pump. This pump is capable of producing flowrates of over 7 m^3 per day; the flowrate is controlled to within the required range (2 m^3 per day $\pm 10\%$) by a flow limiting critical orifice.

The critical orifice assembly is fitted between the meter outlet and the pump inlet; it consists of a sealed black plastic cylinder about 5cm long, housing a $5\mu\text{m}$ filter (the “safety filter”), which captures any remaining dirt particles in the sampled air. This cylinder has a small side boss; threaded into it is a small white connector which contains a flow limiting orifice itself – a tiny disc of hard material with a hole in its centre. Any damage or blockage of this component will adversely affect the flowrate; the purpose of the safety filter is to capture any particles remaining in the sampled air, which would otherwise build up on the critical orifice, and eventually block it. This assembly is connected to the inlet of the pump itself by a 20 cm length of reinforced tubing (ordinary PVC tubing would collapse under the pump suction). On the pump outlet there is another black plastic cylinder similar to the safety filter case; this is a silencer (and is marked as such).

The manufacturer, Charles Austen Pumps Ltd, recommends that the whole filter and critical orifice assembly should be replaced every two years. If the flowrate is checked each week, any persistent downward trends in flowrate should be spotted before the flowrate falls below the lower limit of 1.80 m^3 per day, giving ample time for a new filter and orifice assembly to be fitted. **We recommend that you keep a new filter and critical orifice assembly to hand. This way, replacement can be carried out quickly and easily, without losing any data. They are available from suppliers of Capex pumps (see our list of suppliers), are not expensive, and are supplied ready assembled, with the filter case sealed and the correct length of reinforced tubing.** Do not fit a new critical orifice without also replacing the filter, or the new orifice will block very quickly.

Replacement pump diaphragms are also available from the manufacturer, or from the supplier of the sampler.

5.6.2 The Dymax Pump

Although the CAPEX is now the recommended pump, some samplers still contain the older Dymax Mk IIA pump. This was designed to sample at the standard rate without attention for a year. At least once a year it should be returned to the makers for servicing, even if it appears to be running correctly. An increase in the amount of noise generated by the pump is a sign that the bearings are running dry, but this may not necessarily be accompanied by a fall-off in the pumping rate.

The Dymax pump runs hot; always allow the body of the pump to cool for several minutes before attempting to touch it, since it may reach 70°C in a normal room. A pump at room temperature, particularly one which has been stored for some time, may take several minutes to reach maximum speed, but under normal circumstances this time is not critical.

Note that the volume passed may be reduced if the smoke stain is very dark, owing to blockage of the pores of the filter paper and the resulting increase in resistance to the flow of air. When this resistance rises to produce a pressure drop of 130 mm Hg across the paper, the pump cannot draw air through the system.

5.7 CHECKING FLOWRATES

ISO 9835, 1993 specifies that the sample flowrate shall be 2 m³ per day, ± 0.2 m³ per day, that is 1.80 to 2.20 m³ per day. Data must be rejected if the sample flowrate is substantially outside the acceptable range. *It is therefore important that operators check their sample flowrates every time the site is visited*, and take action if the flowrate rises above, or falls below, the acceptable range. The daily sampling flowrate (f) is calculated as follows:

(i) For two meter readings, R_1 and R_2 , exactly d days apart:

$$f = \frac{(R_2 - R_1)}{d}$$

e.g.:

7th April, time 1030, reading $R_1 = 52.47$ m³

14th April, time 1030, reading $R_2 = 66.89$ m³

$d = 7$ whole days

$$f = \frac{(66.89 - 52.47)}{7} = 2.06 \text{ m}^3$$

(ii) For two meter readings R_1 and R_2 , d days + h hours apart :

$$f = \frac{(R_2 - R_1)}{(d + (h/24))}$$

e.g.:

2nd November, time 1330, reading $R_1 = 30.58$ m³

9th November, time 1030, reading $R_2 = 43.99$ m³

$d = 6$ whole days, $h = 21$ hours

$$f = \frac{(43.99 - 30.58)}{(6 + (21/24))} = 1.95 \text{ m}^3$$

(iii) For two meter readings R_1 and R_2 , d days + h hours apart + m minutes apart:

$$f = \frac{(R_2 - R_1)}{(d + (h + (m/60))/24)}$$

e.g.:

10th February, time 0920, reading $R_1 = 22.08$ m³

17th February, time 1140, reading $R_2 = 35.59$ m³

$d = 7$ whole days, $h = 2$ whole hours, $m = 20$ minutes.

$$f = \frac{(35.59 - 22.08)}{(7 + (2 + (20/60))/24)} = 1.90 \text{ m}^3$$

These examples use metric meter readings, but the procedure is the same for meter readings in cubic feet. **netcen**'s data processing software calculates sample flowrates using times to the minute, but for the purposes of checking flowrates it is usually sufficient to work to the nearest hour or half hour.

5.8 WHAT TO DO ABOUT HIGH FLOWRATES

If the calculated flowrate is apparently high (that is, greater than 2.20 m^3 per day), the operator will need to address the following questions.

- **Has the meter been checked recently?**

One common cause of apparent high flowrates is a meter which is reading high. The meter should be tested against a calibrated standard meter. This can be done by **netcen**, or in some cases by the supplier for a small fee. The meter should be accurate to within $\pm 3\%$. If it is reading over 3% high, it will probably need to be replaced. Remember that if a meter is replaced, either temporarily or permanently, this must be entered on the data return form. The “new meters” procedure is given on the back of the form.

- **Is the sampler pump a “Dymax”?**

This type of pump is the older style. It is designed to produce a flowrate of around 2 m^3 per day. When a Dymax pump develops a fault, the flowrate usually falls rather than rises, so apparent high flowrates in a sampler with a Dymax pump are most likely to indicate a faulty meter.

- **Is the sampler pump a “Capex”?**

This is the newer type of pump. Between the meter and the pump inlet there should be a “safety filter and critical orifice assembly” – a sealed black plastic cylinder about 5cm long, housing a $5\mu\text{m}$ filter (the “safety filter”). This cylinder has a small side boss; threaded into it is a small white connector which contains a flow-limiting orifice. It is this “critical orifice” – a tiny disc of hard material with a hole in its centre – which determines the flowrate. Without it, the flowrate would be considerably higher than required. So a fault in this component could result in a substantially high flowrate.

- **Is the pump neither of the above?**

Contact **netcen**. It may be an obsolete or unsuitable type. The meter should also be checked.

- **Has the sampler flowrate suddenly increased by large amount (e.g. several m^3 per day)?**

In this case, the sampler will be bubbling visibly faster than normal. A sudden large increase in flowrate can occur if the critical orifice becomes damaged. In this case, the critical orifice will need to be replaced. Replacements are available from suppliers of the Capex pump (see our list of equipment suppliers), and are not expensive. This fault is rare, so please let **netcen** know if it occurs.

- **Did the problem start when the critical orifice assembly was routinely changed?**

Occasionally a new critical orifice is outside the specified range. However, a more common scenario is that (i) the old critical orifice had gradually accumulated dirt and was giving a low flowrate, but (ii) the meter was reading high, so the flowrate appeared OK. In this situation, when a new critical orifice is put in, and the true flowrate is restored to 2 m^3 per day, the over-reading meter indicates that the flow is high. The meter should be tested. If the meter is reading correctly, return the critical orifice to the manufacturer for replacement. If the meter is faulty it may need replacing.

- **Has the flowrate slowly increased over a period of months?**

It is possible for the critical orifice to become damaged, giving an increased flowrate. However, this is rare (it is far more common for the critical orifice to become partly blocked by accumulated dirt, thus reducing the flowrate). The most likely reason is that the meter is beginning to read high, and the meter should be tested.

5.9 WHAT TO DO ABOUT LOW FLOWRATES

If the flowrate according to the meter is checked and found to be low, (that is, less than 1.80 m³ per day), the operator should address the following questions.

- **Is there water in the tubing or anywhere except the bottles?**

The inlet tube has been obstructed – squashed, kinked or blocked. This is infrequent but can cause serious damage. Switch off and unplug the sampler immediately, and ring **netcen** for advice. You will almost certainly need to disconnect the sampler's components to drain the water out. The 8-port valve and meter may be damaged. Prevention: ensure that the tube is supported, with no tight bends, and that no objects can crush it. Also keep the inlet funnel in good condition.

- **Is the timer showing its normal changeover time?**

If not, there may have been a power interruption – either a power cut or accidental switch off. Re-set the timer and check the sampler again as soon as possible. Make a note on the data return form.

- **Has the meter been tested recently?**

One cause of apparent low flowrates is a meter which is reading low, and this possibility should always be investigated. The meter should be tested against a calibrated standard meter. This can be done by **netcen**, (or in some cases by the supplier for a small fee). The meter should be accurate to within $\pm 3\%$. Remember that if a meter is replaced, either temporarily or permanently, this must be entered on the data return form. The “new meters” procedure is given on the back of the data return form.

- **Is the sampler pump a “Dymax”?**

If the meter is accurate but the flowrate is still low, the Dymax pump is probably faulty and needs to be serviced or replaced.

- **Is the sampler pump a “Capex”?**

If the pump is a Capex, there are two possible causes of low flowrates: partial blockage of the critical orifice, or a fault in the pump itself: see below.

- **Is the pump neither of the above?**

Contact **netcen**. It may be an obsolete or unsuitable type. The meter should also be checked.

- **Did the flowrate drop quickly?**

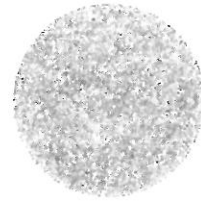
Possibly a faulty pump. This is still fairly rare with the newer Capex pumps, but is possible. Ring **netcen** for advice, or contact the supplier.

- **Has the sampler flowrate fallen slowly over a number of weeks or months?**

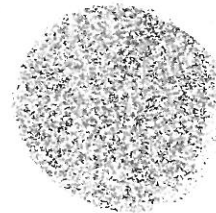
For a Capex pump, the most common reason for low flowrates is that the critical orifice has become partly blocked. The 5 μm “safety filter”, which protects the critical orifice from any remaining dirt particles in the sampled air, loses its efficiency over time. The dirt then builds up on the critical orifice, narrowing the hole. This causes a slow decline in flowrate.

The manufacturer, Charles Austen Pumps Ltd, recommends that the whole filter and critical orifice assembly should be replaced every two years. If the flowrate is checked each week, any persistent downward trends in flowrate should be spotted before the flowrate falls below the lower limit of 1.80 m³ per day, giving ample time for a new filter and orifice assembly to be fitted. We recommend that you keep a new filter and critical orifice assembly to hand. This way, replacement can be carried out quickly and easily, without losing any data. They are available from suppliers of Capex pumps (see our list of suppliers), are not expensive, and are supplied ready assembled, with the filter case sealed and the correct length of reinforced tubing on the end. Do not fit a new critical orifice without also replacing the filter, or the new orifice will block very quickly.

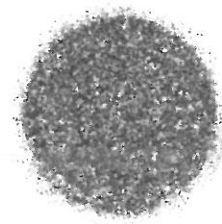
Good Stain: light to medium grey, even density, sharply defined edge. Darkness increased for clarity.



Bad Stain: clamps misaligned resulting in oval stain of uneven density.



Bad Stain: clamps not tightened sufficiently, resulting in leakage. Edges are fuzzy, and stain is spread over too large an area.



Bad stain: much too dark. Pores of paper are clogged, causing air to leak in between edges of clamp.

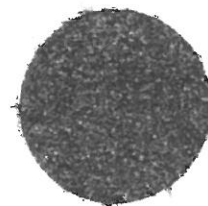


Fig. 5.1 Examples of Good and Bad Smoke Stains

6 The Assessment of Sulphur Dioxide

6.1 PRINCIPLES OF THE METHOD

As explained in Section 2, the concentration of sulphur dioxide in the air is estimated by drawing a metered volume of air through dilute, acidified hydrogen peroxide initially at pH 4.5 in a bubbler. The solution is acidified to pH 4.5 so that strong acids (primarily SO_2) are absorbed in preference to weakly acidic compounds such as carbon dioxide. Sulphur dioxide in the air reacts with the peroxide to form sulphuric acid in solution, increasing its acidity (decreasing the pH). The total amount of acid in the exposed solution is determined by titration with a standard alkaline solution of di-Sodium tetraborate, back to pH 4.5. This 'titre' is then used in the calculation of the ambient concentration of SO_2 .

The procedure uses three solutions:

- Dilute hydrogen peroxide, acidified to pH 4.5 by addition of dilute sulphuric acid
- dilute (0.002 M) sulphuric acid; this is used to adjust the pH of the peroxide solution to pH 4.5 before use
- dilute (0.002 M) di-Sodium tetraborate; this is used to titrate the exposed samples back to pH 4.5.

Successful titration depends on the accurate preparation of acid and alkaline solutions and the delivery of these in accurate amounts by means of burettes. This section describes how these solutions should be prepared, tested, and used.

Chemical indicator is used to determine the end-point of the titration; specifically, BDH pH 4.5 indicator (manufactured by BDH Merck) is used. At pH 4.5, this indicator is grey, with neither a pinkish or bluish tinge. This is termed 'neutral grey'. The indicator has a pinkish colour in more acidic solutions, and a bluish colour in more alkaline solutions. BDH pH 4.5 indicator should always be used; operators should only use a pH meter instead if they are colour-blind.

6.2 STRENGTH OF SOLUTIONS

6.2.1 Sulphuric acid and di-Sodium Tetraborate

The current convention for describing strength of a solution is in terms of **moles per cubic decimetre** (a cubic decimetre, dm^3 , is more commonly termed a litre). However, the terms 'Molar' and 'Normal' are also still in use.

A '**Molar**' (or 1M) solution was an alternative term for one which contains 1 molecular weight (in grammes) of solute in a litre of solution (1 mole per dm^3 , or mol dm^{-3}). The molecular weight of a substance is a constant. The abbreviation 'M' is still used, however the term molar is obsolete.

'Normal' is an older term, also obsolete. It refers to a solution of one gram-equivalent weight of the reacting substance in one litre of solution. One litre of a 'Normal' (1N) solution of any alkali contains the amount of that alkali required to neutralize one litre of 1N acid. Thus, one litre of N/250 or 0.004N sulphuric acid will neutralise one litre of N/250 alkali or alternatively, 1000/250 ml of 1N alkali. A Normal solution of sulphuric acid contains 49 grammes of sulphuric acid in one litre of solution.

The solutions used here are $0.002 \text{ mol dm}^{-3}$ (0.002 M, N/250) di-Sodium tetraborate (Na_2BO_7 (aq)) in deionised water, and $0.002 \text{ mol dm}^{-3}$ (0.002 M, N/250) sulphuric acid (H_2SO_4 (aq)) in deionised water.

6.2.2 Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) is unstable, and decomposes to water and oxygen (slowly in dark, cool conditions but rapidly in ultra-violet light). This process is not reversible however high the pressure of oxygen. Hence, even in a closed container, the strength of a hydrogen peroxide solution is never exactly known. Therefore, the concentration or dilution of hydrogen peroxide can only be approximate. The strength of a solution of hydrogen peroxide (H_2O_2) is expressed as 'volume' strength; for example a 100 volume concentrated solution is capable of releasing, on decomposition, 100 times its own volume of oxygen.

The peroxide solution used in these procedures is very dilute; 1 volume strength. However, the precise strength of the peroxide solution is not critical to the measurement process.

6.3 USE AND CARE OF LABORATORY GLASSWARE

The term "glassware" here is used to refer to all laboratory ware, whether glass or plastic. Glassware used for acid, peroxide and borate should be kept separate; e.g. separate burettes, and beakers used to fill them. Separate volumetric flasks etc. should be used to make up the solutions. It may be helpful to adopt a colour coding system, marking the top of burettes, beakers, and volumetric flasks with a small strip of coloured tape, e.g. red for acid, blue for borate, black for peroxide. Any such marking should not obscure graduations on the glassware, or be used on titration flasks where it could affect perception of the end-point. All storage bottles should be clearly labelled with the contents and date of preparation. Fig. 6.1 shows some of the apparatus used.

6.3.1 Cleaning and Rinsing

All laboratory glassware should be clean before use, washed with detergent if necessary, followed by several rinses with tap water, and two rinses with deionised water. Invert the glassware to drain. Storage containers used for prepared solutions should be rinsed at least twice with small amounts of the solution before the main bulk of the solution is transferred. Likewise burettes and flasks should be rinsed twice before use with small amounts of the solution to be placed in them. It is not necessary to fill the whole container when rinsing; a small amount is sufficient as long as all surfaces are rinsed. Volumetric flasks should be stoppered and inverted several times; burettes can be tilted back and forth.

6.3.2 Filling Volumetric Containers

When using burettes and volumetric flasks, it is often necessary to fill with liquid to a mark on the container. The mark should be at eye level, where it will appear as a single horizontal line. Stand the container on a firm level surface (or for a burette, ensure it is vertical in its stand) and bring the eye into line with the liquid by sitting or bending down (this is much more accurate than lifting the container up to eye level, and also keeps both hands free). Fill almost to the mark, but stop a little short of the final amount and wait for liquid on the walls to run down. The last few drops are best added from a small beaker than from a bottle. If the liquid being added is deionised water, a wash bottle can be used.

The **bottom** of the meniscus (the concave surface of the liquid within the burette or the neck of a flask) is always used as the point of reference. When the container is filled exactly to the mark, the bottom of the meniscus will rest exactly on the line when viewed at eye level. Some types of plastic laboratory ware give a flat meniscus; in this case the horizontal line of the meniscus is the point of reference, but it is still important that the mark is at eye level.

