3627

HSE
Health & Safety
Executive

OFFSHORE TECHNOLOGY REPORT - OTO 98 146

Demand Regulators Surface Bench Tests

Date of Issue :November 1998 *Health & Safety Executive*

TO DETERMINE THE EFFECTIVENESS OF SURFACE BENCH TESTS TO DEFINE THE DEPTH PERFORMANCE OF DEMAND REGULATORS

PREPARED FOR:

Health & Safety Executive
Offshore Safety Division
Rose Court
2 Southwark Bridge
London
SE1 9HS

☎ (0171) 717 6000
Fax (0171) 717 6717

PREPARED BY:
I.A.Himmens
ANSTI Test Systems Ltd
7 Brunel Way
Fareham
Hampshire
PO15 5TX

☎ (01489) 575228
Fax (01489) 575229

1. ISSUE RECORD

ISSUE	CHANGE	Authorised	DATE
1	AS ISSUED		24 July 1998

2. SUMMARY

ANSTI TEST SYSTEMS LTD was contracted by the HEALTH & SAFETY EXECUTIVE, Offshore Safety Division, Agreement : D 3627 to undertake a study to determine whether surface bench tests could define the depth performance of demand regulators.

The results of the breathing simulator tests clearly showed that commonly used surface bench test techniques cannot define a demand regulators depth performance. Extending these bench tests to include measurement of a steady state flow, equivalent to the average (Ventilation) flow of 62.5 $l.min^{-1}$ at depth, still did not permit any meaningful estimate of a demand regulator's depth performance.

A theoretical assessment of flow requirements suggested that a surface flow test should be based on determining a peak flow not an average flow. ANSTI therefore devised a test to measure the maximum air flow a demand regulator was capable of delivering whilst at atmospheric pressure.

The results from a sample of 10 (different) demand regulators, suggested that there is a strong link between maximum surface flow capability and depth performance. However, with such a small sample size and the wide variability of results, no attempt was made to establish a general mathematical relationship.

The application of the test identified a number of practical problems. The most significant of which caused a severe mechanical failure in one of the demand regulators. Most importantly had the failure remained undetected it may have led to a potentially serious diving incident, obviously bringing into question the efficacy of the test. However, the problems were not considered to be excessively difficult or prohibitively expensive to overcome.

Overall it is considered that the development of a maximum surface flow test would present the possibility of significant improvements to determining the effectiveness of the service and repair of demand regulators. The relatively low capital investment cost of a maximum flow test system compared to a breathing simulator based system may promote it's wider acceptance within the diving industry.

3. CONTENTS

4. INTRODUCTION

4.1 The objective of the study is to determine the effectiveness of surface bench tests to define the depth performance of demand regulators. Ansti Test Systems Ltd conducted the study on behalf of the Heath and Safety Executive, Offshore Safety Division, under Agreement : D 3627, Dated 30 January 1998.

4.2 The accepted practice within the diving industry is to refer to the depth of a dive rather than pressure. The report therefore refers to depth which is expressed in metres of sea water (msw)

4.3 The Depth Performance of a demand regulator, is for the purposes of this study, based on the tests and acceptance criteria specified in the European Standard for SCUBA [1,2] and the Department of Energy Guidelines [3]. The test is defined as the maximum depth to which a demand regulator will, when supplied with air at a pressure of 50 bar and breathed at a ventilation of 62.5 $l.min^{-1}$ remain within the maximum physiological limits for Inhalation / Exhalation Pressure ($\pm$ 25 mbar) and External Work of Breathing (3.0 J/l).

4.4 Laboratory tests were conducted on 10, two stage, demand regulators manufactured before and after the Personal Protective Equipment (EC Directive) Regulations implementation date of 30 June 1995[4].

Contents

5. SCOPE OF WORK

5.1 Conduct a literature search for information on the effectiveness of surface bench tests to define the depth performance of demand regulators. To review a number of demand regulator manufacturers' authorised Service and Repair Manuals.

5.2 To undertake laboratory measurements of demand regulator performance using recommended surface bench test procedures and dynamic (breathing) performance test techniques at simulated depth. Specific points raised in the discussion will be illustrated with graphs and Pressure - Volume diagrams recorded during the test programme.

5.3 The dynamic performance tests to be conducted with the demand regulator immersed in fresh water at a temperature of 10°C and retained as though the diver's head is in the upright position. The breathing simulator is to be set to ventilation rates of 15.0 and 62.5 $l.min^{-1}$. The chamber is to be pressurised from the surface to pressures equivalent to depths of 10, 30 and 50 msw.

