

Addendum Chapter.

Due to the enormity of the project to produce a manual of this quality, methods and ideas have in some areas changed since the original authors submitted their work.

In light of these changes and questions arising from the membership in relation to the assessment scheme, it was felt necessary to address these points within this document.

It is part of the ARTP ongoing commitment to education and training to make new ideas available quickly and efficiently to the membership.

The Editorial Board.

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1.1.4 Standardisation of Gas Volumes

Due to the different equations in published work, further expansion demonstrates;-

For SI users

$$V_{\text{BTPS}} = V_{\text{ATPS}} \times \left[\frac{(\text{Pb} - \text{PH}_2\text{O}_{\text{temp}})}{(\text{Pb} - 6.28)} \times \frac{310}{273 + \text{Temp}} \right]$$

Equation from berry

$$\text{PH}_2\text{O}_{\text{temp}} = 0.1333 \times (9.993 - 0.3952_{\text{temp}} + 0.03775 \text{Temp}^2)$$

$$V_{\text{STPD}} = V_{\text{ATP}} \times \left[\frac{(\text{Pb} - \text{PH}_2\text{O}_{\text{temp}})}{101.3} \times \frac{273}{273 + \text{Temp}} \right]$$

Whilst in Imperial units (ATS Guidelines Chapter 6 page 12)

$$V_{\text{BTPS}} = V_{\text{ATPS}} \times \left[\frac{(\text{Pb} - \text{PH}_2\text{O}_{\text{temp}})}{(\text{Pb} - 47.1)} \times \frac{310}{273 + \text{Temp}} \right]$$

Pb = Barometric pressure in mmHg

PH₂O = Vapour pressure at spirometer pressure

Temp = Temperature in ° C

47.1 = Vapour pressure of water at 37° C

310 = Absolute body Temperature

PH₂O_{temp} is calculated as follows

$$\text{PH}_2\text{O}_{\text{temp}} = 47.07 \times 10 \left[\frac{6.36 \times (\text{Temp} - 37)}{232 + \text{Temp}} \right]$$

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3.5 Adult and Paediatric Reference Equations

The table published missed the IVC equation this is the recommendation for measurements of Vital Capacity and yield higher numbers than the FVC equation

From Page 26 of 1993 ERS Guidelines

Table 6. — Summary equations for lung volumes and ventilatory flows for adults aged 18 -70 yrs. The lower 5 or upper 95 percentiles are obtained by subtracting or adding the figure in the last column from the predicted mean.

Variable	Unit	Regression equation	RSD	1.64RSD
Men				
IVC	<i>l</i>	6.10H - 0.028A - 4.65	0.56	0.92
FVC	<i>l</i>	5.76H - 0.026A - 4.34	0.61	1.00
TLC	<i>l</i>	7.99H - 7.08	0.70	1.15
RV	<i>l</i>	1.31H + 0.022A - 1.23	0.41	0.67
FRC	<i>l</i>	2.34H + 0.009A - 1.09	0.6	0.99
RV/TLC	%	0.39A + 13.96	5.46	9.0
FRC/TLC	%	0.21A + 43.8	6.74	11.1
FEV ₁	<i>l</i>	4.30H - 0.029A - 2.49	0.51	0.84
FEV ₁ /VC	%	-0.18A + 87.21	7.17	11.8
FEF _{25-75%}	<i>l</i> -s ⁻¹	1.94H - 0.043A + 2.70	1.04	1.71
PEF	<i>l</i> -s ⁻¹	6.14H - 0.043A + 0.15	1.21	1.99
MEF ₇₅	<i>l</i> -s ⁻¹	5.46H - 0.029A - 0.47	1.71	2.81
MEF ₅₀	<i>l</i> -s ⁻¹	3.79H - 0.031A - 0.35	1.32	2.17
MEF ₂₅	<i>l</i> -s ⁻¹	2.61H - 0.026A - 1.34	0.78	1.28
Women				
IVC	<i>l</i>	4.66H - 0.026A - 3.28	0.42	0.69
FVC	<i>l</i>	4.43H - 0.026A - 2.89	0.43	0.71
TLC	<i>l</i>	6.60H - 5.79	0.60	0.99
RV	<i>l</i>	1.81H + 0.016A - 2.00	0.35	0.58
FRC	<i>l</i>	2.24H + 0.001A - 1.00	0.50	0.82
RV/TLC	%	0.34A + 18.96	5.83	9.6
FRC/TLC	%	0.16A + 45.1	5.93	9.8
FEV ₁	<i>l</i>	3.95H - 0.025A - 2.60	0.38	0.62
FEV ₁ /FVC	%	-0.19A + 89.10	6.51	10.7
FEF _{25-75%}	<i>l</i> -s ⁻¹	1.25H - 0.034A + 2.92	0.85	1.40