6.3.3 Use and Care of the Burettes

Two separate burettes are needed for acid and di-Sodium tetraborate. They should be labelled clearly, and always kept in the same positions in the burette stand to avoid confusion. The tap of a burette occasionally requires lubricating; a *very small* amount of tap lubricant should be used – too much will eventually cause a blockage. Blockages in the tap or the tip of the burette can be cleared using a fine wire. Do not use a needle as this may damage the glass.

Before filling, rinse the burette with a small amount of the solution to be used. Only a small volume is needed for this; tilt the burette to ensure all surfaces are rinsed. Discard the rinsings. Fill the rinsed burette to just above the zero mark, using a small beaker (one each is needed for each reagent, clearly labelled). With the beaker under the tip, open the tap fully for a few seconds to remove any bubbles from the tip. Allow the solution to settle. Make sure the burette is vertical in its stand, and adjust the level to the zero mark.

If funnels are needed *in addition to the beakers*, they should be kept separate for each reagent. Do not leave funnels standing in burettes ‘permanently’ as (i) they may drip into the burette during titration, affecting the measurement and (ii) they may collect dust which will be washed into the burette.

6.3.4 Reading the Burette

The burette must be vertical in its stand. The reading is taken with the liquid meniscus at eye level.

Reading the level of the bottom of the meniscus is easier if a piece of white paper is threaded over the burette by two horizontal slits, the central area lying behind the tube and carrying a black band (e.g. a strip of black plastic tape) which is placed a little below the meniscus. The black is reflected in the lower surface of the meniscus, and is contrasted with the white paper directly behind.

The paper strip is not necessary with “Schellbach” type burettes. These have a vertical blue band on the rear side. When the liquid surface is viewed at eye level, this band appears as an upward-pointing arrow, with the bottom of the meniscus at its point.

When reading the level, the scale on the burette should be read **to the nearest 0.01 ml** (two decimal places) as follows:

1. Note **whole number** from that printed at the side of the scale (long marks).
2. Note **first decimal** from short scale marks (one interval equals 0.10ml).
3. Note **second decimal** by *estimating* in **tenths of one interval** the distance between the last mark and the bottom of the meniscus (see examples in Fig 6.3).
4. **If the titration is for preparation or testing of solutions (as in Section 6.5 and 6.6),** calculate the measured volume without correction.
5. **If titrating an exposed peroxide solution with borate (as in Section 6.4),** correct the measured volume to **one** decimal place before entering on the Data Return Form. When the second decimal place is "5", correct to an **even** digit, (e.g. 0.45 to 0.4, 0.55 to 0.6).

The burette may need re-filling during a titration. If so, stop before the end of the scale is reached, record the reading, and work out how much liquid has already been added. Remove the titration container from under the burette so no drips fall into it. Fill the burette and allow to settle. Read and record the new level, complete the titration and calculate the additional volume added to the sample. The sum of the two volumes is the complete titration, and should be rounded to the nearest 0.1 ml as above and recorded.

6.4 TITRATION OF EXPOSED SAMPLES

Each time the sampler is visited, seven days' peroxide samples will be obtained. These should be kept sealed, labelled with the site and date of exposure, and preferably in a refrigerator until they can be titrated.

When titrating the solutions, lighting and surroundings can affect your perception of the titration end point. Ensure adequate lighting, ideally daylight, and north light if possible. Avoid bright direct sunlight. Artificial lighting should be of the "daylight" type. The colour of surroundings, such as walls, ceilings, furniture, and even clothes, can affect colour perception. The work surface should be white, or covered with white paper or bench protector, as should the walls facing the work area and behind the burette. Replace the white paper as soon as it starts to get yellow or dirty. Wear a white lab coat or overall.

Always use a sample of unexposed peroxide, from the same batch as the exposed samples, as a reference to help identify the neutral grey end point. This is termed a 'colour control'.

Ensure all glassware is clean. Use conical flasks for titration, rather than the bubbler bottles. The flasks should be kept for this purpose only, and rinsed well before each use with a little of the fresh pH 4.5 1 volume hydrogen peroxide solution.

The procedure for titration of exposed samples is as follows:

1. Fill a clean, dry burette with 0.002 mol dm⁻³ di-Sodium tetraborate, using a small beaker kept for this purpose only. Clear any bubbles from the burette tip.
2. Allow to settle, set the bottom of the meniscus to zero (or any convenient level; there is no need to fill the burette to the top), and wipe outside of tip dry using a clean paper tissue.

3. Take two clean 150 ml conical flasks, identical in shape, size, and glass colour. Rinse twice with some pH 4.5 1 volume hydrogen peroxide solution.
4. Take the first of the exposed peroxide samples; record the site name and date of exposure, empty into one of the flasks and label as the sample.
5. Into the other flask, pour some unexposed pH 4.5 1 volume hydrogen peroxide solution; the same volume as the solution in the sample flask. Label as 'colour control'; this unexposed peroxide will be used as a reference to help identify the titration end point.
6. To the colour control add 1 to 4 drops of BDH 4.5 indicator. Colour should be very pale "neutral grey"; if not, steps must be taken to check pH and indicator.
7. Add the **same amount** of indicator to exposed sample(s), if control is correct. If colour of exposed sample is blue, write "ALK" on record form; if neutral grey write "0.0", but if pink, or pinkish-grey, titrate as follows:-
 - (i) Read the burette to nearest 0.01 ml (take reading from bottom of meniscus).
 - (ii) Add borate solution carefully to sample until colour exactly matches that of neutral grey control. Add last drops slowly and swirl flask to mix before comparing.
 - (iii) Read burette again to nearest 0.01 ml and deduct first reading; record the volume of solution added, to the nearest 0.01 ml. Now correct this value to the nearest **0.1 ml**, before entering on network data return form against the date of exposure.

(The aim is to titrate to exactly neutral grey. However, if the end-point is accidentally overshot and a blue colour appears, correction can be made as follows. Record the burette reading, and add 0.002 M sulphuric acid to bring the solution back to neutral grey. Subtract the volume of acid added from the volume of borate added, to give the corrected borate titre. Please note that this should be avoided, as it increases error.)

8. Proceed with the next sample. The flask in which the exposed samples are titrated need not be rinsed and dried between samples, just drained thoroughly.

The same colour control can be used for all seven day's samples, but work quickly; the indicator will start to deteriorate after around 20 minutes (tending to become more blue).

Do not leave solutions standing in an open burette from one week to the next, as evaporation will cause the solution to become stronger. When you have finished titrating, either:

- seal the top of the burette with a plastic bung (a rubber bung may be used for the di-sodium tetraborate burette but not for the one containing sulphuric acid). Before each measurement session, remove the stopper, and run out around 1 ml of the solution, to clear the burette tip of any solution which may have become more concentrated by evaporation (If your burette is filled via a tube from a sealed squeeze bottle, do the same).
- Or -
- alternatively, empty the burette after use, rinse through with deionised water, and leave to dry with the tap open.

The beakers used to fill the burettes should be rinsed with deionised water and drained. This also applies to funnels, if used. Un-used solution left in the filling beaker or the burette should be discarded, not returned to the storage bottle. With experience, operators will get to know how much solution is usually needed, and waste will be minimised.

6.5 PREPARATION OF SOLUTIONS

All solutions must be made up with deionised water. Ordinary tap water is not suitable, nor is distilled water obtained from garages, as this may be contaminated.

6.5.1 di-Sodium tetraborate Solution $0.002 \text{ mol dm}^{-3}$ (0.002 M, N/250)

The most convenient method of making up this solution is to use commercially available 'ConvoL' or similar ampoules, which contain a concentrated solution for dilution. The instructions are as follows:

1. Take a clean 500ml volumetric flask, and one ampoule.
2. Following the instructions on the pack, empty the contents of the ampoule into the flask.
3. It is important to ensure that all the ampoule contents are transferred to the flask. So, using a plastic wash bottle filled with deionised water, rinse out the ampoule and the top of the neck, at least three times. Pour the rinsings into the flask. **Note: Take care not to use too much force that water splashes.**
4. Insert the flask stopper and invert the flask several times to mix well. The flask now contains 500 ml of $0.002 \text{ mol dm}^{-3}$ di-Sodium tetraborate solution. Do not use any of this for rinsing. Pour the contents of the flask into a clean and dry 500ml reagent storage bottle. Then label the reagent bottle with contents and preparation date.
5. Rinse the graduated flask with deionised water and invert to drain. The stopper should also be washed.

6. Now test the strength of the solution, using the procedure in section 6.6

If you have difficulty in obtaining ampoules, **netcen** make up the solution from the solid ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ (s)), and can supply this free of charge to Network site operators. If you need borate from **netcen**, please send us -

- a plastic screw-topped bottle, approx. 500 ml volume, cleaned and rinsed thoroughly with deionised water, and labelled with the contents, "0.002 M di-Sodium tetraborate in deionised water, $\text{Na}_2\text{B}_4\text{O}_7$ (aq)". This should be tough and leak-proof.
- a sticky label, giving the address to which the borate should be sent (your office or lab). It need not be reply-paid, but must be suitable for addressing the outside of a package.

Pack these in a sturdy cardboard box (NOT a padded envelope) which will stand the journey to **netcen** and back. We will rinse and fill the bottle with di-Sodium tetraborate solution, re-pack it in the box, affix your label and return it to you. Please phone and let us know you will be sending a bottle. Currently, we do not send out any other solutions by post.

The made-up solution has a shelf-life of upto nine months. It should be kept in a sealed container, to prevent it becoming more concentrated by evaporation. Shake the container before use if it has been standing for a long while.

6.5.2 Sulphuric Acid $0.002 \text{ mol dm}^{-3}$ (0.002 M or N/250)

This solution is also most conveniently made up from commercially available 'ConvoL' (or similar) ampoules, containing concentrated sulphuric acid for dilution. However, these are not supplied for $0.002 \text{ mol dm}^{-3}$ strength, but only for 0.01 mol dm^{-3} (0.02N or N/50) solution. This is five times the required strength, so additional dilution is necessary. The $0.002 \text{ mol dm}^{-3}$ strength solution required is obtained by making up the solution to 500ml, as in the instructions, **and then further diluting to obtain 2500 ml of $0.002 \text{ mol dm}^{-3}$ strength solution.** The instructions are as follows:

1. Follow steps 1 to 3 above, as for borate.
2. Insert the stopper and invert the flask several times. The flask now contains 500 ml of 0.01 mol dm^{-3} (N/50) sulphuric acid. Do not use any of this for rinsing. Pour the contents of the graduated flask into a clean and dry 2500ml reagent storage bottle.
3. Now carry out the additional dilution. Immediately re-fill the graduated flask with deionised water, accurately to the mark as before, and empty the contents into the reagent bottle. Repeat this action a further three times, with deionised water, bringing the total in the storage bottle to 2500ml.
4. Cap the reagent bottle securely and invert several times to mix the solution. Then label the reagent bottle with contents and preparation date. If using labels supplied with the pack of ampoules, remember to alter the label to read " $0.002 \text{ mol dm}^{-3}$ ".
5. Rinse the graduated flask with deionised water and invert to drain. The stopper should also be washed.
6. Now test the strength of the solution, using the procedure in section 6.6.

6.5.3 Preparation of pH 4.5 dilute hydrogen peroxide solution (1 vol)

The dilute, acidified hydrogen peroxide solution used in the bubblers is made up by diluting concentrated hydrogen peroxide to the required strength, and adjusting to pH 4.5 by adding dilute ($0.002 \text{ mol dm}^{-3}$) sulphuric acid. *Note: this will involve a titration, requiring some of the previous batch of pH 4.5 peroxide to use as a colour control. If this is the first batch, or the 'old' solution is unreliable, follow the procedure in Section 6.6 to make a colour control.*

Safety precautions are needed when handling concentrated hydrogen peroxide solution, as it is a strong oxidising agent. Always follow the instructions on the bottle: it is advisable to wear gloves, a laboratory coat and safety glasses. If the concentrated peroxide gets on the skin, wash immediately with plenty of water. If the concentrated solution is supplied in an ordinary screw-capped bottle, take care when opening: the build up of oxygen may cause a fine spray of liquid as it is opened. However, most manufacturers now supply concentrated peroxide in bottles designed to prevent this happening. Keep concentrated peroxide in a cool dark place, preferably a refrigerator.

The 1 vol (dilute) solution is prepared by diluting 100 vol strength (concentrated) hydrogen peroxide with deionised water, in a ratio of 1:99. For example, 10 ml may be diluted with 990

ml of deionised water to make 1 litre; 25 ml may be diluted with 2475 ml of deionised water to make 2.5 litres, and so on. Once diluted, the solution must be brought to exactly pH 4.5 by addition of sulphuric acid (this is sometimes referred to as 'neutralising' the solution to pH 4.5).

To make up one litre:

1. Fill a clean dry burette with $0.002 \text{ mol dm}^{-3}$ sulphuric acid, allow to reach room temperature and set the bottom of the meniscus to the zero mark.
2. Using a clean **dry** 10 ml measuring cylinder, measure 10 ml of **concentrated** peroxide. To get exactly 10 ml, fill to just over the line, and remove the excess using a clean dropper kept for this purpose only. Discard the excess drops of concentrated peroxide carefully.
3. Tip the 10 ml of concentrated peroxide into a clean 1 litre measuring cylinder. Rinse the 10ml cylinder carefully, using a wash bottle of deionised water, pouring the rinsings into the large cylinder.
4. Fill the 1 litre cylinder almost to the 1 litre mark with deionised water. Use the wash bottle to top up accurately to exactly 1 litre.
5. Pour the contents into the reagent storage bottle to be used (See section on treatment of new storage bottles). Cap securely, and shake well for about 30 seconds to mix.
6. Take exactly 50 ml of the above solution, using a 50 ml measuring cylinder, and pour into a clean dry 150 ml conical flask. Add 1 to 4 drops of BDH "4.5" indicator, enough to give a definite but not deep colour. The solution will probably be blue, or blue-grey.
7. Take an identical conical flask, and pour in 50 ml of the previous batch of peroxide. This will be the 'colour control', for reference. Mark the flask neck 'cc'. Add 1 to 4 drops of indicator as above; the colour control should be neutral grey.
8. Return to the flask of fresh solution. From the burette, add acid (reading the meniscus first) until the sample exactly matches the neutral grey colour control. **The amount needed will be small, so add the acid carefully; drop by drop at the end.** Read the meniscus again and calculate the volume of acid added, to the nearest 0.01 ml.
9. Now calculate the volume of acid needed to neutralise to pH 4.5 the 1 vol hydrogen peroxide remaining in the storage bottle, as follows:

$$\text{volume of acid} = y \left(\frac{V - 50}{50} \right) \text{ml}$$

-where y = volume of acid added to the 50 ml sample (ml), and V is the volume of dilute peroxide made up.

e.g. if 2500 ml of 1 vol hydrogen peroxide is made up (V), and the volume of acid (y) used for the 50 ml sample is 0.30 ml, then the amount required for the storage bottle is $0.30 \times (2500 - 50)/50$ ml or (0.30×49) ml, i.e. 14.70 ml.

10. Add the calculated amount of acid from the burette **directly into the storage bottle** by adding the volume required to the existing meniscus reading and allowing the meniscus to fall to the new figure. The last few drops should be added slowly. Cap the bottle and shake well to mix.
11. Measure 50 ml from the storage bottle into a third flask. Add the same amount of indicator as to the earlier sample. The three samples should now be the same colour. If the third sample shows appreciably more blue or more pink colour than the colour control, it must be brought back to neutral grey in exactly the same way as for the first sample; 0.002 M sulphuric acid being used if the colour is blue, 0.002 M di-Sodium tetraborate if pink. As

before, the amount to be added to the storage bottle must be calculated, using $\left(\frac{V - 100}{50}\right)$

instead of $\left(\frac{V - 50}{50}\right)$ and run in; a fourth sample is taken to check that the colour is now correct.

12. **Indicator must never be added to the solution in the storage bottle**, only to a sample in a separate vessel.
13. Label the bottle with the contents and date. Provided that the bottle has been “conditioned” so that no alkali is given off from the glass, the solution should remain unchanged for at least two weeks if kept in a cool, dark place. Solution more than two weeks old can be kept for rinsing glassware.
14. **Every new batch of diluted hydrogen peroxide must be carefully titrated and brought to pH 4.5 in this way; different batches of deionised water will vary in pH and it cannot be assumed, because (say) 14.7 ml of acid were required on one occasion, that the same amount will be needed on the next.**
15. Occasionally, non-neutralised 1 vol hydrogen peroxide may be pink when the indicator is added (step 5); this may be due to contaminated water. When the solution is acid, the neutralisation is carried out with borate in place of the sulphuric acid. Procedure and calculation are identical in both cases. It is advisable to check the pH of the deionised water if this occurs, and if necessary change the source of supply.

Carry out steps 6 to 11 within about 20 minutes, because once the indicator is added to a solution it will deteriorate, and appear more blue.

6.6 TESTING ACID AND BORATE STRENGTH

Every time a fresh supply of either 0.002 M di-Sodium tetraborate or 0.002 M sulphuric acid is prepared, its accuracy must be tested by titration as follows. The procedure used is the same whether the acid or borate is being tested; however, it is essential that the other solution is known to be accurate. It is also essential that the hydrogen peroxide solution is exactly pH 4.5.

1. Fill the acid and borate burettes, allow to reach room temperature and zero.
2. Take a clean dry 150-ml conical flask or beaker and pour in about 30 ml (this volume is not critical) of 1 vol hydrogen peroxide, neutralised to pH 4.5 as described above.
3. Add exactly 10 ml of 0.002 M sulphuric acid from the burette. Add 3 to 5 drops of BDH pH 4.5 indicator to give a definite, but not deep, pink colour.
4. Take an identical conical flask, and pour in 50 ml of peroxide. This is the ‘colour control’. Mark the flask neck ‘cc’. Add 3 to 5 drops of indicator as above; the colour control should be neutral grey.
5. Titrate the sample with 0.002 M di-Sodium tetraborate to the “neutral grey” end-point. Record the volume to the nearest 0.01 ml. The amount used should be between 9.60 and 9.90 ml (**not** 10 ml, as might be expected, because of the pH selected as the end-point).