5.4 Parameters to be measured / calculated :

- High pressure supply
- Inter-stage pressure (First Stage Output pressure)
- Mouth pressure
- Ventilation
- Flow
- External work of breathing
- Peak Inhale pressure
- Peak Exhale pressure
- Depth
- Water Temperature

Contents

6. PROCEDURES

Depth Performance Tests

6.1 The ANSTI test facility was specifically designed to test the dynamic (breathing) performance of demand regulators in accordance with the requirements of EN250, the European Standard for SCUBA. The facility comprises stainless steel breathing simulator and test chamber assemblies linked to a computerised instrumentation and data acquisition system. A cylinder valve with known performance (pressure drop) was connected via the quick release lid assembly to an external air source. The demand regulator first stage was connected to the cylinder valve and supplied with air at a constant pressure of 50 bar. The demand valve (second stage) was connected to the breathing simulator and breathed at the ventilation rates specified. The chamber was pressurised to each of the test depths and data recorded via the computer system. The results were printed in the form of test certificates which showed the conditions of test, calculated results and the associated Pressure - Volume (P-V) Diagram. Prior to each test programme the system was prepared and calibrated in accordance with ANSTI's ISO 9001 Quality Assurance Procedures [5].

6.2 A Pressure-Volume diagram is generated by continuously plotting the variation in mouth pressure occurring within the demand valve, with the corresponding displaced volume of the breathing simulator. The P-V diagram shown in Figure 1, illustrates the typical response of a demand regulator. Mouth pressure is measured with a sensitive differential pressure transducer referenced to the air space above the immersed equipment. The zero reference point is unique to each demand regulator and the depth of immersion. It therefore has to be measured prior to each test. The zero in all cases is denoted by the horizontal (Volume) axis line of P-V diagram. Inhalation is indicated by a reduction in mouth pressure below the zero line and begins on the right hand side of the diagram. The plotted points traverse in a clockwise direction. Exhalation begins on the left hand side and is indicated by an increase in mouth pressure above the horizontal axis. The area bounded by the diagram is proportional to external work of breathing and computed for each printed test cycle.

6.3 The chamber depth was increased gradually until the demand regulator exhibited a decrease in performance to the EN250 limiting values or reached a test depth of 50 m.

Contents

Surface Bench Tests

6.4 The test specifications for the conduct of surface bench tests of demand regulators are contained in the Service and Repair Manuals supplied by the manufacturer. A selection of these manuals were therefore reviewed and the data used to ensure that the surface bench tests were valid.

6.5 Generally, the parameters to be measured with a surface test bench were limited to the high pressure supply and inter-stage pressure. Hence, no specific information on the type or construction of a test bench was available. A surface test bench was therefore assembled, using instrumentation with traceable calibrations, to allow the accurate measurement of manufacturers' recommended parameters of supply pressure, inter-stage pressure and mouth pressure.

6.6 After completing these tests a flow meter and high flow vacuum system was added to allow the measurement of demand flow. An inline control valve enabled the demand flow to be varied within the range of 100 - 1200 $l.min^{-1}$. It became evident during these tests that some demand regulators caused wide fluctuations of mouth pressure which would prevent the acquisition of reliable data.

6.7 To overcome this problem the ANSTI Test Facility computerised data acquisition system was re-configured to allow capture of these wide fluctuations and to present them in a manner that would allow valid comparisons. The demand regulator was connected to a 50 bar supply, and the second stage connected to the inlet of the flow meter. The demand flow was gradually increased until a limiting mouth pressure of 25 mbar below ambient was reached. The 25mbar pressure represents a maximum physiological limit for the human respiratory system and is also used as the maximum limit for the inhalation / exhalation pressures in the European Standard for SCUBA, EN250. The computer accurately recorded the variations in mouth pressure during each flow test and thus enable the data to be printed in a similar manner to that of the depth performance test. The observed flows were entered into the computer system, manually and printed in the Remarks section of the Test Certificate.

Contents

7. RESULTS and DISCUSSION

7.1. The preliminary results of the literature search indicated that although depth performance information was now more readily available from the public domain, ie dive magazine articles etc. no references specifically linking depth performance with surface bench tests could be found. The emphasis was therefore changed to reviewing authorised Service and Repair Manuals for two stage demand regulators manufactured before and after 30 June 1995. The manuals are considered important because they contain all of the detailed information a technician would require to ensure that a demand regulator was serviced correctly and to ultimately judge whether it is fit for diving.