PEF	$l-s^{-1}$	$5.50H - 0.030A - 1.11$	0.90	1.48
MEF ₇₅	$l-s^{-1}$	$3.22H - 0.025A + 1.60$	1.35	2.22
MEF ₅₀	$l-s^{-1}$	$2.45H - 0.025A + 1.16$	1.10	1.81
MEF ₂₅	$l-s^{-1}$	$1.05H - 0.025A + 1.11$	0.69	1.13

H: standing height (in); A: age (yr); RSD: residual standard deviation.

Between 18 and 25 yr substitute 25 yr in the equations .

PEF Mixture from (mini-)Wright peak flowmeter and pneumotachometer: more work is needed.

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3.5 Paediatric Regression Equations

Male(<162.6 cm) RV Should read: $0.00818H - 0.283$

Male (>162.5 cm) PEF Should read: $0.125H - 13.14$

Male (>162.5 cm) MEF25 Should read: $0.00074H + 0.218$

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Polynomial Regression Equations

Female TLCO Should read: $16.781H - 0.1811017H^2 + 0.0008636953H^3 - 0.0000015287H^4 - 577.13$

There is also an error in the original Rosenthal 1993 paper in Thorax

The regression equation for VA in females (which was not printed in the part I handbook) has an error in 2nd digit after the decimal place

should read $-7.669615 \cdot 10^{-7}H^4$ and NOT $-7.649615 \cdot 10^{-7}H^4$.

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4.2.1. Infrared Analyser (Carbon monoxide, Carbon dioxide, Methane and Acetylene)

Whilst this section deals with a an analyser for general use, it was felt that it would be more applicable and assist in the understanding of the principle to

describe an analyser that is specific for the measurements we make in respiratory medicine.

Principle of measurements for infrared gas analysis.

The infrared principle is non-specific and can therefore measure all the gases in the infrared spectrum.

With the twin beam analyser using a "Luft" style detector, the following applies;-

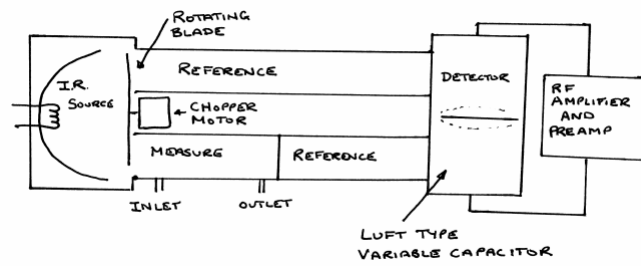
The "Luft" detector is a variable capacitor forming part of a tuned circuit. The circuit relies on the fact that gases in the infrared spectrum absorb the energy. The construction of the infrared bench is such that one tube is set as a reference and the other consists of a section that is both reference and measurement. The infrared source is then projected down each tube with a parabolic reflector. The resulting energy if equal will maintain the detector in balance, however as the infrared energy is absorbed the detector is thrown out of balance and the tuning of the circuit is altered. It is this change that is relative to the percentage of the gas.