Three test titrations should be done and the mean taken. A mean result less than 9.60 indicates that the borate is too strong (or the acid, if this is being tested, is too weak). A mean result greater than 9.90 indicates that the borate is too weak (or the acid is too strong).

6.7 PREPARATION OF A NEW COLOUR CONTROL

A correct colour control must always be used when titrating with BDH 4.5 indicator. When making up fresh pH 4.5 peroxide solution, it is normal to use a small quantity of the previous batch. However, if this is your first batch, or the old batch is not neutral grey to the indicator, a correct colour control can be made up as follows.

Five clean, dry conical flasks, e.g. 150 ml size, are needed. It is important that these flasks are identical in shape, size, and glass colour. At least 500 ml of 1 volume hydrogen peroxide solution, nominally pH 4.5 will be needed. If none is available, it can be made up as in Section 6.2 above but without the colour control. This volume is not critical, and some will be used for rinsing flasks. Both 0.002 M sulphuric acid and 0.002 M di-Sodium tetraborate solutions are needed, in their usual clean burettes. Only small quantities will actually be used.

The method is as follows:

1. Measure the same volume of nominally pH 4.5 hydrogen peroxide into each flask: 40 ml is adequate, but use 50ml if preferred.
2. Add 3 drops of indicator to each flask, and swirl to mix well.
3. Check carefully that all five solutions are identical in colour at this stage. If not, the glassware may be contaminated: discard, rinse thoroughly with pH 4.5 peroxide and try again.
4. Identify the flasks as A, B, C, D, and E. Proceed as follows:
 - to A, add just 2 drops of 0.002 M sulphuric acid
 - to B, add just 1 drop of 0.002 M sulphuric acid
 - leave C alone
 - to D, add just 1 drop of 0.002 M di-Sodium tetraborate
 - to E, add just 2 drops of 0.002 M di-Sodium tetraborate

- and swirl each flask to mix.

Each of the five solutions now differs from its neighbours by one drop of acid or borate.

5. Against a white background, compare the colours of the solutions. They should vary very slightly, showing the range of colours seen around the titration end point.
6. Compare the colours of the solutions. A will obviously be different to E, and so on. It is assumed here that the colour of C is close to neutral grey. If C is very wrong, the following tests may need to be modified, and in the extreme case a "3 drop A" or "E" solution may need to be prepared.
7. Compare the colour of C critically with its neighbours. You may decide that C appears slightly "cold" or blue-grey (alkaline) while B is neutral. Alternatively you may decide that C is slightly "warm" or straw-pink (acid) while D is neutral. However, **and this is most likely to be the case**, you may decide that none of your solutions is truly neutral grey, and the true end-point falls somewhere between an adjacent pair of colours.
8. Whatever the outcome, select the 3 solutions whose colours "bracket" neutral-grey most closely, and discard the other two. Your choice should be one of:

- A B C and discard D E, or
- B C D and discard A E, or
- C D E and discard A B.

Make a note of your choice.

Now prove that your choice is correct by the "half drop" test below.

Preparing a half-drop solution:

9. Rinse the 2 discarded flasks well with nominally pH 4.5 neutralised peroxide and drain well.
10. Measure 80 ml of peroxide (or 100 ml if the original quantity was 50 ml) and add 6 drops of indicator into one flask.

- If your choice of colours was A B C or B C D, add one drop of acid.
- If your choice of colours was C D E, add one drop of borate.

11. Mix thoroughly, by pouring the full flask into the empty one and back several times, being careful not to spill any.

12. Finally, split the solution carefully into two equal parts, one in each flask. Use the measuring cylinder for this - it must be accurate.

13. Each of these two flasks now contains half a drop of acid or borate. Identify them as X and Y. Now select whichever one of the following options applies:

- If you chose A B C above, add just one drop of acid to X only, and swirl to mix. Colourwise, X (1.5 drops of acid) fits between A and B, while Y (0.5 drop acid) fits between B and C.
- If you chose B C D above, add just one drop of borate to Y only, and swirl to mix. Colourwise, X (0.5 drop acid) fits between B and C, while Y (0.5 drop borate) fits between C and D.
- If you chose C D E above, add just one drop of borate to Y only, and swirl to mix. Colourwise, X (0.5 drop borate) fits between C and D, while Y (1.5 drops borate) fits between D and E.

14. Repeat the neutral-grey comparison, as above, and select the one solution which now seems to be accurately neutral-grey against its neighbours. Discard the rest.

15. Now prepare a fresh batch of pH 4.5 1 volume hydrogen peroxide **to this same colour standard**. Do this within 20 minutes, as the colour control will deteriorate quickly on contact with air.

Please note that the samples of peroxide used for testing must now be discarded: **do not return them to the bulk storage bottle. Never add indicator to the bulk stock solution.**

Always keep enough of your previous batch of peroxide to use as a colour control for the next batch. This will help maintain a consistent standard. However, you should repeat above procedure from time to time (e.g. every few months) to maintain accuracy.

If you have difficulty in identifying the neutral-grey end-point, your indicator may be faulty, your nominally neutral peroxide is not neutral or is more than 1 vol strength, or your acid and/or borate solutions are the wrong strength.

6.8 CALCULATION OF SULPHUR DIOXIDE CONCENTRATIONS

The concentration of sulphur dioxide is calculated using the volume of air sampled and the volume in ml of 0.002 M di-Sodium tetraborate required for the titration. The equation for this calculation is as follows:

$$C_{\text{SO}_2} = \frac{4520T}{V}$$

where C_{SO_2} is the concentration of sulphur dioxide ($\mu\text{g m}^{-3}$),
 T is the amount of di-Sodium tetraborate added in the titration (ml), and
 V is the volume of air (for historical reasons this is in ft^3 : to convert from metric, $1 \text{ m}^3 = 35.314667 \text{ ft}^3$).

This calculation can be incorporated into a computer program or spreadsheet. Alternatively, as in the case of smoke measurements, “look-up” tables are supplied by **netcen** (Appendix 3). These give the SO_2 concentration for known values of V and T , and both ft^3 and metric versions are available.

6.9 PREPARATION OF NEW STORAGE CONTAINERS

New storage containers for the 1 vol pH 4.5 dilute peroxide solution need to be prepared before use. This section describes the procedures.

6.9.1 Glass

Although “hard” (borosilicate) glass is specified for use with dilute hydrogen peroxide solution, alkali is commonly given up by the glass when new, and this will interfere with the measurement of sulphur dioxide. It is therefore necessary to eliminate this alkali before using the glassware.

Any new bottle or container should be washed with deionised water, rinsed with 1 vol pH 4.5 hydrogen peroxide solution and then completely filled with the peroxide and sealed with the stopper (or screw cap) provided. Leave for at least a day, then place about 50 ml of this solution in a beaker, then add BDH 4.5 indicator, and compare with a fresh 50 ml sample of the hydrogen peroxide placed in a similar beaker to which indicator has also been added.

If the colours of the two samples are identical, the container is suitable for use. If the colours differ, the procedure should be repeated until there is no colour change.

In the case of a glass storage bottle for 1 vol hydrogen peroxide which is to be used for the first time, a strong solution of hydrochloric acid (25% v/v HCl in deionised water) can be used to remove any alkali present. This should be obtained ready mixed and handled with caution, wearing gloves and goggles. After the storage bottle has been completely filled with the acid by means of a large funnel and allowed to stand for 24 hours, the acid can either be disposed of in accordance with safety procedures, or returned to its own labelled storage bottle and stored for another occasion. The storage bottle for hydrogen peroxide should then be rinsed several times with tap water and then filled with deionised water, which is left in the bottle for a further 24 hours. After this and a further rinse with deionised water the bottle is ready for use. If it is intended to have a preliminary trial period of one month or more when the results will not be

required for the permanent records, there is no need to carry out this conditioning with strong acid as the storage bottle will be automatically conditioned after a period of 3 or 4 weeks.

If Dreschel bottles, or other glass vessels used for storage, have to be left unused for any length of time, they should be completely filled with 1 vol hydrogen peroxide at pH 4.5 and stored in the dark. If a glass vessel is allowed to stand dry for any length of time the effects of the above conditioning may wear off.

6.9.2 Plastic Containers

Plastic containers may be used for transporting exposed reagent but certain precautions must be observed. Before use the containers should be tested with neutral 1 vol hydrogen peroxide as described above for Dreschel bottles, and only those which remain neutral should be used.

Plastic containers do **not** respond to the conditioning process described in the previous section, and that different containers of the same type may differ markedly in their effect on the dilute hydrogen peroxide solution.

6.10 DETERIORATION OF THE INDICATOR

BDH pH 4.5 indicator contains several compounds, one of which is broken down by contact with the air. It should be kept in a sealed bottle in a cool, dark place, ideally a refrigerator. It is supplied in quantities of 500 ml; smaller quantities can be transferred to a small dropper bottle. The **solution** of the indicator is normally stable for many months, but indicator which is left to dry out around the top of the bottle will decompose. The bottle and its dropper should be kept free from any residue by wiping with a tissue. As a safeguard, indicator should always be added first to the control sample, and if this gives the correct colour, it can then be added to the exposed sample. The control sample is easily replaced if the indicator has decomposed.

Decomposed indicator takes on a more brown colour; it will change from amber through brown to green, rather than from pink through grey to blue. There is no longer a clear-cut colour change at the pH 4.5 end-point. If this occurs, fresh indicator should be obtained. If a pH meter is available, and an amber colour is obtained in the exposed sample on the addition of indicator, the meter can be used to determine the end-point; the presence of the indicator does not affect the result.

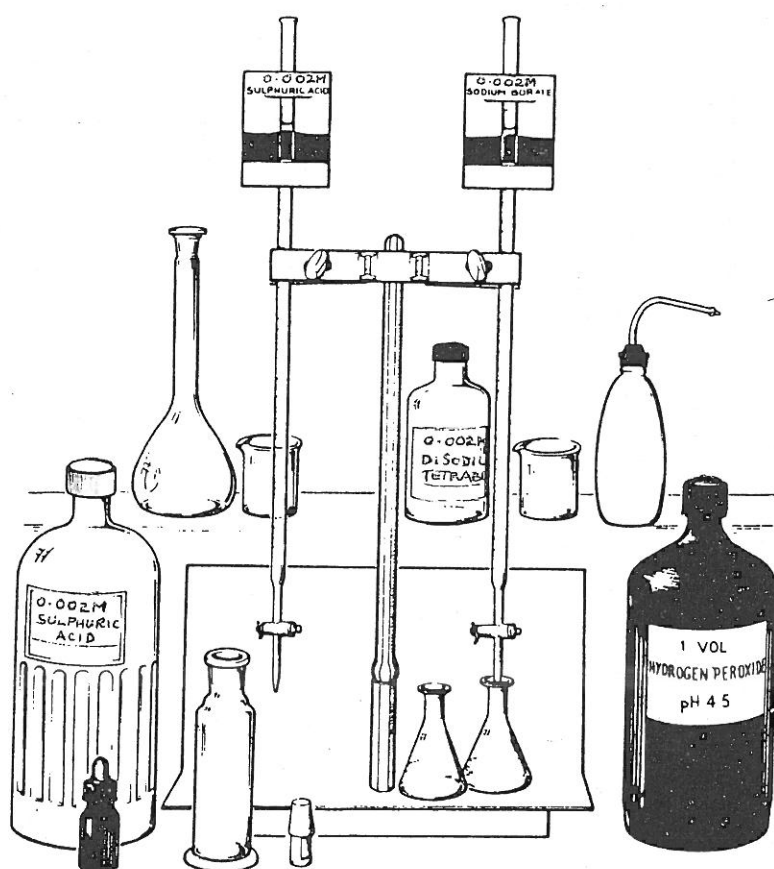


Fig. 6.1 Laboratory Apparatus for Preparation and Titration of Solutions

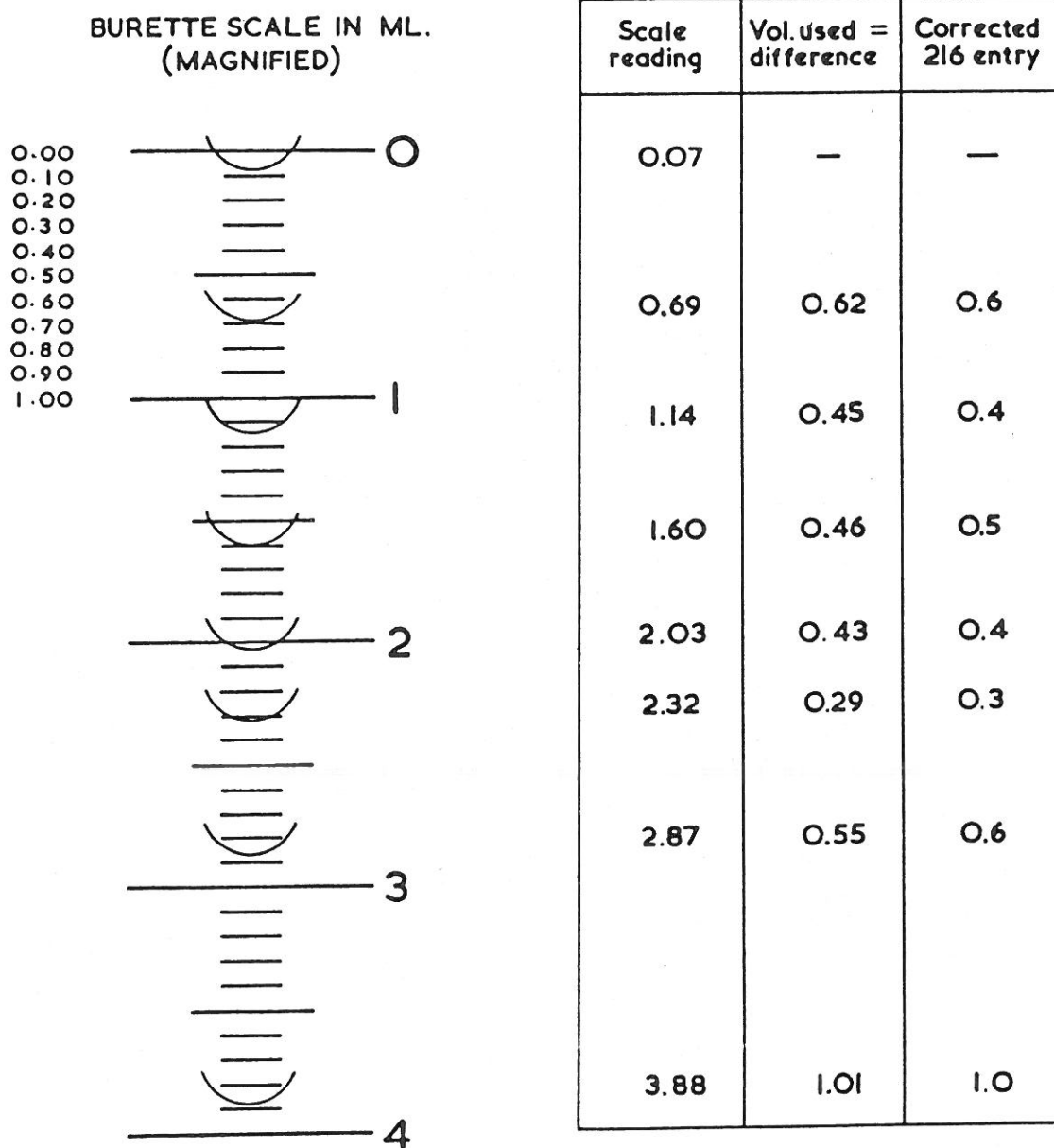


Fig. 6.2 Burette Scale with Examples of Readings

7 Assessment of Smoke Stains

7.1 THE REFLECTOMETER

The first stage in calculating the ambient concentration of black smoke is to measure the darkness of the smoke stains obtained from the sampler. This is carried out using a photo-electric reflectometer. This instrument emits a steady light onto the smoke stain, which is reflected back from the smoke stain to a photo-sensitive element. The electrical response is then amplified to produce a meter reading. The darker the stain, the less light is reflected, so a low meter reading corresponds to a dark surface, and a high reading to a light surface. The reflectometer reads on a scale of 0 (black) to 100 (white). This reflectometer reading, together with the measured volume of air sampled, and the filter clamp size, is used to calculate the ambient concentration of black smoke from a standard calibration.

Three types of reflectometer are in use: the EEL Models 43 (analogue), the 43D (digital), and the Kemtronix MK 1 (digital conversion of the analogue EEL 43). These reflectometers are the reference instruments for the EC Directive 80/799/EEC for the measurement of smoke stain reflectance. All three have a measuring head, which comprises a source of light (a tungsten lamp) and a photo-sensitive element (a selenium disc). The surface of this element is fragile and should not be touched, marked or exposed to direct sunlight. The head fits into a detachable mask which consists of a locating ring with a metal plate. The mask covers all the working area of the element except for an aperture 1.25cm in diameter, through which the stain is measured.

A standard grey and white tile is supplied for test purposes. This is used to set two fixed points before measurement. The grey part is marked with its reflectance value (usually around 34 to 36). The white part must be used as a backing for all other media handled, including setting to '100' for a blank filter paper AND stain reflectance. The smoke stain must be formed on the **smooth surface** of a clean **Whatman grade 1 (No 1)** filter paper.

7.2 SET-UP AND USE OF REFLECTOMETER

The operation of all three models is very similar. However, there are some differences, particularly in the setting up procedures. This section gives separate instructions for each type, followed by instructions for measurement of smoke stains, which are applicable to all three models. The relevant set of instructions can be photocopied and kept with the reflectometer.