7.2. Five manufacturers Service and Repair Manuals were reviewed and particular attention paid to the technical specifications and surface bench test requirements. Obviously, all of the manuals specified the critical parameters of cylinder pressure, corresponding first stage output (inter-stage) pressure with tolerance limits. The information for the second stage regulator, however, consisted primarily of adjustment lever heights and the detection / prevention of air leaks. Only one manufacturer provided a specification for steady state surface flow and corresponding mouth pressure. Otherwise, tuning the complete demand regulator assembly was generally limited to specifying a subjective assessment of inhalation resistance. Importantly, none of the manuals were found to contain any information correlating the results of the surface bench tests to the demand regulators depth performance. The lack of information in this area clearly suggest that it would not be possible to define the demand regulators depth performance from the results of these basic tests.

7.3. The depth performance of a demand regulator is currently defined using breathing simulators to generate inhalation and exhalation flows whilst the demand regulator is immersed at hyperbaric pressures. Unlike humans, the breathing simulator has an unsympathetic response to the failure of a demand regulator to meet the inhalation flow demand. The P-V diagram, shown in Figure 2, illustrates this effect by showing how, at the point of failure, the mouth pressure drops steeply below the 25 mbar limiting line. The breathing simulator test is therefore a particularly accurate method of defining the limiting depth performance of demand regulators.

7.4. If the response in Figure 2 is studied in detail, it is apparent that the failure is caused by the inability of demand regulator to meet the instantaneous peak flow demand at that point of the inhale (demand) cycle. A theoretical assessment of the flow generated by a sinusoidal breathing simulator during one half cycle shows that it varies between zero and a maximum or peak value equivalent to π x Ventilation, where Ventilation represents the average flow.

Contents

7.5. If the ventilation remains constant and the simulated depth is increased then the volume of air consumed per cycle varies directly as a function of the increase in ambient pressure. At it's simplest level, the surface flow required to meet the inhalation demand varies as a function of Boyle's Law and may be calculated by the formula :

$$\text{Average Flow}_{(surface)} = \text{Ventilation x Pressure}_{(absolute)} \text{ l.min}^{-1}$$

7.6. Similarly, the theoretical peak or maximum AIR flow at the surface may be calculated by the formula

$$\text{Maximum Flow}_{(surface)} = \pi \text{ x Ventilation x Pressure}_{(absolute)} \text{ l.min}^{-1}$$

7.7. It is therefore important to consider air flow in terms of peak rather than average flow. Experiments were undertaken to determine the maximum surface flow a demand regulator was capable of supplying whilst maintaining a mouth pressure, below ambient, of 25 mbar or less. The results were then compared to the maximum depth performance achieved by the same demand regulator when breathed at a ventilation of 62.5 l.min^{-1}. The results of both tests for each demand regulator are shown in Figures 3 - 11, respectively. The results for maximum surface flow and corresponding maximum depth performance were combined and plotted on the Surface flow v Depth graph shown in Figure 12. It is important to note that the tests at the lowest ventilation of 15.0 l.min^{-1} were considered to be ineffective because they were unable to identify demand regulators that had failed during the high ventilation test at shallower depths. Although recorded, the results have not been presented in this report.

7.8. As shown above, it is logical to assume that during inhalation a demand regulator will be required to deliver an equivalent surface flow varying from zero to the theoretical peak flow for each depth. As test systems are not perfect and the calculations may be too simplistic, it is also reasonable to assume the maximum flow capability of a demand regulator will lay between the average and theoretical peak flow, for it's particular maximum depth performance. The results indicated only one demand regulator achieved a maximum surface flow of 93% of it's theoretical peak value. The remaining demand regulators achieved maximum surface flows ranging between 69% to 82% of their respective theoretical peak values. It is clear that the variation in depth performance is due to the design and dynamic response characteristics of individual demand regulators. This is illustrated by the results in general and by three demand regulators in particular. These produced similar maximum surface flows (660-680 l.min^{-1}) but widely varying depth performances (26 - 41 msw).

7.9. Three demand regulator achieved depth performances of at least 50msw and all recorded maximum surface flows in excess of 900 $l.min^{-1}$, some 77% - 82% of their theoretical peak flows.

7.10. The significance of this latter relationship is that all the demand regulators were manufactured after 1995 and were all CE type approved. The other 6 demand regulators were either manufactured before 1995 and/or were not CE type approved.