In order to make the analyser specific for the respiratory gas analysis, the reference is made equal to 100% CO₂ therefore the small relative quantity of 5% CO₂ in exhaled breath will not impact on the measurement. This is achieved in earlier versions by filling the reference with 100% CO₂ in later designs an optical filter is used to perform the same task.

Further to this the detector body is typically filled with 100% of the gas to be measured, in the case of the carbon monoxide analyser the detector is filled with 100% CO, this ensures that the tuning of the circuit and the level of amplification is appropriate for the gas to be measured.

The signal is chopped to provide an oscillating frequency and the sample volume is a large portion of the tube compared with CO₂ to have enough signal to measure because of the low concentrations we require to measure.

The twin beam system was deployed for many years as it is extremely stable and virtually unaffected by environmental change, the 'Trade off' for this format of analyser was cost.



The modern analyser falls into two similar categories, the standard single beam analyser, this again has two groups, in the case of CO a single long sample tube is used, the infrared source is a wire round resistor that emits infrared radiation and the detector is similar to that found in the home fire alarm. The system uses an electronic zero reference and a chopper system to get the modulated output.

The second analyser in this group is for the measurement of CO₂ as in Capnography. Due to the higher concentration the sample cell can be quite small in volume reducing the physical size of the system. With this design it is popular to use a filament bulb for the infrared radiation and then to turn the bulb on and off for a chopped signal to achieve an oscillating frequency. The only requirement is that the bulb has a rapid warm up feature to ensure constant infrared each time it is switched on, this can be promoted by heating the whole unit. A gradual heating and rising infrared output would present undesirable effects.

The last analyser in this series is the rapid response infrared analyser this is similar to the single beam in the previous application. The infrared source is always on and the sample chamber is separated from the detector by rotating a disk. This disk contains multiple windows that are optical filters for the gases to be measured with one clear window as a reference.

The advanced electronic processing looks at the sequence of signals following the reference to separate out the different gases to be measured. Speed up algorithms within the associated firmware can be looking at a small section of the gas rise time to which level the gas must rise in the full rise time, this then allows the analyser to give a result in 100 milliseconds.

This type of analyser is especially useful to measure gases such as carbon monoxide, methane and acetylene and with an amplifier gain adjustment also Carbon Dioxide.

It is this form of analyser that is common use today with fast gas diffusion and intra-breath methods.

A typical diagram of the twin beam analyser is provided to assist your understanding of this principle.

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4.2.4 Ultraviolet Emission Analyzer - Nitrogen

The last paragraph on this page states:-

“A vacuum pump maintains a constant pressure in the ionisation chamber by bleeding gas through a needle valve”

To avoid confusion the term pressure can be used in the positive or negative mode. Under negative pressure (vacuum) the gas is stretched or undergoes rarefaction. In the case of the nitrogen analyser when the gas is stretched under vacuum the high electrical charge typically 1.5 – 2 Kilovolts causes the gas to ionise and emit light in the ultra violet spectrum.

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4.2.5.2. Paramagnetic Analyser – Oxygen

Many of the analysers currently in use will have a response that is in the order of 20 – 30 milliseconds. The principle of paramagnetic analysers is not limited to a slow response as was shown with the **Rapox** from Godart in the late 1960 – 1979, this had a typical response of 90 – 130 milliseconds as does the **Datex** analyser in common use today in some systems. This makes the method of analysis suitable for CPX Breath by Breath and also N₂ washout techniques.

The advantages of paramagnetic analysers is the stability and linearity which covers the range 0 – 100 %, the disadvantage is the susceptibility to water droplet damage.

Historically it was the practice to dry all gases before sampling with the aid of chemical drying agents (i.e. Calcium chloride, Drierite or silica gel – the later was ill advised due to the fact that it gives off carbon dioxide as it takes on water vapour – This could of course influence measurements.) Drying the gases is to establish the conditions in the same way that BTPS correction is applied to the volume. So if the gases are dried at calibration and at the point of measurement then the conditions match.