7.2.1 Setting up the *Analogue Reflectometer*

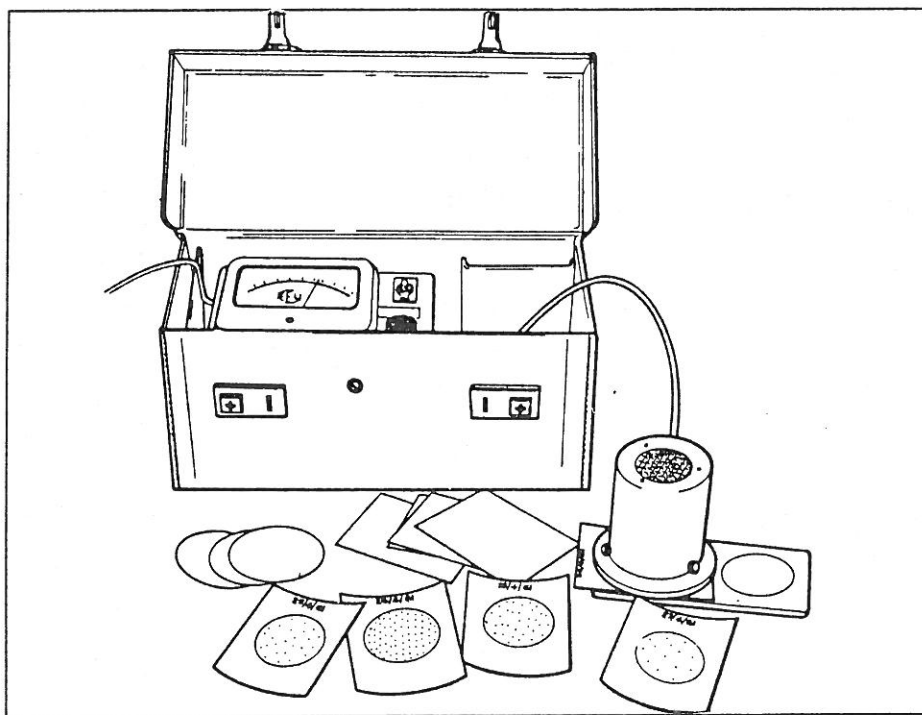


Fig 7.1 The EEL Model 43 - Analogue

The EEL Model 43 consists of a meter unit fixed in a case and a measuring head, which is connected to the unit. The unit also carries the mains switch and the sensitivity control.

1. The reflectometer must be used on a flat, level surface with its meter glass facing upwards.
2. Remove the measuring head from the case and ensure the lead is unwound.

Care must be taken when handling the measuring head. Never expose the underside of the head to bright light, electric lighting, daylight etc. For this reason, always keep the underside facing down. Also, make sure that light does not reflect upwards onto the underside of the head from shiny or light coloured surfaces below. It is advisable to cover the work surface with matt dark material. Bright light may damage the selenium disc, the increase in the electrical output may damage the meter, and the instrument calibration may alter.

3. Place the measuring head in the circular mask on the work surface. This mask must be used at all times when taking any measurement.

The head should fit freely into the mask. The mask is too tight if it remains attached to the head when it is raised. The mask should be kept in good condition. If the mask breaks, a proper repair is necessary - do not use any type of adhesive, tape or material which will alter the effective thickness of the plate.

4. Turn the meter to a convenient position so that the field of vision is sighted along the pointer and note the scale directly down below. Do not look sideways onto the pointer because of possible parallax error when reading the scale.
5. Check the pointer is exactly on zero position. If not, set to zero using the slotted adjuster seen on the face of the meter below the centre of the glass window. Turn the adjuster and gently swing the pointer. This can be done by gently rotating the reflectometer case side to side so that the pointer swings to and fro about the zero mark. Allow to settle, and repeat if necessary until the pointer rests on the zero mark.
6. Connect the measuring head to the meter: the plug is keyed and will only enter the socket in one position.
7. Connect the reflectometer to the mains supply, switch on and allow to warm up for at least 10 minutes.
8. Take the white and grey standard test tile, and wipe any dust from its glass surface. This tile is used to check the linearity of the reflectometer before use.
9. Place the circular mask over the white tile on the standard, insert the measuring head fully and let go. Take a reading from the meter and adjust the sensitivity accordingly, using the SENS control, until the pointer is on exactly '100'.
10. Move the circular mask over to the grey tile, insert the measuring head fully and let go. Note the reading on the meter: this must agree with the value on the cover glass of the tile (usually around 34 to 36) to within $\pm 1\frac{1}{2}$ divisions.
11. Repeat the above actions several times until a constant grey tile value is obtained AND the pointer returns to exactly '100' each time.

Before measuring the smoke stains, the pointer must be set to '100' on a clean, unused and undamaged Whatman No1 filter paper preferably from the same batch of filters used in the filter clamps.

12. Place a blank filter paper, smooth side uppermost, on the white tile. Place the circular mask on the blank filter, fully insert the measuring head and let go. Take a reading from the meter and adjust accordingly, using the SENS control, until the pointer is on exactly '100'. Keep adjusting the sensitivity until a stable reading of '100' can be obtained.

It is essential that the '100' setting is made on a blank filter paper from the same pack as the exposed papers. The white tile '100' applies only to the standard grey tile.

The analogue reflectometer is now set up and ready to use.

7.2.2 Setting up the *Digital (43D) Reflectometer*

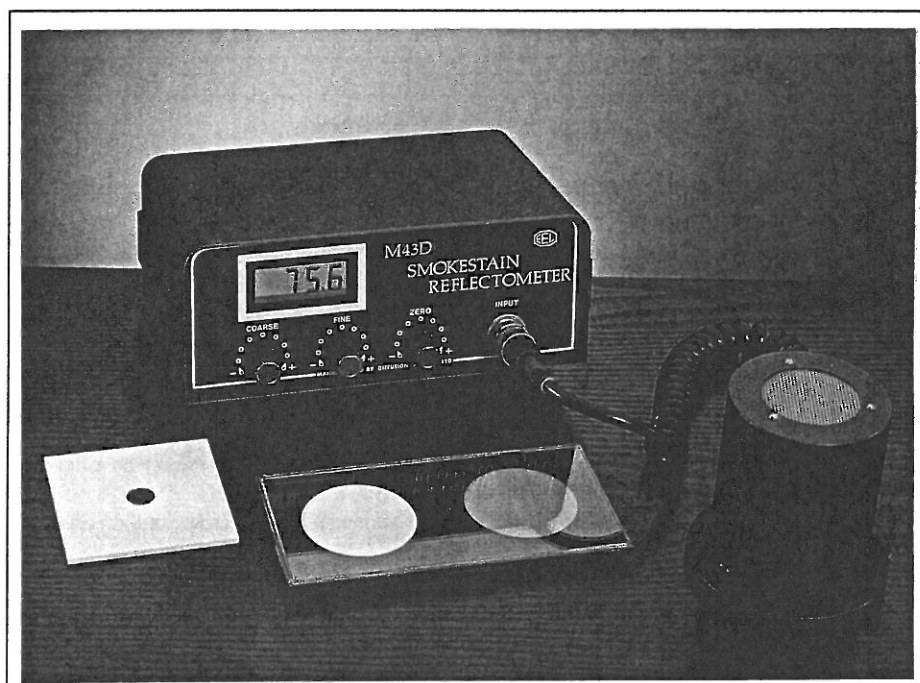


Fig. 7.2 EEL Model 43D Reflectometer (Digital)

The digital model consists of a LCD display meter unit and a measuring head, which is connected to the unit. The unit also carries the main switch (at the back of the meter), coarse and fine sensitivity controls and the zero control.

1. The Reflectometer must be used on a flat, level surface with its LCD digital display facing forwards.
2. Connect the meter to the main power supply and switch the 'on/off' switch at the back of the meter. Check the display unit is showing a value of '0.00'. If it is not exactly displaying '0.00', proceed as follows:

*To set to '0.00', use the ZERO control seen on the front of the meter. Turn the control **either anti-clockwise**, if the value is above '0.00', or **clockwise**, if the value is below '0.00'. The zero adjuster is very sensitive so turn it very slowly and then check if a value of '0.00' is displayed. Continue this adjustment until a stable reading of '0.00' is obtained.*

3. Connect the measuring head to the meter, this is a screw fitting at the front of the meter, and allow to warm up for at least 10 to 15 minutes.

Care must be taken when handling the measuring head. Never expose the underside of the head to bright light, electric lighting, daylight etc. For this reason, always keep the underside facing down. Also, make sure that light does not reflect upwards onto the underside of the head from shiny or light

coloured surfaces below. It is advisable to cover the work surface, under the tile, with matt dark material. Bright light may damage the photocell, the increase in the electrical output may damage the meter, and the instrument calibration may alter.

4. Place the measuring head in the circular mask. This must be used at all times when taking any measurement.

The head should fit freely into the mask. The mask is too tight if it remains attached to the head when it is raised. The mask should be kept in good condition. If the mask breaks, a proper repair is necessary - do not use any type of adhesive, tape or material which will alter the effective thickness of the plate.

5. Take the white and grey standard test tile, and wipe any dust from its glass surface. This tile is used to check the reflectometer before use.
6. Place the circular mask over the white tile on the standard, insert the measuring head fully and let go. Take a reading from the meter and adjust the sensitivity accordingly, using the COARSE and FINE controls, until a value of '100.00' is obtained.
7. Move the circular mask over to the grey tile, insert the measuring head fully and let go. Note the reading on the meter: this must agree with the value on the cover glass of the tile (usually around 34 to 36) to within $\pm 1\frac{1}{2}$ divisions.
8. Repeat the above actions several times until a constant grey tile value is obtained AND the value returns to '100.00' each time.

Before measuring the smoke stains, the pointer must be set to '100.00' on a clean, unused and undamaged Whatman No 1 filter paper preferably from the same batch of filters used in the filter clamps.

9. Place a blank Whatman No 1 filter paper, smooth side uppermost, on the white tile. Place the circular mask on the blank filter, fully insert the measuring head and let go. Take a reading from the meter and adjust accordingly, using the COARSE and FINE controls, until the value is exactly '100.00'. Keep adjusting the sensitivity until a stable reading of '100.00' can be obtained.

It is essential that the '100.00' setting is made on a blank filter paper from the same pack as the exposed papers. The white tile '100.00' applies only to the standard grey tile.

The digital reflectometer is now ready to use.

7.2.3 Setting up the *Kemtronix (Digital conversion) Reflectometer*

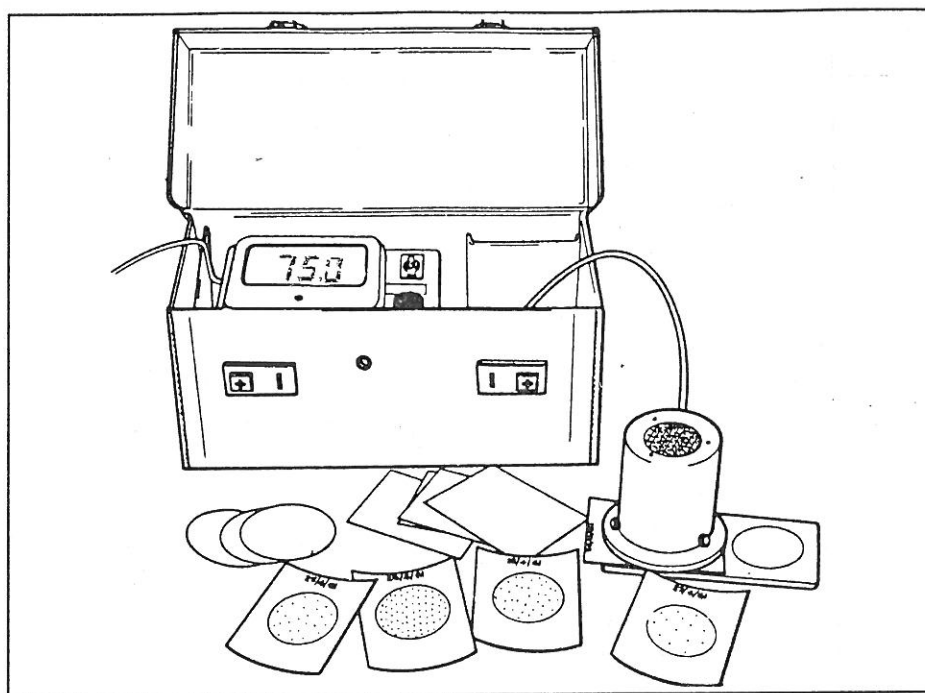


Fig. 7.3 EEL Model 43 Reflectometer (Kemtronix Digital conversion)

The Kemtronix digital EEL Model 43 is an analogue reflectometer converted to give a digital reading. It consists of a meter unit fixed in a case and a measuring head, which is connected to the unit. The analogue scale has been replaced with a digital display, and the sensitivity control has been replaced with an "Auto Range" button. The unit also carries the mains switch.

1. The reflectometer must be used on a flat, level surface.
2. Remove the measuring head from the case and ensure the lead is unwound.

Care must be taken when handling the measuring head. Never expose the underside of the head to bright light, electric lighting, daylight etc. For this reason, always keep the underside facing down. Also, make sure that light does not reflect upwards onto the underside of the head from shiny or light coloured surfaces below. It is advisable to cover the work surface with matt dark material. Bright light may damage the selenium disc, the increase in the electrical output may damage the meter, and the instrument calibration may alter.

3. Place the measuring head in the circular mask on the work surface. This mask must be used at all times when taking any measurement.

The head should fit freely into the mask. The mask is too tight if it remains attached to the head when it is raised. The mask should be kept in good condition. If the mask breaks, a proper repair is necessary - do not use any type of adhesive, tape or material which will alter the effective thickness of the plate.

4. Ensure the measuring head is connected to the meter. The plug is keyed and will only enter the socket in one position; alternatively the plug may have been fixed in place by the manufacturer.
5. Connect the reflectometer to the mains supply, switch on and allow to warm up. The manufacturer recommends at least **30** minutes.
6. Take the white and grey standard test tile, and wipe any dust from its glass surface. This tile is used to check the reflectometer before use.
7. Place the circular mask over the white tile on the standard, insert the measuring head fully and let go. Press and release the "Auto Range" button so that the meter indicates a reading of 100.0. It may be necessary to do this more than once to obtain 100.0.
8. Move the circular mask over to the grey tile, insert the measuring head fully and let go. Note the reading on the meter: this must agree with the value on the cover glass of the tile (usually around 36) to within ± 1.5 divisions.

Before measuring the smoke stains, the pointer must be set to '100' on a clean, unused and undamaged Whatman No1 filter paper preferably from the same batch of filters used in the filter clamps.

9. Place a blank filter paper, smooth side uppermost, on the white tile. Place the circular mask on the blank filter, fully insert the measuring head and let go. Set to 100.0 using the "Auto Range" button.

It is essential that the '100' setting is made on a blank filter paper from the same pack as the exposed papers. The white tile '100' applies only to the standard grey tile.

The Kemtronix reflectometer is now set up and ready to use.

7.2.4 Measurement of smoke stains

Having set up the reflectometer according to the appropriate set of instructions, and set a reading of 100.0 using a blank filter paper from the same batch as the exposed papers, proceed as follows for each smoke stain:

1. Place the filter paper on the white tile, **ensuring the stain is uppermost** and centred on the white tile. Place the circular mask centrally on the stain, and check carefully that none of the “clean” part of the filter is visible through the hole. Hold the mask so that it does not move while the measuring head is inserted and let go.

One of the common sources of errors is the smoke stain being measured on the wrong side. To avoid this happening, take the stain and hold up to the light. As a stain can be seen on both sides, turn the filter paper over until the darker of the two stains can be seen. The side with the darker stain is the one to be measured.

2. Note the reflectance. Record the reading to the nearest whole division on the edge of the filter paper (where the site name, number and date of exposure should already have been recorded).

*Take care not to write on or mark **either** side of the stained area as this will make the stain unusable.*

3. Every few stains measured, (typically around 10, but experience will show how many), recheck the ‘100’ using the blank paper as in the instructions above. If the setting is unchanged, continue with the stain measurement. If the ‘100’ setting has drifted, re-adjust to exactly ‘100.00’ and then remeasure the last stain or two, to ensure that no error has been made.

*If a smoke stain has been formed on the rough surface of the filter paper because the paper was put in the sampler clamps the wrong way, put this stain aside while the normal smooth surface stains are measured. Then reset to ‘100’ as in 11 above, but **using the rough surface of the blank**, and complete the measurement of the rough surface stains.*

4. After all the stains have been measured, switch off and allow the measuring head and bulb to cool.
5. Once cooled, repack the analogue reflectometer components carefully. Handle the cables gently so that the internal wiring is not broken. Before closing the lid, make sure that the plug and cable will not crush the meter glass.

Notes:

1. A quivering or oscillating pointer tip (analogue version) or an unstable reading (digital) may indicate that the measuring head bulb may need replacing.
2. Never touch the bulb glass with bare fingers: traces of sweat or grease will attract dust and cause the bulb to overheat.
3. Always disconnect from the mains before dismantling, and remember, internal components in the measuring head may be extremely hot to touch and are fragile.

4. *Reflectometer test cards are available: the white tile must be used as a backing to the test card and '100.0' must be set on the plain white area of the card. When measuring test card stains, you should record to the nearest tenth of a division (you would normally read to the nearest whole division), and repeat the measuring sequence several times.*
5. *Stains must be stored carefully by site and pollution month and must be saved for a minimum of 18 months, in case they need to be remeasured by you or by **netcen** for quality control purposes.*

7.3 CALCULATION OF SMOKE CONCENTRATIONS

7.3.1 Use of "Look-up Tables"

Results can be determined using "look-up" tables (available from **netcen**), from which the equivalent concentration of standard smoke can be read off, using the volume of air sampled and the reading of the reflectometer. Results should be recorded to the nearest $\mu\text{g m}^{-3}$. The tables are given in Appendix 3.