7.11. The last demand regulator, manufactured after 1995 and CE type approved, suffered a severe mechanical failure as a direct result of the maximum surface flow test. The second stage began to resonate as the demand flow increased beyond 300 $l.min^{-1}$, reaching a maximum 580 $l.min^{-1}$. The resonance suddenly stopped and the flow jumped to 980 $l.min^{-1}$ which was consistent with the previously tested CE approved regulators. The reason for the sudden change only became apparent during a subsequent breathing performance test. The evidence suggests that the resonance was of such magnitude that the inlet valve actuating lever punched out the retaining webs of the non-return valve holder. The complete assembly fell into the enclosed space of the exhaust deflector. Importantly, the serious nature of the fault only became evident during the breathing simulator tests. Had this fault remained undetected, it may have led to a potentially serious diving incident. Obviously bringing into question the efficacy of the maximum surface flow test. The tests also highlighted potential problems with the instrumentation and the ability to take accurate readings. However, these problems are not considered to be excessively difficult or prohibitively expensive to resolve. One other practical issue that would need to be considered is related to air consumption. In order to obtain reliable information the tests took approximately 2 minutes and between 1200 - 1900 litres of air to complete.

7.12. The maximum surface flow test, derived by ANSTI , has raised a dichotomy. There is evidence to show that the test cannot accurately define the depth performance of demand regulators. Yet there also is evidence to suggest a strong link exists between a demand regulators maximum surface flow capability and it's corresponding depth performance. It must be accepted that the breathing simulator test is, at present, the only method capable of accurately defining a demand regulator's depth performance. However, the capital investment cost for this type of equipment is high, typically in the region of £20,000. The surface maximum flow test has considerable potential for further development as a depth performance indicator for demand regulators. The capital investment costs would be significantly lower, estimated to be in the region of £2,500 for a basic unit, rising to approximately £6,000 for a computerised system. However, to be an effective tool though, it would be extremely important to provide the user with model specific flow /depth performance correlation data. The availability of a cheaper alternative to the breathing simulator may then promote it's wider use within the diving industry.

7.13. The information obtained from the tests suggests a general mathematical relationship between maximum surface flow and depth performance may be derived. However, a significantly larger sample size, including several regulators of the same model, would be required to explore this further.

Contents

8.0 CONCLUSIONS

8.1 The surface bench tests for demand regulators specified in five randomly selected manufacturers' Service and Repair manuals, involved setting the inter-stage pressure at specific cylinder pressures and completing a subjective assessment of the second stage inhalation resistance. Only one manual contained a specification for surface flow and corresponding mouth pressure. Otherwise, none of the manuals attempted to predict a demand regulators depth performance from the surface test data. The lack of information in this area clearly suggest that it would not be possible to define the demand regulators depth performance from the results of these basic tests.

8.2 More complex surface bench tests additionally measuring surface flows equivalent to the average (Ventilation) flow of 62.5 $l.min^{-1}$ at depth and corresponding mouth pressure are also ineffective for predicting depth performance.

8.3 At present the only accurate method of defining a demand regulators depth performance is to use breathing simulator tests at hyperbaric pressures.

8.4 An assessment of surface flow required to achieve a specific depth performance with a sinusoidal demand cycle suggested that it is important to consider peak rather than average flows.

8.5 Promising results were achieved when ANSTI devised a surface peak flow test. This test defined the maximum flow the demand regulator was capable of delivering whilst maintaining the maximum physiological mouth pressure limit of -25 mbar. Although it was not considered, at this stage, sufficiently precise to define a depth performance, the results clearly showed a strong link between maximum surface flow and the corresponding limiting depth performance. Due to the small sample size and the variability of the results no attempt was made to define a mathematical relationship between surface maximum flow and depth performance. Otherwise the results suggested that the demand regulators, in the small sample tested, fell into two groups. The first group were not CE type approved and achieved depth performances in the range of 26 m and 48 m with maximum flows of between 660 to 820 $l.min^{-1}$. The second group were CE type approved and achieved surface flows in excess of 900 $l.min^{-1}$ with corresponding depth performances of at least 50 msw.

8.6 The efficacy of the maximum flow test was brought into question when a demand regulator suffered a severe mechanical failure which, if it had remained undetected, may have lead to a potentially serious diving incident. Whilst this and other practical aspects need to be addressed, they were not considered to be excessively difficult or prohibitively expensive to overcome.

8.7 To ensure that the surface maximum flow test is used effectively it is extremely important to provide the technician with demand regulator type specific flow / depth performance correlation data.

8.8 Viewed within the overall context of the small sample size and wide variations observed, the surface maximum flow test has significant potential to be developed as a cost effective depth performance indicator. The lower costs compared to a breathing simulator system may promote it's wider use within the diving industry.

9. RECOMMENDATIONS

9.1 The performance of serviced / repaired demand regulators should be assessed by a quantitative measurement technique. The technique should either be based on:

i) A hyperbaric breathing simulator system which will allow the depth performance of a demand regulator to be accurately measured

or

ii) A surface maximum flow test which when compared to model specific type test data will show that the flow / performance has been properly re-established.