Drying columns were removed when the requirement moved to fast gas responses such as in breath-by-breath measurements. When the gas is in a “wet” condition its relative percentage is altered, for example 20.93% Oxygen measured at 22 degrees, 760 barometric pressure and 50% Humidity would be actually 20.65% in its wet condition. This was discussed in the works of Alan Norton and published from Beckman Instruments with the first commercial breath-by-breath systems for CPX testing.

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4.3.2. Calibration and Verification

The minimal requirement for a quality performance test is a two point calibration. In the case of the gas analysers it is desirable to address the full working range, that is the defining 1) a zero point and 2) a full scale deflection. However, in practice we use **room air** as the base point and **a known gas mixture** as the alternate point. In the case of oxygen this would typically represent a change of 20.94% to 18%, in voltage terms this may only be 1.8 – 2.94 volts on a 10 volt system and would result in a very poor resolution, so usually an oxygen analyser is only checked on a daily basis with the full calibration being from 18% to 100% to give a voltage swing of 1.8 to 10 volt and hence higher resolution. This check is essential and should be performed routinely and at the very minimum by the engineer on the annual service visit.

To set zero with an oxygen analyser white spot nitrogen should be used or alternatively 100% Helium which may be more readily available, however in the case of the latter the zero will only achieve 0.04 in typical operation.

In the event of a problem then it is essential to perform a multipoint calibration either with known gas mixtures or by serial dilution. For the latter a bag of a known gas mixture is taken and then diluted in stages with diluents such as room air or white spot nitrogen. The results then displayed as a table or graph, in the case of carbon monoxide and helium the following describes an ideal table.

Helium	Carbon Monoxide
14	0.280
12	0.240
10	0.200
8	0.160
6	0.120

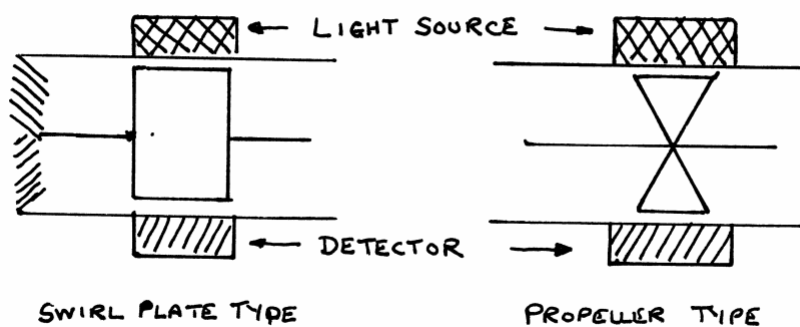
This demonstrates a linear response.

5.4.2 – Rotating vane devices.

These devices fall into two types, the most common in spirometer design is a flat blade that cuts two light sources to indicate a full revolution. The mean number of rotations are directly related to the volume that passes through. There are algorithms to make a calculation for the initial inertia to start spinning and then to allow the overrun at the end of the volume excursion. In order to get the blade to rotate the air is passed through a swirl plate to cause a turbulent flow.

In the case of the second type the flat blade is replaced with a propeller blade, this avoids the need for a swirl plate as the propeller will naturally rotate in an airflow following the screw principle.

With a flat blade version in order to obtain bi-directional operation the device must have opposite swirl plates at each end. The Triple V is a particular type of turbine used in the Oxycon, K4 and Quark instruments. This has a special arrangement of swirl plates with minimal number of inserts to keep the resistance very low whilst creating a rotation.



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7.3.11 Steady State Helium Dilution.

This method employs Boyle's law, so an initial known volume of a known partial pressure (% gas) is prepared in a closed circuit. The initial volume is the product of the known volume plus any system dead-space up to the point that the subject is connected.

When the subject is connected to the system, the circuit volume is maintained at the FRC Breathing level, this is accounting for CO₂ being scrubbed from the circuit and an equal volume of oxygen then added bring the system back to the FRC level. This ensures the subject is comfortable and will not hyperventilate.