7.3.2 Formulae used in Calculating Concentrations

Smoke concentrations in the UK have always been calculated by the use of the British Standard Smoke Calibration Curve (BS 1747: Part 2: 1991).

For reflectometer readings of 40 to 99 the following formula is used:

$$C = \frac{F}{V} (91,679.22 - 3,332.0460R + 49.618884R^2 - 0.35329778R^3 + 0.0009863435R^4)$$

where

C	=	concentration in micrograms per cubic meter, British Standard calibration
V	=	volume of air sampled (for historical reasons this is in ft^3 : to convert from metric, $1 \text{ m}^3 = 35.314667 \text{ ft}^3$).
F	=	a factor relating to the sampler clamp size, as follows:
		0.288 for ½ inch clamp
		1.000 for 1 inch clamp
		3.680 for 2 inch clamp
		12.80 for 4 inch clamp
R	=	reflectometer reading

This formula represents the calibration curve to within $\pm 1.3\%$ over the range of the reflectometer readings between 40 and 90. When used to calculate concentrations from reflectometer readings between 91 and 98 the results may be underestimated by as much as 6%.

For darker stains with reflectometer readings between 40 and 20 the formula used is:

$$C = \frac{F}{V} (214,245.1 - 15,130.512R + 508.181R^2 - 8.831144R^3 + 0.0628057R^4)$$

For stains with reflectometer readings of less than 20 this formula gives only an approximation to the concentration, the result being well below the true value. Reflectometer readings of less than 10 are impossible to assess accurately and hence the results are calculated as if the reading had been 10, which gives a minimum value.

Outside the UK, however, the Organisation for Economic Co-operation and Development (OECD) calibration is used, not the British Standard. The black smoke concentration according to the OECD calibration is calculated by dividing the BS concentration by 0.85:

$$C_{\text{OECD}} = C_{\text{BS}} / 0.85$$

8 Network Data Return

8.1 POLLUTION YEAR CALENDAR

The Network is operated according to a long-established “Pollution Year calendar”. The Pollution Year always begins on the Tuesday nearest to 1st April, and contains twelve months, each of exactly 4 or 5 weeks, all beginning on Tuesdays (to minimise problems with public holidays, which often occur on Mondays). The months are arranged to correspond as closely as possible to calendar months. Weeks are numbered. The year is divided into “summer” (April to September) and “winter” (October to March). Data from the Network are processed in batches corresponding to one Pollution Calendar month, and the site operators receive a monthly printout of results.

8.2 DATA RETURN FORM

In order to ensure that all site operators send their results for processing in a consistent format, a standard data return form is used. **netcen** issues these pre-printed forms monthly. The data return form is two-sided. The front is for data entry, the back contains instructions for completion; the front and back are shown in Fig. 8.1 and 8.2 respectively.

The form should be completed according to the instructions on the back. **Please do your best to return your completed forms within 2 weeks of the end of the month shown at the top of the form, and no later than 4 weeks after the end of the month.** Forms arriving later than this will have to be processed separately, and it could be several months before you get the results printouts.

If at all possible, the operator should take the Data Return Form to the sites when they are visited, and record the gas meter reading directly onto the form. Likewise, titration results and reflectometer readings should be recorded on the form at the time these measurements are made. This avoids transcription errors. However, if this is not possible, a logbook should be kept in which the above data can be recorded. All entries should identify the site and date. The logbook should be used *for this purpose only*, and great care should be taken when results are copied onto the form.

8.3 POINTS TO NOTE

Please bear the following points in mind when completing the form:

- Please use black or dark blue pen, not pencil or red.
- Please include the name and full telephone number (including the area code) of the people who actually took the measurements.
- Please record measurements directly on the form, not from rough notes (to avoid transcription errors).

- Figures should not be entered in the shaded areas of the form.
- Please write clearly, with one digit per box.
- Mistakes should be rectified neatly using correcting fluid.
- If there is any malfunction of the equipment through loss of power supply or pump or timer failure, or blockage of the air supply, please write a note in the "Comments" column, on the right-hand side of the form.
- If there are bonfires in the immediate vicinity, or pollution of the local atmosphere through fumes or dust raised by building or road construction workers, this should be noted in the 'Comments' column.
- Do not write notes or other extraneous data within the solid green boxes, except in the space reserved for comments.
- If the site was out of operation for the entire month, fill in the form as for a site breakdown and make a note explaining the circumstances.
- Take a copy of the completed form before sending it to **netcen**. Most operators have access to a photocopier, but **netcen** still supply two copies of each form so that a carbon copy can be made if necessary.

Meter readings & times

- The maximum gap between meter readings is 8 full 24-hour periods. In practice, this means the sampler will need to be visited every week.
- If more than 8 24-hour periods elapse between site visits, the first and eighth days' results will be lost due to double exposure.
- Please enter the time of the meter reading to the nearest minute.
- Do not forget to complete the "last meter reading in previous month" and "next meter reading" boxes if applicable.
- Please check air volume flow-rates weekly to ensure that they are within the acceptable range of 1.8 to 2.2 m³ per day (65 to 75 cubic feet per day). This works out at around 14 m³ (500 cubic feet) per week. If this is done while at the site, mis-readings can be corrected, and faults identified quickly.
- Check that all times and meter reading are entered against the day they were **actually taken**.
- If the meter is changed, complete the form as instructed on the back.

New Meters

- When the meter has to be changed, there will be two meter readings on the day of the change: one from the old meter, and one from the new. The old meter's reading must be entered in the usual way. That from the **new meter** must be written **at the foot of the form**, in the section marked '1st New Meter' which also includes space for the clamp size. In order to draw the attention of the data entry operator to the meter change, the letter **M** is placed in the box for clamp size, the **day following the change**.
- If the meter was changed twice, complete the '2nd New Meter' box also.
- If the old meter read in cubic feet, and the new one is metric, please fill in the 'M/F' box at the top of the form as for the **old** meter, but make a note in the "Comments" column to alert **netcen** to this.

Reflectometer Readings

- Please remember to complete the "clamp size" column.
- The **clamp size** required is the diameter of the stain in inches, not of the outside of the filter clamp. In most, but not all cases this is now 1. This column must not be left blank.

- Where N is entered in the reflectometer box, (no valid reflectometer reading) then the clamp box must also be N.
- If there appears to be **no stain**, as occasionally happens, the reflectometer reading should be entered as **99, not 100 or 00**. Check that air has, in fact, been drawn through the filter and that there are no loose connections through which air could be drawn without passing through the filter. Alternatively, the inlet tube may have become loose, allowing clean indoor air to be drawn in.

Titration Results

- If, when indicator is added to the exposed solution, it is exactly the same neutral grey as the unexposed colour control, write 0.0 in the titration box.
- If, when indicator is added to the exposed solution, it is blue, write ALK in the titration box. If more than 5 ALK readings occur during the month, make a note in the RHS margin, and check for possible reasons.

8.4 COMMON ERRORS

Certain errors occur frequently; these are listed below.

- Meter readings of 5 digits instead of 4, or not in the correct format.
- Meter readings entered with the decimal point in the wrong place.
- Time and meter readings entered on the wrong date line, one day out.
- Clamp figures missing.
- Gaps of more than 8 days between meter readings
- Failure to carry forward to the new form (in the space marked "Last meter reading in previous month") the final time and meter reading of the period just ending.
- Failure to enter in the 'Next meter reading' boxes at the foot of the page, the first time and meter reading of the next new form (this is not necessary if the last Monday on the form has a 'Time' and 'Meter Reading' entry).
- Absence of full telephone numbers (especially the telephone area code) of responsible staff.

8.5 DATA REQUIRED FOR CALCULATIONS

Certain criteria have been adopted in the computer validation program so that no calculations can be carried out when the results would, in effect, be meaningless. The main safeguards are as follows:

- Checks for invalid times, meter readings, clamp sizes, reflectometer readings, titrations.
- Checks for missing times, meter readings, clamp sizes, reflectometer readings, titrations.
- Checks that correct month's data is being processed
- Gaps of over 8 days between meter readings
- Air volumes of less than 1.80 m³ per 24 hours (63 cubic feet per 24 hours), or more than 2.18 m³ per 24 hours (77 cubic feet per 24 hours): these will cause data to be rejected.

Also, the following occurrences are highlighted for attention, as they may indicate an error or a problem:

- Any reflectometer reading less than 40
- Large increases in reflectometer reading or titration between one day and the next.
- Large decreases in reflectometer reading or titration between one day and the next.
- Flowrates greater than 2.15 but less than 2.20m³per day are flagged as 'A' (above optimum flowrate) but the data are not rejected.
- Flowrates greater than 2.20m³per day (77 cubic feet per day) are flagged as 'H' (high flowrate) and the data are rejected.
- Flowrates less than 1.85 but greater than 1.80m³per day are flagged as 'B' (below optimum flowrate) but the data are not rejected.
- Flowrates less than 1.80m³per day (63 cubic feet per day) are flagged as 'L' (low flowrate) and the data are rejected.
- A period of low flowrate immediately followed by a period of high flowrate, or vice versa: **this usually indicates a time and meter reading has been entered on the data return form one day late or early.**

8.6 CONTINUITY OF MONITORING: BREAKDOWN OF EQUIPMENT

netcen is committed to maximising data capture from the UK Smoke and SO₂ Network, and the efforts made by site operators to avoid breakdowns are greatly appreciated. Regular maintenance, and weekly checks of sampling flowrate reduce the likelihood of breakdowns and provide early warning of problems before they become serious. It is useful to keep spare components if possible; in particular, if a Capex pump is in use, the site operator should keep a spare filter and critical orifice assembly to hand. If an equipment breakdown occurs, please fill in the data return form as instructed on the back.

It is also greatly appreciated if measurements can be kept up over the Christmas holiday when heavy pollution is not unusual. It is usually possible to make an extra site visit before the holidays, so that unattended periods of more than 7 days can be avoided.

UK Smoke and Sulphur Dioxide Network

APRIL 2002									
1 Site Name & Number:					2 Contact for Enquiries				
3 Operating Authority:					Name:				
Site Location:					Full Tel. No:				
					e-mail:				
					Received by Netcen? <input type="checkbox"/>				
4 8-port change time:		5 Site Code: <input type="text"/>			Adj. Day <input type="checkbox"/>		Ext. Day <input type="checkbox"/>		1st Week No. <input type="text"/>
6 Date of Previous Meter Reading:		7 Last Meter Reading in PREVIOUS month:							
		Time		Meter Rdg		M (m ³) or F (ft ³)		8pv	
								8/R	
		Week Number	Time 24hr Clock	Meter Rdg. (e.g. 12.34m ³ /123.4ft ³)	Clamp Inches	Refl	Titre ml.	Comments	
8 Tue 02-Apr-02		0 1							
Wed 03-Apr-02									
Thu 04-Apr-02									
Fri 05-Apr-02									
Sat 06-Apr-02									
Sun 07-Apr-02									
Mon 08-Apr-02									U
Tue 09-Apr-02		0 2							
Wed 10-Apr-02									
Thu 11-Apr-02									
Fri 12-Apr-02									
Sat 13-Apr-02									
Sun 14-Apr-02									
Mon 15-Apr-02									U
Tue 16-Apr-02		0 3							
Wed 17-Apr-02									
Thu 18-Apr-02									
Fri 19-Apr-02									
Sat 20-Apr-02									
Sun 21-Apr-02									
Mon 22-Apr-02									U
Tue 23-Apr-02		0 4							
Wed 24-Apr-02									
Thu 25-Apr-02									
Fri 26-Apr-02									
Sat 27-Apr-02									
Sun 28-Apr-02									
Mon 29-Apr-02									U
<p>Flowrate should be 2m³ (or 70ft³) per day, +/-10%. This is approx. equivalent to 14m³ per week.</p> <p>Please check sampled volume each week, preferably while still at the site – thank you.</p> <p>High or low flowrate? See the instruction Manual, or contact Netcen for advice.</p>									
9 NEXT Meter Reading									
Date <input type="text"/>		<input type="text"/>							
Fill in the boxes below only if the meter was replaced during the month:									
1st new meter		<input type="text"/>							
2nd new meter		<input type="text"/>							
For instructions, see over.									

Figure 8.1 Data Return Form (front)

UK Smoke and SO₂ Monitoring Network

Notes for guidance on completing this form.

1. **Site name & number** are as on the results sheet, e.g. "ABERDEEN 3".
2. **Contact for Enquiries** should be the name of the person(s) who actually took the measurements and can answer any questions. Please give the full telephone number (including the area code and any extensions), and an e-mail address if possible.
3. **Operating Authority** is the organisation operating the site (usually the local authority), e.g. "Manchester City Council". **Site Location** is a brief description of the location of the site, e.g. "Town Hall, High Street".
4. **8-port change time** is the time the 8-port valve is set to change over. This should normally be midnight GMT (ignore change to BST).
5. **Site code** is the 7 digit number by which our computer identifies the site. This appears at the top left of the page of processed results returned to you each month.
- 6, 7. **Last meter reading in previous month** is the *last* meter reading taken in the *previous* "pollution month". Please enter the date, time of reading and reading in the appropriate boxes. If the meter readings are in cubic metres, enter M in the next box; if they are in cubic feet, enter F. Note: this date, meter reading and time should match the last entry on the main body of the previous month's form.
7. **Time of meter readings** should be given to the nearest minute, against the actual date on which they were taken, and using 24 hour clock notation, e.g. 0900 for 9am, 1520 for 3.20pm. A reading taken at midnight should be entered as 2400.
8. **Entering The Data.** Please enter one digit or letter per box, using black or blue pen. A photocopy can be used as a "working copy" if necessary. Keep a copy of the *completed* form for your own records before returning the original to NETCEN

Please note that the positions of decimal points are shown on the form.

Time: enter the time at which the meter reading was taken against the date, using 24 hour clock notation, with leading zero if appropriate, without any point: e.g. 0935 .

Meter reading: if in cubic meters enter tens, units, and two decimal places (e.g. 12.34). If in cubic feet enter hundreds, tens, units and one decimal place (e.g. 123.4). The meter reading must contain exactly 4 figures.

One reading is required every seven days. Enter the time and the meter reading against the appropriate day whenever the samples are changed. Do not disturb an active sample. Check the time set for the automatic changeover, and note in the box provided. This should be midnight GMT (ignore BST).

Clamp size: enter clamp size in use, in inches: this is usually 1 but may be 2, 4, or H (half inch). A valid value must be entered for every day.

Reflectance: enter this value to the nearest unit. Note: if the actual reading was 100, enter 99, *not* 00.

Titre: enter in ml to the first decimal place. Specify "0.", or ".0" as appropriate. If the solution went blue when indicator was added, enter ALK in the titre column. If it went neutral grey when indicator was added, write "000".

If no data: write N in the left hand box of each affected column as appropriate. If reflectance is N, clamp must be N. Time column may be left blank when the meter column is N.

Results are entered against the date which corresponds to the end of the sampling period. Midnight is taken to be the *end* of the day.

Over-runs: if an 8-port sampler over-runs because a visit is delayed, so that one or more bottles and filters are exposed twice, then **both days' results are invalid and should be entered as N.**

Sampler breakdowns, interruptions, no access etc. On the first day of a "breakdown" period, write N in the first box of the meter, clamp, reflectance and titre columns. Do the same for each successive day of the breakdown period. On the day the sampler is re-started, insert the re-start time and meter reading, but enter N in the first box of the clamp, reflectance and titre columns (the re-start day will not give valid results).

Comments. Enter relevant comments such as power cuts, pump changes, or any factors which might affect the results, at the right hand side of the form.

9. **Next meter reading:** If the site was not visited on the last Monday shown on this form, enter the 1st meter reading in the *next* pollution month, and its date and time, in the "next meter reading" boxes provided, at the foot of the form.

New or replacement meters. If the meter was replaced during the month:

- Record the final time and reading for the old meter against the appropriate date when it was removed.
- Enter the original reading for the new meter, and the date and time it was installed, in the "1st New Meter" box at the bottom of the form.
- Write M in the clamp size box against the first whole day using the new meter (*not* against the final reading using the old meter).
- Write the actual clamp size for this day against the first new meter reading.
- There is provision for up to two meter changes in the month. Use the "2nd new meter" boxes if necessary, but the number of Ms in the clamp column must match the number of new meters used.

Checking the flowrate. Each week, *while still at the site*, check that the flowrate for the past week has been around 2m³ (or 70ft³) per day, \pm 10% (around 14m³ for the whole week). It should also be consistent from week to week. This check will allow many problems to be identified before they become serious, and also eliminate many errors in recording the meter reading.

Completed forms: please post completed form to NETCEN, using the pre-paid address label supplied, and include the card from the envelope in which they were received - this is supplied to avoid the form getting crumpled in the post. Please ensure the form reaches NETCEN within 14 days of the end of the month.

No results: if the sampler was out of action for the whole month, please fill in the site name and number, and return the form to NETCEN with a brief explanation.

Last updated February 2002

Figure 8.2 Data Return Form (back)

9 Regular Checks

This section describes a system of regular checks similar to that proposed in the 1979 National Survey Advisory Handbook on Quality Control. The six-monthly tests should be duplicated by two people if possible, and in addition, the six-monthly checks should be carried out if a change of operator occurs.

9.1 WEEKLY CHECKS

Each time the site is visited, the operator should:

1. Check that the funnel is intact and properly positioned.
2. Check the tubing between the funnel and sampler is free from obstructions, kinks, items which could crush it, etc.
3. Check the sampler's internal tubing for obstructions, kinks, moisture, loose or badly sealing joints.
4. Check that the unions to the gas meter are tight.
5. Check that the expected bubbler is active, and that the timer is showing the correct number of hours to the next changeover.
6. Ensure that the rate of bubble formation appears normal.
7. Calculate the flowrate over the past week; is it within the acceptable range of 2 m^3 per day, $\pm 10\%$.
8. Note any unusual occurrences which might affect results, e.g. bonfires or demolition work in the area.

9.2 TWO-MONTHLY CHECKS:

These should be performed at the start of pollution months April, June, August, October, December and February.

1. Examine the smoke stains obtained during the past two months. If there is any blurring, fuzzy edges, or evidence of non-centring attend to the clamps.
2. Check the reflectometer readings on your copies of the data return forms. Are any unusually high or low?
3. Pick one stain from each week in the period, and re-measure them. Ideally, a different operator should do this. The original and repeat readings should agree to within ± 2 units for individual stains and ± 1 unit on average. Check that the papers were read on the correct side. Look for any overall bias between first and second readings, and if any fault is suspected contact the manufacturer of the reflectometer and arrange for it to be serviced.
4. Check the current batch of 1 vol hydrogen peroxide as follows: rinse a clean conical flask with a little of the solution. Pour in approximately 50ml, and add 3 or 4 drops of indicator. The colour should be neutral grey, with neither a pinkish or bluish tinge. If there is a hint of colour, titrate with previously checked 0.002M borate or 0.002M sulphuric acid depending on whether a pinkish-grey (acid) or bluish-grey (alkaline) colour is observed. No more than

0.2 ml of acid or borate should be needed to produce neutral grey. If not, repeat the test. If consistently outside the limit, make up a fresh batch of 1 volume, *nominally* pH 4.5 hydrogen peroxide, and *follow the procedure in Section 6 for preparation of a correct colour control*.

5. Check the accuracy of the volumetric solutions (acid and borate) using the procedure in Section 6.5. If at all possible, 5 test titrations should be done by two separate operators. The titre should be between 9.60 and 9.90 ml. If consistently outside, discard the solutions and prepare fresh batches. *n.b. This should also be done every time a fresh batch of solution is prepared.* Besides being within the prescribed limits, the spread of the individual titres for each determination should be within 0.2 ml.

9.3 SIX-MONTHLY CHECKS

In addition to the two-monthly checks, the following should be carried out at the beginning of the pollution months April and October.

1. Advise **netcen** if there have been any changes which might mean the sampler has to be relocated in future.
2. If it is necessary, move the sampler to a warmer/cooler location for the forthcoming season, or add/remove insulation.
3. Check the sampler's internal tubing and components for leaks or poor seals.
4. Replace any tubing which has become sticky, mouldy, discoloured, or hard.
5. Check that the inlet tubes in the Dreschel bottles are long enough, and the volume of peroxide being used is adequate, especially before the summer.
6. When carrying out the smoke stain re-measurements, make sure that any possible problems noted at an earlier stage have been dealt with.
7. If possible, it is useful to exchange a sample of smoke stains with a neighbouring Local Authority for measurement using a different reflectometer. The same criteria apply as above, i.e. the original and repeat readings should agree to within ± 2 units for individual stains and ± 1 unit on average. If not, there may be a fault with the operation or calibration with one of the reflectometers, which should be investigated.
8. Check supplies of concentrated acid/borate ampoules, concentrated peroxide, indicator etc. are not past their expiry date.
9. Prepare fresh solutions of 0.002 M sulphuric acid and obtain from **netcen** (or prepare) fresh 0.002M di-Sodium tetraborate solution if needed.
10. Check the accuracy of the acid against the borate by the procedure given in Section 6.4. If possible, two operators should carry out the tests. Again, it may be useful if possible to exchange samples with a neighbouring Local Authority for testing.
11. Review the area where titration takes place. Is there adequate light? Are the work surface and walls behind the burette white, or covered with white paper or bench protector? Is a white lab coat or overall available?
12. Ensure all glassware is clean and free from contamination.

9.4 CHECKING FOR LEAKAGE

When the sampler is in use, all components preceding the pump will be under negative pressure with respect to the surrounding atmosphere. Therefore, any leaks or bad seals will allow air to leak in from the room in which the sampler is kept. If such air ingress occurs, the actual volume of "dirty" outdoor air passing through the filter and bubbler will be less than the total volume

registered by the meter, causing underestimation of the ambient smoke and SO₂ concentration. The standard method for determination of black smoke concentration, ISO 9835 (1993) (equivalent to BS 1747, Part 11, 1993) states that **“The leakage across the filter and valves.... should not exceed 2% of the total flowrate”**.

Testing a sampler for leakage is not always straightforward. The original Instruction Manual (1966) gives a method for testing individual components, using either a vacuum dessicator, or a sealed flexible container made from a plastic bag. This method is perfectly sound, however it is rarely used. Many site operators do not have access to a vacuum dessicator, and the plastic bag method has been found awkward. Also, this method does not address the problem of leaks in the connections between components, and is not practical for testing a whole sampler.

It is possible to measure the leakage between the sampler's inlet manifold and the meter, by attaching a spare meter to the inlet, and comparing the volume registered by the two meters over a given time (e.g. one hour). However, for this to work, both the spare meter and the meter in the sampler must have been accurately calibrated beforehand, against the same standard.

A quicker alternative is to use a variable-area flowmeter (also known as a “rotameter” or “float” flowmeter), to compare the flowrate into the sampler inlet manifold with the flowrate into the meter. A variable area flowmeter capable of reading upto around 1700 cc per minute (1.7 litres per minute) will be needed, together with some soft, flexible tubing (it is helpful to use tubing softer than the PVC tubing used in the sampler). Tubing of 8mm nominal bore will fit most inlet manifolds and some meter connectors; 5mm may be needed to fit the plastic connectors on some “Remus” gas meters. Some quick-release connectors will be necessary if different sizes of tubing are needed to fit the manifold, meter inlet and flowmeter. “Jubilee” clips may be useful to secure the tubing. The method is not perfect, and is affected by the pressure drop across the various components. However, it provides a quick way of identifying samplers with serious leakage problems. **Carry out the test with a clean filter in the active clamp**; a dirty filter will increase the pressure drop between the manifold and meter, but the clamp may not seal properly without a filter in place. The procedure is as follows.

1. Switch off the sampler and carefully remove the inlet tube from the manifold inlet.
2. Connect one end of the soft tubing to the top of the flowmeter tube, and the other to the manifold inlet.
3. Ensure the tubing is not kinked or constricted, and switch the sampler back on. Check that it is bubbling normally. Hold the flowmeter vertically, or support it in e.g. a laboratory clamp stand.
4. Read the flowmeter, and record the reading.
5. Detach the soft tubing from the manifold inlet.
6. Gently disconnect the existing PVC tubing from the inlet of the sampler's dry gas meter.
7. Connect the top of the variable area flowmeter to the meter inlet using soft tubing. The flowmeter and gas meter inlets may require different sizes of tubing to fit (e.g. 8mm and 6mm nominal bore). If so, use quick-release connectors to join them.
8. Hold the flowmeter vertically, and record the reading. This is the flowrate into the meter.
9. Subtract the inlet flowrate (which should be the lower of the two values) from the meter flowrate. Divide the resulting value by the meter flowrate. Multiply by 100 to obtain the percentage leakage.

10. Disconnect the flowmeter, reconnect the meter inlet as normal, and check that the sampler resumes normal bubbling.

11. Remember to reconnect the sampler's inlet tube to the manifold so it resumes sampling outdoor air!

In our experience it is rare to obtain a result less than 2%, even with a sampler in good condition; 5% is a more usual figure. This difference is likely to be due to pressure drop across the components, rather than air ingress. However, if the result is greater than 5%, this indicates there is probably some air ingress, and it will be necessary to investigate the cause. Sources of leakage within the sampler include the following:

- Leaks in the manifold (fairly rare). Consult the supplier if this is suspected.
- Worn clamp surfaces; re-surface as in section 5.2 or return to supplier.
- Clamps misaligned or inadequately tightened.
- Loose or damaged clamp holders in some models.
- Filter paper not covering the entire space between the clamp surfaces.
- Bubbler head not making a good seal with bubbler bottle. Use a little silicone grease.
- Internal tubing deteriorated by age and sunlight, not sealing on clamps, bottles etc. Re-tube.
- If the sampler contains quick-release connectors, these can leak due to age and wear. If they appear at all loose, replace them. Alternatively, remove them altogether, but increase the length of tubing slightly to allow for the bubblers to be removed easily.
- Leakage within the 8-port valve, due to age and wear. Consult supplier.
- Meter connectors loose (they should be just spanner-tight), or rubber bungs being used instead of proper connectors.

Leakage can also occur through any joins in the tubing connecting the funnel to the sampler. This is much more difficult to measure. For this reason, the funnel should be connected to the sampler by one single length of tubing, without joins. For more information on re-tubing, see sections 3.1 and 4.3.

Appendices

CONTENTS

Appendix 1	Reading the Gas Meter
Appendix 2	Setting the Digital 8-Port Timer
Appendix 3	Look-up Tables

Appendix 1

Reading the Gas Meter

CONTENTS

UK SMOKE AND SULPHUR DIOXIDE MONITORING NETWORKS

Guidance Note: Reading the Gas Meter

Mis-reading the gas meter, or entering the reading incorrectly on our Form 216, is a common source of error. This Guidance Note has been prepared to help prevent errors of this type. Meter readings must be accurate: readers are advised to take their time and check their readings carefully.

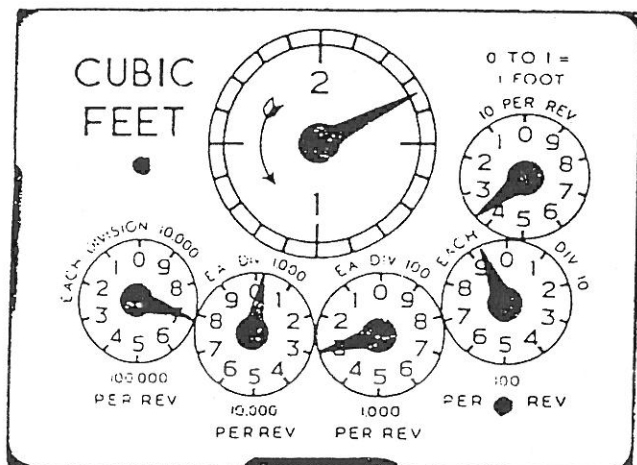
Always note the time corresponding to the meter reading, correct to the nearest minute. This will either be in GMT or BST, according to the time of year: do not convert BST to GMT. The time should be written on our Form 216 in 24-hour clock form, eg. 9 am as 0900, 1.30 pm as 1330, etc. Make sure that the time is entered against the correct date.

The pictures A to F below show the display seen on some of the commonly used gas meters, and have been selected to illustrate some of the common reading difficulties encountered. The reading indicated is shown next to the picture, as well as the symbol used to represent the decimal point, and how the reading should be entered on Form 216. The entry on Form 216 must always consist of exactly 4 figures, correctly aligned around the pre-printed decimal point:

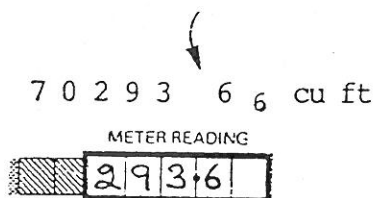
for a meter recording in units of cubic feet, the format is 123.4
for a meter recording in units of cubic metres, the format is 12.34

(see the back of Form 216, para. 7.)

Cubic feet readings are entered to one place of decimals, and cubic metre readings are entered to two places of decimals: it is not necessary to round up the reading. Leading zeros must appear where appropriate, eg. 003.4, 02.34. You may find it helpful to cover part of the meter display window with masking tape, so that only the four required figure positions are visible, and mark the position of the decimal point.



CAUTION: Domestic gas meters with this display show 0 to 1 = 10 feet

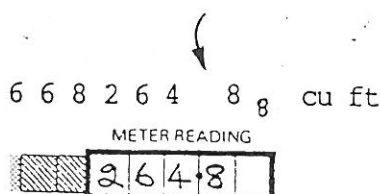
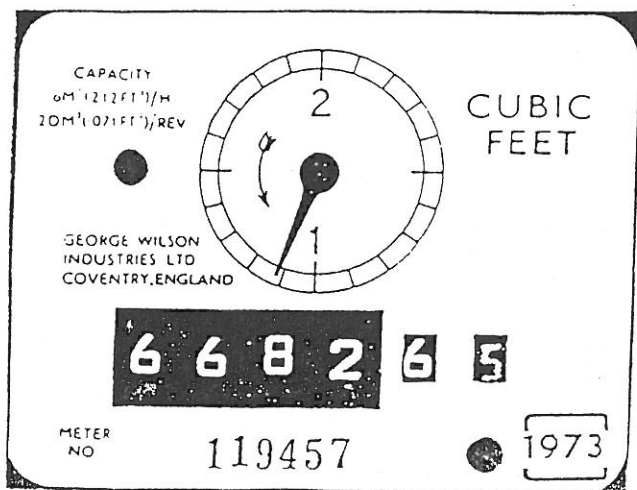


The units digit is shown by the top right-hand small dial in picture A, and appears in the right-hand window in picture B. For both pictures A and B, the decimal values are shown by the large dial. On the large dial, the figure 1 corresponds to the "zero" position for the decimal when the units digit is odd (1,3,5,7,9), while the figure 2 corresponds to the "zero" position for the decimal when the units digit is even (0,2,4,6,8).

In picture A, the units digit is more than 3 but not yet 4, hence the decimal value is read from the right or "odd" half of the large dial with its zero at '1'.

In picture B, the units digit is actually 4 (although disappeared from view) and not yet 5 (this figure is still below the centre line of the window and moving upwards). This is confirmed by the pointer which is still in the left or "even" half of the dial with its zero at '2'. Only when the pointer reaches and passes '1' will the units digit become 5 with the figure centred in the window. The units figure moves progressively higher in the window as the pointer approaches the next "zero" position.

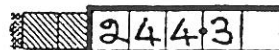
Sometimes the tenths pointer can lose synchronisation with the units: if this has happened to your meter, please ask for advice on correct reading.





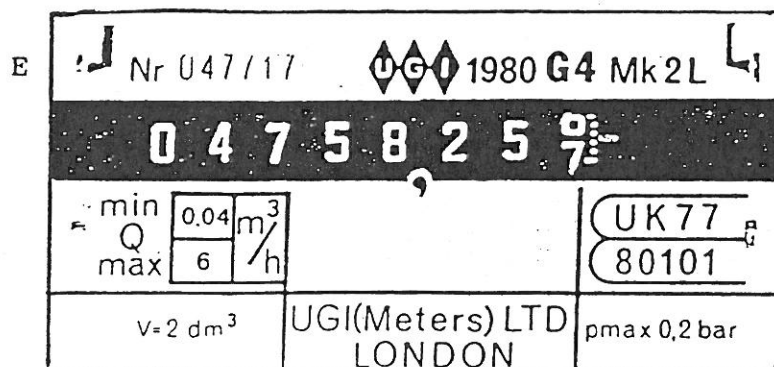
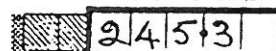
0 3 4 2 4 4 3 8 cu ft

METER READING



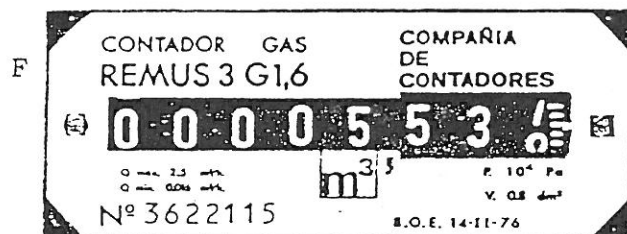
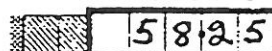
0 0 3 6 2 4 5 3 4 cu ft

METER READING



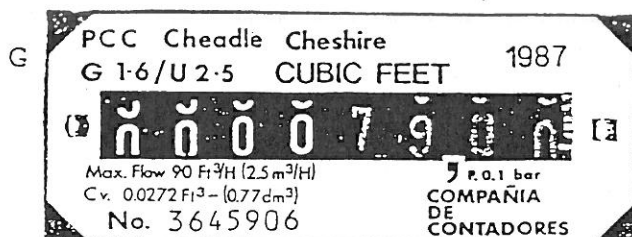
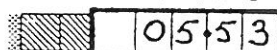
0 4 7 5 8 2 5 6 5 cu m

METER READING



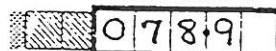
0 0 0 0 5 5 3 7 4 cu m

METER READING



0 0 0 0 7 8 9 9 7 cu ft

METER READING



The person who reads the meter should calculate the volume of air recorded since the last reading, and check that this is within the acceptable range (see the back of Form 216). Any unexpected variation should be checked: this way, problems with the sampling equipment can often be dealt with before they become serious and lead to loss of data. If a power cut is suspected, please indicate this on Form 216: on which day and for how long?

If your meter has a display which matches none of these, please let AEA Technology know its details. There are some types of domestic gas meters which only measure to the nearest 100 cubic feet: these do not give the required precision for use in smoke and sulphur dioxide samplers, and are therefore not suitable for this application.

Please note that the accuracy of the meter should be within +/- 3%. We can test your meter free of charge to confirm whether or not it meets this specification.

If someone other than the usual member of staff has to do the meter reading, please make sure they are shown how, and give them a copy of this Guidance Note. If you have any further questions about gas meters, please contact AEA Technology, (01235) 463133 or 463140 (Alison Loader or Diane Mooney)

Appendix 2

Setting the Digital 8-Port Timer

CONTENTS

Setting The Digital 8-Port Timer

Setting the Digital 8-Port Timer

These notes describe the operation of the 8-port valve with digital timer, ie. the Randall and Sangamo types.