The FRC level is set by a period of quiet breathing during which time the subject is instructed in breathing correctly and sitting correctly.

As the subject breathes from the closed system the air contained in the lungs dilutes the original partial pressure (%gas), as the volume of the circuit is constant the change in pressure should represent the volume, the difference between the start circuit volume and the final volume is the Functional Residual Capacity (FRC)

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8.5 – Diffusion Calculations

In the traditional calculations all readings were taken directly from the volume device (Kymograph paper) at Ambient Temperature Pressure ATP conditions therefore:-

$$V_A = (V_{\text{insp ATP}} - V_{\text{dead ATP}}) \times \frac{F_{\text{insp He}}}{F_{\text{alveolar He}} \times 0.95} \times \text{BTPS factor}$$

However on computerised systems the volume is already presented on screen at BTPS conditions, when this is the case all volumes should be

reported at the BTPS condition and further correction of the result is not required.

$$V_A = (V_{\text{insp BTPS}} - V_{\text{dead BTPS}}) \times \frac{F_{\text{insp He}}}{F_{\text{alveolar He}} \times 0.95} .$$

As discussed in the full text the 0.95 correction is only necessary when the CO₂ has been removed in the analysis circuit by chemical absorbers.

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Because of the previously mentioned confusion over the reporting of V_A it is essential that we respect the way in which the V_A is introduced to the equation. The equations should be used as follows to avoid confusion.

Equation 8.10

$$T_{\text{LCO}} = \left[(V_{\text{insp ATP}} - V_{\text{dead ATP}}) \times \frac{F_{\text{insp He}}}{F_{\text{alveolar He}} \times 0.95} \right] \times \text{BTPS} \cdot \left[\frac{53.6}{t} \times \log_{10} \right] \frac{F_i \text{CO}}{F_a \text{CO}} \times \frac{F_a \text{He}}{F_i \text{He}}$$

Or

$$T_{\text{LCO}} = \left[(V_{\text{insp BTPS}} - V_{\text{dead BTPS}}) \times \frac{F_{\text{insp He}}}{F_{\text{alveolar He}} \times 0.95} \right] \cdot \left[\frac{53.6}{t} \times \log_{10} \right] \frac{F_i \text{CO}}{F_a \text{CO}} \times \frac{F_a \text{He}}{F_i \text{He}}$$

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This rule also applies to equation 8.11 where the 53.6 factor is adopted.

$$T_{\text{LCO RB}} = (V_{\text{bag ATP}}) \times \left[\frac{F_{\text{insp He}}}{F_{\text{alveolar He}} \times 0.95} \right] \times \text{BTPS} \cdot \left[\frac{53.6}{t} \times \log_{10} \right] \frac{F_i \text{CO}}{F_a \text{CO}} \times \frac{F_a \text{He}}{F_i \text{He}}$$

Or

$$T_{\text{LCO RB}} = (V_{\text{bag BTPS}}) \times \left[\frac{F_{\text{insp He}}}{F_{\text{alveolar He}} \times 0.95} \right] \cdot \left[\frac{53.6}{t} \times \log_{10} \right] \frac{F_i \text{CO}}{F_a \text{CO}} \times \frac{F_a \text{He}}{F_i \text{He}}$$

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Equation 8.12 should be interpreted as;-

$$T_{LCO\ EX} = V_{E\ BTPS} \times 28.19 \times \frac{\log_e \frac{F_A / F_{A,O_2}}{V_A / V_{A,O}}}{\log_e \frac{F_A / F_{A,O_2}}{V_A / V_{A,O}}}$$

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8.11 Quality Control and Infection Control (Transfer Factor)

Some physiological reasons for error that can influence the measurement to be observed are;

- Elevated Cardiac Output
- Elevated Heart rate
- Change in Capillary blood volume
- Change in Alveolar pressure
- Lung bleeding or other open blood source