This contains a rechargeable battery which maintains the clock time and programmed sequences in the event of a temporary mains power failure. There should therefore be no need to have to reset time and switching sequences after a power failure. However, a power failure will cause the pump to stop for some time, and hence the volume of air sampled by the affected filter and bubbler will be less than expected. Mains power is also required at all times to drive the valve changeover motor, so if the power is off at the time set for valve change, the changeover will not occur, even though the time switch continues to run uninterrupted. This will result in the same filter and bubbler being used continuously for more than 24 hours. For this reason, always check that the expected bottle is bubbling when you make your routine visit.

The red circular push button on the face of the unit below the time switch is used for manually changing valve ports. Depressing this button will illuminate the neon indicator: the button should be held down for 1 second until the neon remains 'on' when the button is released. The motor will then continue to drive the valve to its next position when the neon will go 'off'. Do not attempt to use the manual changeover button when an automatically timed changeover is about to take place.

The procedure below should be used when it is necessary to set up the Randall or Sangamo E1 programmable time switch. The steps in block capitals (eg PROG, CANCEL, EXIT etc) mean that the appropriate red, rectangular control button must be pressed once and once only. To get at these buttons it may be necessary to open the grey plastic cover at the front, using a small screwdriver. The steps must be followed in the numbered sequence. Press the control buttons gently but firmly in the centre ; take care not to jam the button in a permanently 'down' position. You may find it easier to use the blunt end of a pen or pencil, rather than your finger.

If it is necessary only to set the correct GMT time of day, follow Stage 1 steps 1 to 8. Stages 2, 3 and 4 can be omitted if the switching sequences are already set correctly. Altering the time of day has no effect on the daily programmed or copied switching sequences.

If the GMT time of day is correct, but it is required to set the programmed times of operation, omit Stage 1, steps 1 to 8, and start at Stage 2, step 9.

Steps enclosed in square brackets [] can be omitted if the selected flashing option is already correct, but all other steps must be completed.

Stage 1: Setting correct GMT clock time (when necessary)

1. TIME
- [2. DAY]
- [3. INC/DEC until correct day flashes]
- [4. HR]
- [5. INC/DEC until correct AM or PM hour flashes. Note: If BST is in effect, subtract 1 hour, eg 1254 BST is 1154 GMT]
- [6. MIN]
- [7. INC/DEC until correct minutes flash]
8. ENTER

Time is now set: this is the normal 'RUN' mode.

Stage 2: Clear all day and copied switching sequences

9. PROG
10. CANCEL
11. CANCEL
12. COPY
13. CANCEL
14. CANCEL

The time switch is now completely cleared of all programmed switching sequences.

Stage 3:

15. PROG
- [16. INC/DEC until ON/OFF mode 1 symbol flashes]
17. ENTER
18. SET 'program level 21'
19. DAY
- [20. INC/DEC until MON flashes]
21. HR
22. INC/DEC until PM hour 11 flashes
23. MIN
24. INC/DEC until minutes 58 flashes
25. ENTER sets ON time of 1158 pm; switch status 1 'ON' changes to 0 'OFF'
- [26. HR]
- [27. INC/DEC until PM hour 11 flashes]
28. MIN
29. INC/DEC until minutes 59 flashes

- 30. ENTER sets OFF time of 1159 pm which will actually take effect 1 minute later at midnight; 'program level 21' changes to 'programme level 20'
- 31. EXIT
- 32. EXIT

Monday is now set in ON/OFF mode to trip at 1158 pm and start valve movement at midnight GMT.

Stage 4: Copy Monday's program into Tuesday through Sunday.

- 33. COPY
- 34. SET
- 35. DAY
- [36. INC/DEC until MON flashes]
- 37. ENTER the 'base' day is now Monday
- 38. INC/DEC until TUE flashes
- 39. ENTER Monday's program is copied into Tuesday
- 40. DAY MON should flash (the 'base' day)
- 41. ENTER
- 42. INC/DEC until WED flashes
- 43. ENTER Monday's program is copied into Wednesday
- 44. DAY MON should flash (the 'base' day)
- 45. ENTER
- 46. INC/DEC until THU flashes
- 47. ENTER Monday's program is copied into Thursday
- 48. DAY MON should flash (the 'base' day)
- 49. ENTER
- 50. INC/DEC until FRI flashes
- 51. ENTER Monday's program is copied into Friday
- 52. DAY MON should flash (the 'base' day)
- 53. ENTER
- 54. INC/DEC until SAT flashes
- 55. ENTER Monday's program is copied into Saturday
- 56. DAY MON should flash (the 'base' day)
- 57. ENTER
- 58. INC/DEC until SUN flashes
- 59. ENTER Monday's program is copied into Sunday
- 60. EXIT
- 61. EXIT

Every day of the week is now set to be a copy of Monday.

The switch status (below AM/PM) should now be 0 for OFF, and the red LED on the right hand side of the LCD display should be 'off'. If status is 1 for ON and the LED is 'on', press O/R once.

IMPORTANT: DO NOT TOUCH THE 'CONTINUOUS OFF BUTTON'

If required, use the manual changeover button to step the valve until the desired bottle is seen to be bubbling.

What to do if you make a mistake in the setting sequence

Press ENTER/EXIT . . . EXIT until the LCD display shows normal time-of-day 'RUN' mode. Then start again from the beginning of Stage 2.

To review the sequence programmed for Monday, without altering anything:

- 62. PROG
- 63. REVU
- 64. INC/DEC to view the 1 'ON' and 0 'OFF' settings
- [65. DAY]
- [66. INC/DEC to select another day]
- [67. ENTER]
- [68. INC/DEC to view the selected day's settings]

If you are curious, steps 65 through 68 may be repeated to examine any other day of your choice.

- 69. EXIT
- 70. EXIT to normal 'RUN' mode.

Note: the only day intentionally wet with an ON/OFF sequence is Monday. Tuesday through Sunday will normally show no programmed sequence, indicated by a displayed set time of 0:00.

To review days using a copied program, without altering anything:

- 71. COPY
- 72. REVU MON, the 'base' day, should appear solid, while TUE through SUN should all flash, indicating that they are copies of Monday's sequence.
- 73. EXIT
- 74. EXIT to normal 'RUN' mode.

Footnote

Only the defined sequences above should be used. The Randall / Sangamo time switch can be programmed in other ways, but these are not recommended for this application.

Appendix 3

Look-Up Tables

Tables for Calculation of Black Smoke Concentration: British Standard Calibration (UK only).

	Daily air sample volume in cubic metres																						
	1.7	1.73	1.76	1.79	1.82	1.85	1.88	1.91	1.94	1.97	2	2.03	2.06	2.09	2.12	2.15	2.18	2.21	2.24	2.27	2.3		
10	1758	1728	1698	1670	1642	1616	1590	1565	1541	1517	1494	1472	1451	1430	1410	1390	1371	1352	1334	1317	1300		
11	1640	1612	1584	1558	1532	1507	1483	1460	1437	1415	1394	1374	1353	1334	1315	1297	1279	1262	1245	1228	1212		
12	1531	1504	1479	1454	1430	1407	1384	1362	1341	1321	1301	1282	1263	1245	1227	1210	1194	1178	1162	1146	1131		
13	1430	1405	1381	1358	1335	1314	1293	1272	1253	1234	1215	1197	1180	1163	1146	1130	1115	1100	1085	1071	1057		
14	1336	1313	1290	1269	1248	1228	1208	1189	1171	1153	1136	1119	1102	1087	1071	1056	1042	1028	1014	1000	987		
15	1249	1228	1207	1187	1167	1148	1130	1112	1095	1078	1062	1046	1031	1016	1002	988	974	961	948	936	923		
16	1169	1149	1129	1110	1092	1074	1057	1041	1025	1009	994	979	965	951	938	925	912	899	887	876	864		
17	1095	1076	1058	1040	1023	1006	990	975	960	945	931	917	904	891	878	866	854	842	831	820	809		
18	1027	1009	992	975	959	943	928	914	900	886	873	860	847	835	823	812	801	790	779	769	759		
19	963	947	930	915	900	885	871	857	844	831	819	807	795	784	772	762	751	741	731	721	712		
20	905	889	874	859	845	831	818	805	793	781	769	758	747	736	725	715	705	696	687	677	669		
21	850	835	821	807	794	781	769	757	745	734	723	712	702	692	682	672	663	654	645	637	628		
22	800	786	772	760	747	735	723	712	701	690	680	670	660	651	641	632	624	615	607	599	591		
23	753	740	727	715	703	692	681	670	660	650	640	630	621	612	604	595	587	579	571	564	556		
24	709	697	685	674	663	652	641	631	622	612	603	594	585	577	569	561	553	546	538	531	524		
25	669	657	646	635	625	614	605	595	586	577	568	560	552	544	536	529	521	514	507	501	494		
26	631	620	609	599	589	580	570	561	553	544	536	528	521	513	506	499	492	485	479	472	466		
27	595	585	575	565	556	547	538	530	522	514	506	499	491	484	477	471	464	458	452	446	440		
28	562	552	543	534	525	517	508	500	493	485	478	471	464	457	451	444	438	432	427	421	415		
29	531	522	513	504	496	488	480	473	465	458	451	445	438	432	426	420	414	408	403	398	392		
30	502	493	485	477	469	461	454	447	440	433	427	420	414	408	402	397	391	386	381	376	371		
31	474	466	458	450	443	436	429	422	416	409	403	397	391	386	380	375	370	365	360	355	351		
32	448	441	433	426	419	412	406	399	393	387	381	376	370	365	360	355	350	345	340	336	331		
33	424	417	410	403	396	390	384	378	372	366	361	355	350	345	340	335	331	326	322	318	314		
34	401	394	388	381	375	369	363	357	352	346	341	336	331	326	322	317	313	309	305	301	297		
35	380	373	367	361	355	349	344	338	333	328	323	318	314	309	305	300	296	292	288	285	281		
36	360	354	348	342	336	331	326	320	315	311	306	301	297	293	289	285	281	277	273	270	266		
37	341	336	330	324	319	314	309	304	299	295	290	286	282	278	274	270	266	263	259	256	252		
38	324	319	313	308	303	298	293	289	284	280	276	272	268	264	260	256	253	250	246	243	240		
39	309	303	298	293	288	284	279	275	271	267	263	259	255	251	248	244	241	238	234	231	228		
40	295	290	285	280	275	271	267	262	258	254	251	247	243	240	236	233	230	227	224	221	218		
41	282	277	272	268	263	259	255	251	247	243	239	236	232	229	226	223	220	217	214	211	208		
42	269	264	260	256	251	247	243	240	236	232	229	225	222	219	216	213	210	207	204	202	199		
43	257	253	248	244	240	236	232	229	225	222	218	215	212	209	206	203	200	198	195	192	190		
44	245	241	237	233	229	226	222	218	215	212	209	206	203	200	197	194	191	189	186	184	181		
45	234	230	226	223	219	215	212	209	205	202	199	196	193	191	188	185	183	180	178	175	173		
46	224	220	216	212	209	206	202	199	196	193	190	187	185	182	179	177	174	172	170	167	165		
47	213	210	206	203	199	196	193	190	187	184	181	179	176	174	171	169	166	164	162	160	158		
48	204	200	197	193	190	187	184	181	178	176	173	171	168	166	163	161	159	157	155	153	151		
49	194	191	188	185	181	179	176	173	170	168	165	163	160	158	156	154	152	149	147	146	144		
50	185	182	179	176	173	170	168	165	162	160	158	155	153	151	149	147	145	143	141	139	137		
51	177	174	171	168	165	162	160	157	155	153	150	148	146	144	142	140	138	136	134	132	131		
52	169	166	163	160	157	155	152	150	148	145	143	141	139	137	135	133	131	130	128	126	125		
53	161	158	155	153	150	148	145	143	141	139	137	135	133	131	129	127	125	124	122	120	119		
54	153	150	148	145	143	141	138	136	134	132	130	128	126	125	123	121	119	118	116	115	113		
55	146	143	141	139	136	134	132	130	128	126	124	122	120	119	117	115	114	112	111	109	108		
56	139	137	134	132	130	128	126	124	122	120	118	116	115	113	111	110	108	107	105	104	103		
57	132	130	128	126	124	122	120	118	116	114	113	111	109	108	106	105	103	102	100	99	98		
58	126	124	122	120	118	116	114	112	110	109	107	106	104	103	101	100	98	97	96	94	93		
59	120	118	116	114	112	110	109	107	105	104	102	100	99	98	96	95	94	92	91	90	89		
60	114	112	110	108	107	105	103	102	100	99	97	96	94	93	92	90	89	88	87	86	84		
61	109	107	105	103	101	100	98	97	95	94	92	91	90	88	87	86	85	84	82	81	80		
62	103	102	100	98	96	95	93	92	91	89	88	87	85	84	83	82	81	79	78	77	76		
63	98	96	95	93	92	90	89	87	86	85	83	82	81	80	79	78	77	76	75	74	73		
64	93	92	90	89	87	86	84	83	82	81	79	78	77	76	75	74	73	72	71	70	69		
65	89	87	86	84	83	81	80	79	78	76	75	74	73	72	71	70	69	68	67	66	65		
66	84	83	81	80	79	77	76	75	74	73	71	70	69	68	67	66	65	64	63	62	61		
67	80	78	77	76	74	73	72	71	70	69	68	67	66	65	64	63	62	61	61	60	59		
68	76	74	73	72	71	69	68	67	66	65	64	63	62	61	61	60	59	58	57	57	56		

Tables for Calculation of Black Smoke Concentration: British Standard Calibration (UK only).

Daily air sample volume in cubic feet

	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
10	1759	1730	1702	1675	1649	1624	1599	1575	1552	1530	1508	1487	1466	1446	1426	1407	1389	1371	1353	1336	1319
11	1641	1614	1588	1563	1539	1515	1492	1470	1448	1427	1407	1387	1368	1349	1331	1313	1296	1279	1262	1246	1231
12	1532	1507	1482	1459	1436	1414	1392	1372	1351	1332	1313	1294	1276	1259	1242	1225	1209	1193	1178	1163	1149
13	1430	1407	1384	1362	1341	1320	1300	1281	1262	1244	1226	1209	1192	1176	1160	1144	1129	1115	1100	1086	1073
14	1337	1315	1294	1273	1253	1234	1215	1197	1179	1162	1146	1130	1114	1099	1084	1069	1055	1042	1028	1015	1003
15	1250	1230	1210	1191	1172	1154	1136	1119	1103	1087	1071	1056	1042	1027	1014	1000	987	974	962	949	938
16	1170	1151	1132	1114	1097	1080	1064	1048	1032	1017	1003	989	975	962	949	936	924	912	900	889	877
17	1096	1078	1060	1044	1027	1012	996	981	967	953	939	926	913	901	888	877	865	854	843	832	822
18	1027	1010	994	978	963	948	934	920	906	893	881	868	856	844	833	822	811	800	790	780	770
19	964	948	933	918	904	890	876	863	850	838	826	815	803	792	781	771	761	751	741	732	723
20	905	890	876	862	849	835	823	811	799	787	776	765	754	744	734	724	715	705	696	687	679
21	851	837	823	810	798	785	773	762	751	740	729	719	709	699	690	681	672	663	654	646	638
22	800	787	774	762	750	739	727	717	706	696	686	676	667	658	649	640	632	624	616	608	600
23	753	741	729	717	706	695	685	675	665	655	646	637	628	619	611	603	595	587	579	572	565
24	710	698	687	676	665	655	645	636	626	617	608	600	591	583	575	568	560	553	546	539	532
25	669	658	647	637	627	618	608	599	590	582	573	565	558	550	542	535	528	521	515	508	502
26	631	621	611	601	592	583	574	565	557	549	541	533	526	519	512	505	498	492	485	479	473
27	596	586	576	567	558	550	542	533	525	518	511	503	496	490	483	477	470	464	458	452	447
28	562	553	544	536	527	519	511	504	496	489	482	475	469	462	456	450	444	438	433	427	422
29	531	523	514	506	498	490	483	476	469	462	455	449	443	437	431	425	419	414	409	404	398
30	502	494	486	478	471	463	456	450	443	437	430	424	418	413	407	402	396	391	386	381	377
31	475	467	459	452	445	438	431	425	419	413	407	401	395	390	385	380	375	370	365	360	356
32	449	441	434	427	421	414	408	402	396	390	385	379	374	369	364	359	354	350	345	341	337
33	424	417	411	404	398	392	386	380	374	369	364	359	354	349	344	340	335	331	326	322	318
34	402	395	389	382	376	371	365	360	354	349	344	339	335	330	326	321	317	313	309	305	301
35	380	374	368	362	356	351	346	340	335	331	326	321	317	312	308	304	300	296	292	288	285
36	360	354	349	343	338	333	327	323	318	313	309	304	300	296	292	288	284	281	277	274	270
37	342	336	331	325	320	315	311	306	301	297	293	289	285	281	277	273	270	266	263	259	256
38	325	319	314	309	304	300	295	291	286	282	278	274	270	267	263	260	256	253	250	247	243
39	309	304	299	294	290	285	281	277	273	269	265	261	258	254	251	247	244	241	238	235	232
40	295	290	286	281	277	272	268	264	260	257	253	249	246	242	239	236	233	230	227	224	221
41	282	277	273	268	264	260	256	252	249	245	242	238	235	232	229	225	223	220	217	214	211
42	269	265	261	256	252	249	245	241	238	234	231	228	224	221	218	215	213	210	207	204	202
43	257	253	249	245	241	237	234	230	227	224	220	217	214	211	209	206	203	200	198	195	193
44	246	242	238	234	230	227	223	220	217	214	210	208	205	202	199	196	194	191	189	186	184
45	234	231	227	223	220	216	213	210	207	204	201	198	195	193	190	188	185	183	180	178	176
46	224	220	217	213	210	207	203	200	197	195	192	189	186	184	181	179	177	174	172	170	168
47	214	210	207	203	200	197	194	191	188	186	183	180	178	176	173	171	169	166	164	162	160
48	204	200	197	194	191	188	185	182	180	177	175	172	170	167	165	163	161	159	157	155	153
49	194	191	188	185	182	179	177	174	172	169	167	164	162	160	158	156	153	151	150	148	146
50	185	182	179	177	174	171	169	166	164	161	159	157	155	152	150	148	146	145	143	141	139
51	177	174	171	168	166	163	161	158	156	154	152	149	147	145	143	141	140	138	136	134	133
52	169	166	163	161	158	156	153	151	149	147	145	143	141	139	137	135	133	131	130	128	126
53	161	158	156	153	151	148	146	144	142	140	138	136	134	132	130	129	127	125	124	122	121
54	153	151	148	146	144	141	139	137	135	133	131	129	127	125	123	122	120	118	117	115	115
55	146	144	141	139	137	135	133	131	129	127	125	123	121	119	118	116	114	113	111	110	109
56	139	137	135	132	130	128	126	125	123	121	119	118	116	114	113	111	110	108	107	106	104
57	132	130	128	126	124	122	120	119	117	115	114	112	110	109	107	106	105	103	102	101	99
58	126	124	122	120	118	116	115	113	111	110	108	107	105	104	102	101	100	98	97	96	95
59	120	118	116	114	113	111	109	108	106	104	103	101	100	99	97	96	95	94	92	91	90
60	114	112	111	109	107	105	104	102	101	99	98	97	95	94	93	91	90	89	88	87	86
61	109	107	105	104	102	100	99	97	96	95	93	92	91	89	88	87	86	85	84	83	82
62	103	102	100	98	97	95	94	93	91	90	89	87	86	85	84	83	82	81	80	78	78
63	98	97	95	94	92	91	89	88	87	85	84	83	82	81	80	79	78	77	76	75	74
64	93	92	90	89	88	86	85	84	82	81	80	79	78	77	76	75	74	73	72	71	70
65	89	87	86	84	83	82	81	79	78	77	76	75	74	73	72	71	70	69	68	67	66
66	84	83	81	80	79	78	76	75	74	73	72	71	70	69	68	67	66	65	64	63	63
67	80	78	77	76	75	74	73	71	70	69	68	67	66	65	64	63	62	61	61	61	60
68	76	74	73	72	71	70	69	68	67	66	65	64	63	62	61	61	60	59	58	57	57
69	72	70	69	68	67	66	65	64	63	62	61	61	60	59	58	57	56	55	54	54	54
70	68	67	66	65	64	63	62	61	60	59	58	57	57	56	55	54	53	52	51	51	51
71	64	63	62	61	60	59	58	57	56	55	54	53	53	52	51	50	49	48	47	47	47
72	61	60	59	58	57	56	55	54	53	53	52	51	50	50	49	48	48	47	47	46	45
73	57	56	55	54	53	52	51	50	50	49	48	48	47	46	46	45	45	44	44	43	43
74	54	53	52	51	51	50	49	48	48	47	46	46	45	44	44	43	43	42	41	41	41
75	51	50	49	48	48	47	46	45	45	44	43	43	42	42	41	41	40	40	39	39	38
76	48	47	46	45	45	44	43	43	42	41	41	40	40	39	39	38	38	37	37	36	36
77	45	44	43	43	42	41	41	40	39	39	38	38	37	37	36	36	35	35	34	34	34
78	42	41	41	40	39	39	38	37	37	36	36	35									

Tables for Calculation of Sulphur Dioxide Concentration.

Daily air sample volume in cubic metres																								
V o l u m e o f 0 . 0 2 M d i S o d i u m t e t r a b o r a t e t i t r a t e d ml	1.7	1.73	1.76	1.79	1.82	1.85	1.88	1.91	1.94	1.97	2	2.03	2.06	2.09	2.12	2.15	2.18	2.21	2.24	2.27	2.3			
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0.1	8	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6			
0.2	15	15	15	14	14	14	14	13	13	13	13	13	12	12	12	12	12	12	11	11	11			
0.3	23	22	22	21	21	21	20	20	20	19	19	19	19	18	18	18	18	17	17	17	17			
0.4	30	30	29	29	28	28	27	27	26	26	26	25	25	24	24	24	23	23	23	23	22			
0.5	38	37	36	36	35	35	34	34	33	32	32	32	31	31	30	30	29	29	29	28	28			
0.6	45	44	44	43	42	42	41	40	40	39	38	38	37	37	36	36	35	35	34	34	33			
0.7	53	52	51	50	49	48	48	47	46	45	45	44	43	43	42	42	41	41	40	39	39			
0.8	60	59	58	57	56	55	54	54	53	52	51	50	50	49	48	48	47	46	46	45	45			
0.9	68	67	65	64	63	62	61	60	59	58	57	56	55	54	54	53	52	51	51	50	50			
1	75	74	73	72	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56	56	56			
1.1	83	81	80	79	77	76	75	74	73	71	70	69	68	67	66	65	65	64	63	62	61			
1.2	90	89	87	86	84	83	82	80	79	78	77	76	75	73	72	71	70	69	69	68	67			
1.3	98	96	95	93	91	90	89	87	86	84	83	82	81	80	78	77	76	75	74	73	72			
1.4	105	104	102	100	98	97	95	94	92	91	90	88	87	86	85	83	82	81	80	79	78			
1.5	113	111	109	107	105	104	102	101	99	97	96	95	93	92	91	89	88	87	86	85	83			
1.6	120	118	116	114	113	111	109	107	106	104	102	101	99	98	97	95	94	93	91	90	89			
1.7	128	126	124	122	120	118	116	114	112	110	109	107	106	104	103	101	100	98	97	96	95			
1.8	136	133	131	129	127	125	123	121	119	117	115	113	112	110	109	107	106	104	103	101	100			
1.9	143	141	138	136	134	131	129	127	125	123	122	120	118	116	115	113	112	110	109	107	106			
2	151	148	145	143	141	138	136	134	132	130	128	126	124	122	121	119	117	116	114	113	111			
2.1	158	155	153	150	148	145	143	141	139	136	134	132	130	129	127	125	123	122	120	118	117			
2.2	166	163	160	157	155	152	150	147	145	143	141	139	137	135	133	131	129	127	126	124	122			
2.3	173	170	167	164	162	159	157	154	152	149	147	145	143	141	139	137	135	133	131	130	128			
2.4	181	178	175	172	169	166	163	161	158	156	154	151	149	147	145	143	141	139	137	135	134			
2.5	188	185	182	179	176	173	170	168	165	162	160	158	155	153	151	149	147	145	143	141	139			
2.6	196	192	189	186	183	180	177	174	172	169	166	164	162	159	157	155	153	151	149	147	145			
2.7	203	200	196	193	190	187	184	181	178	175	173	170	168	165	163	161	159	156	154	152	150			
2.8	211	207	204	200	197	194	191	188	185	182	179	177	174	171	169	167	164	162	160	158	156			
2.9	218	215	211	207	204	201	197	194	191	188	186	183	180	178	175	173	170	168	166	164	161			
3	226	222	218	215	211	208	204	201	198	195	192	189	186	184	181	179	176	174	171	169	167			
3.1	233	229	225	222	218	214	211	208	205	201	198	195	193	190	187	185	182	180	177	175	173			
3.2	241	237	233	229	225	221	218	214	211	208	205	202	199	196	193	190	188	185	183	180	178			
3.3	248	244	240	236	232	228	225	221	218	214	211	208	205	202	199	196	194	191	189	186	184			
3.4	256	252	247	243	239	235	231	228	224	221	218	214	211	208	205	202	200	197	194	192	189			
3.5	264	259	255	250	246	242	238	235	231	227	224	221	217	214	211	208	205	203	200	197	195			
3.6	271	266	262	257	253	249	245	241	238	234	230	227	224	220	217	214	211	208	206	203	200			
3.7	279	274	269	265	260	256	252	248	244	240	237	233	230	227	223	220	217	214	211	209	206			
3.8	286	281	276	272	267	263	259	255	251	247	243	240	236	233	229	226	223	220	217	214	211			
3.9	294	289	284	279	274	270	266	261	257	253	250	246	242	239	235	232	229	226	223	220	217			
4	301	296	291	286	281	277	272	268	264	260	256	252	249	245	241	238	235	232	229	226	223			
4.1	309	303	298	293	288	284	279	275	270	266	262	259	255	251	248	244	241	237	234	231	228			
4.2	316	311	305	300	295	291	286	281	277	273	269	265	261	257	254	250	247	243	240	237	234			
4.3	324	318	313	307	302	297	293	288	284	279	275	271	267	263	260	256	252	249	246	242	239			
4.4	331	326	320	315	309	304	300	295	290	286	282	277	273	269	266	262	258	255	251	248	245			
4.5	339	333	327	322	316	311	306	302	297	292	288	284	280	276	272	268	264	261	257	254	250			
4.6	346	340	335	329	323	318	313	308	303	299	294	290	286	282	278	274	270	266	263	259	256			
4.7	354	348	342	336	331	325	320	315	310	305	301	296	292	288	284	280	276	272	269	265	262			
4.8	361	355	349	343	338	332	327	322	317	312	307	303	298	294	290	286	282	278	274	271	267			
4.9	369	363	356	350	345	339	334	328	323	318	314	309	304	300	296	292	288	284	280	276	273			
5	376	370	364	358	352	346	340	335	330	325	320	315	311	306	302	298	294	290	286	282	278			
5.1	384	377	371	365	359	353	347	342	336	331	326	322	317	312	308	304	299	295	291	288	284			
5.2	392	385	378	372	366	360	354	348	343	338	333	328	323	318	314	310	305	301	297	293	289			
5.3	399	392	385	379	373	367	361	355	350	344	339	334	329	325	320	316	311	307	303	299	295			
5.4	407	400	393	386	380	374	368	362	356	351	346	340	336	331	326	321	317	313	309	304	301			
5.5	414	407	400	393	387	381	374	369	363	357	352	347	342	337	332	327	323	319	314	310	306			
5.6	422	414	407	400	394	387	381	375	369	364	358	353	348	343	338	333	329	324	320	316	312			
5.7	429	422	415	408	401	394	388	382	376	370	365	359	354	349	344	339	335	330	326	321	317			
5.8	437	429	422	415	408	401	395	389	383	377	371	366	360	355	350	345	341	336	331	327	323			
5.9	444	437	429	422	415	408																		

Tables for Calculation of Sulphur Dioxide Concentration.

Daily air sample volume in cubic feet

	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
o	0.1	8	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6
l	0.2	15	15	15	14	14	14	13	13	13	13	13	13	12	12	12	12	12	12	11	11
u	0.3	23	22	22	22	21	21	20	20	20	19	19	19	19	18	18	18	18	17	17	17
m	0.4	30	30	29	29	28	28	27	27	26	26	25	25	25	24	24	24	23	23	23	23
e	0.5	38	37	36	36	35	35	34	33	33	32	32	31	31	31	30	30	29	29	29	28
	0.6	45	44	44	43	42	42	41	40	39	39	38	38	37	37	36	36	35	35	34	34
o	0.7	53	52	51	50	49	49	48	47	46	45	45	44	43	43	42	42	41	41	40	40
f	0.8	60	59	58	57	56	55	54	53	52	52	51	50	50	49	48	48	47	46	46	45
	0.9	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	54	53	52	51	51
0	1	75	74	73	72	71	70	68	67	66	65	64	63	62	61	60	59	59	58	57	57
	1.1	83	82	80	79	78	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62
0	1.2	90	89	87	86	85	83	82	81	80	79	77	76	75	74	73	72	71	70	69	68
2	1.3	98	96	95	93	92	90	89	88	86	85	84	83	82	80	79	78	77	76	75	74
0	1.4	105	104	102	100	99	97	96	94	93	92	90	89	88	87	86	84	83	82	81	80
M	1.5	113	111	109	108	106	104	103	101	100	98	97	95	94	93	92	90	89	88	87	86
	1.6	121	119	117	115	113	111	110	108	106	105	103	102	100	99	98	96	95	94	93	92
d	1.7	128	126	124	122	120	118	116	115	113	111	110	108	107	105	104	102	101	100	99	97
i	1.8	136	133	131	129	127	125	123	121	120	118	116	115	113	111	110	108	107	106	104	103
S	1.9	143	141	139	136	134	132	130	128	126	124	123	121	119	118	116	115	113	112	110	109
o	2	151	148	146	143	141	139	137	135	133	131	129	127	126	124	122	121	119	117	116	114
d	2.1	158	156	153	151	148	146	144	142	140	138	136	134	132	130	128	127	125	123	122	120
u	2.2	166	163	160	158	155	153	151	148	146	144	142	140	138	136	134	133	131	129	127	126
m	2.3	173	170	168	165	162	160	158	155	153	151	149	146	144	142	140	139	137	135	133	130
	2.4	181	178	175	172	170	167	164	162	160	157	155	153	151	149	147	145	143	141	139	137
	2.5	188	185	182	179	177	174	171	169	166	164	161	159	157	155	153	151	149	147	145	141
t	2.6	196	193	190	187	184	181	178	175	173	170	168	166	163	161	159	157	155	153	151	149
e	2.7	203	200	197	194	191	188	185	182	179	177	174	172	170	167	165	163	161	158	156	154
t	2.8	211	207	204	201	198	195	192	189	186	183	181	178	176	173	171	169	167	164	162	160
r	2.9	218	215	211	208	205	202	199	196	193	190	187	185	182	180	177	175	172	170	168	166
a	3	226	222	219	215	212	209	205	202	199	197	194	191	188	186	183	181	178	176	174	172
b	3.1	234	230	226	222	219	216	212	209	206	203	200	197	195	192	189	187	184	182	180	177
o	3.2	241	237	233	230	226	223	219	216	213	210	207	204	201	198	195	193	190	188	185	183
r	3.3	249	245	241	237	233	229	226	223	219	216	213	210	207	204	202	199	196	194	191	189
a	3.4	256	252	248	244	240	236	233	229	226	223	220	216	213	211	208	205	202	200	197	195
t	3.5	264	259	255	251	247	243	240	236	233	229	226	223	220	217	214	211	208	205	203	200
e	3.6	271	267	262	258	254	250	247	243	239	236	232	229	226	223	220	217	214	211	209	206
	3.7	279	274	270	265	261	257	253	250	246	242	239	236	232	229	226	223	220	217	214	209
t	3.8	286	282	277	273	268	264	260	256	253	249	245	242	239	235	232	229	226	223	220	215
i	3.9	294	289	284	280	275	271	267	263	259	255	252	248	245	241	238	235	232	229	226	220
t	4	301	296	292	287	283	278	274	270	266	262	258	255	251	248	244	241	238	235	232	226
r	4.1	309	304	299	294	290	285	281	277	273	269	265	261	257	254	250	247	244	241	238	232
a	4.2	316	311	306	301	297	292	288	283	279	275	271	267	264	260	257	253	250	247	243	237
t	4.3	324	319	313	309	304	299	294	290	286	282	278	274	270	266	263	259	256	252	249	243
e	4.4	331	326	321	316	311	306	301	297	292	288	284	280	276	272	269	265	262	258	255	249
d	4.5	339	333	328	323	318	313	308	304	299	295	291	286	283	279	275	271	268	264	261	257
	4.6	347	341	335	330	325	320	315	310	306	301	297	293	289	285	281	277	274	270	267	263
ml	4.7	354	348	343	337	332	327	322	317	312	308	303	299	295	291	287	283	280	276	272	266
	4.8	362	356	350	344	339	334	329	324	319	314	310	306	301	297	293	289	285	282	278	271
	4.9	369	363	357	352	346	341	336	331	326	321	316	312	308	303	299	295	291	288	284	277
5	5	377	370	365	359	353	348	342	337	332	328	323	318	314	310	305	301	297	294	290	283
	5.1	384	378	372	366	360	355	349	344	339	334	329	325	320	316	312	307	303	299	296	288
	5.2	392	385	379	373	367	362	356	351	346	341	336	331	326	322	318	313	309	305	301	298
	5.3	399	393	386	380	374	369	363	358	352	347	342	337	333	328	324	319	315	311	307	303
	5.4	407	400	394	387	381	376	370	364	359	354	349	344	339	334	330	325	321	317	313	309
	5.5	414	408	401	395	388	382	377	371	366	360	355	350	345	341	336	331	327	323	319	315
	5.6	422	415	408	402	396	389	384	378	372	367	362	357	352	347	342	337	333	329	325	320
	5.7	429	422	416	409	403	396	390	385	379	373	368	363	358	353	348	344	339	335	330	326
	5.8	437	430	423	416	410	403	397	391	386	380	375	369	364	359	354	350	345	340	336	332
	5.9	444	437	430	423	417	410	404	398	392	386	381	376	370	365	360	356	351	346	342	338
6	6	452	445	437	430	424	417	411	405	399	393	387	382	377	372	366	362	357	352	348	343
	6.1	460	452	445	438	431	424	418	412	405	400	394	388	383	378	373	368	363	358	353	349
	6.2	467	459	452	445	438	431	425	418	412	406	400	395	389	384	379	374	369	364	359	355
	6.3	475	467	459	452	445	438	431	425	419	413	407	401	396	390	385	380	375	370	365	360
	6.4	482	474	467	459	452	445	438	432	425	419	413	407	402	396	391	386	381	376	371	366
	6.5	490	482	474	466	459	452	445	439	432	426	420	414	408	402	397	392	387	382	377	372
	6.6	497	489	481	474	466	459	452	445	439	432	426	420	414	409	403	398	393	387	382	378
	6.7	505	496	488	481	473	466	459	452	445	439	433	427	421	415	409	404	398	393	388	383
	6.8	512	504	496	488	480	473	466	459	452	445	439	433	427	421	415	410	404	399	394	389
	6.9	520	511	503	495	487	480	473	465	459	452	446	439	433	427	421	415	410	4		