10. REFERENCES

1. Respiratory equipment - Open-circuit self-contained compressed air diving apparatus - Requirements, testing, marking , EN 250 : 1993.

2. Respiratory equipment - Open-circuit self-contained compressed air diving apparatus - Requirements, testing, marking , prEN 250 : 1997.

3. Guidelines for the evaluation of breathing apparatus for use in manned underwater operations in the petroleum activities. Norwegian Petroleum Directorate / Department of Energy, 1991. ISBN 81-7257-308-3.

4. Guidance Document on the UK Regulations (the Personal Protective Equipment (EC Directive) Regulations S.I. 1992/3139) implementing Council Directive 89/686/EEC as amended by the Personal Protective Equipment (EC Directive) (Amendment) Regulations S.I. 1993/3074 implementing Council Directive 93/95/EEC and the Personal Protective Equipment (EC Directive) (Amendment) Regulations 1994 S.I. 1994/2326 implementing Council Directive 93/68/EEC as it relates to PPE.

5. System function and Calibration Checklist, Ansti Test Systems Ltd, ISO 9001 Quality Assurance Form F425/01, Issue 1, December 1996.

FIGURE 1

EXAMPLE PRESSURE VOLUME (PV) DIAGRAM

DEMAND REGULATOR PERFORMANCE

– ANSTI ———— ANSTI ———— ANSTI –

CERTIFICATE REFERENCE :

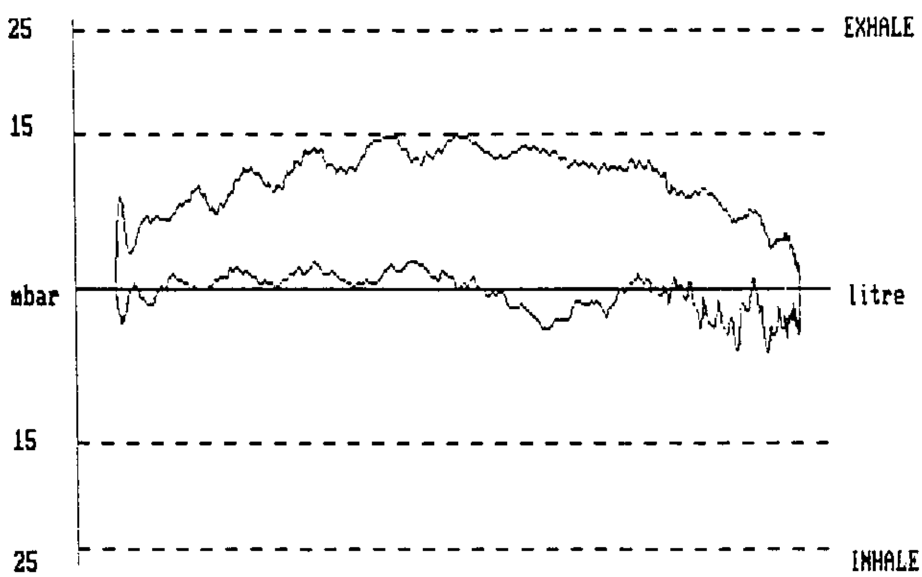
DATE : 15-05-1998 TIME : 10:39:42

EQUIPMENT
REGULATOR TYPE :
SERIAL NUMBER :
INTERSTAGE PRESSURE : 9.9 bar.g (STATIC/SURFACE)

CONDITIONS OF TEST
ROOM TEMPERATURE : 21.0 C
WATER TEMPERATURE : 14.0 C
HP SUPPLY PRESSURE : 55 bar.g (STATIC/SURFACE)
TIDAL VOLUME : 2.50 litre BREATH RATE : 25.16 bpm
VENTILATION RATE : 63.0 lpm

RESULTS
INHALE PRESSURE = 6.28 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE = 2.85 mbar (LIMIT = 5 mbar)
EXHALE PRESSURE = 15.02 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING = 1.17 J/l (LIMIT = 3.0 Joules/litre)
INHALE WORK = 0.10 J/l
POS INHALE WORK = 0.06 J/l (LIMIT = 0.3 Joules/litre)
EXHALE WORK = 1.07 J/l

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 50.8 msw (167 fsw)



REMARKS :

———— ANSTI ————

Contents

FIGURE 2

TYPICAL INHALATION FAILURE RESPONSE P-V DIAGRAM

DEMAND REGULATOR PERFORMANCE

- ANSTI ——— ANSTI ——— ANSTI -

CERTIFICATE REFERENCE :

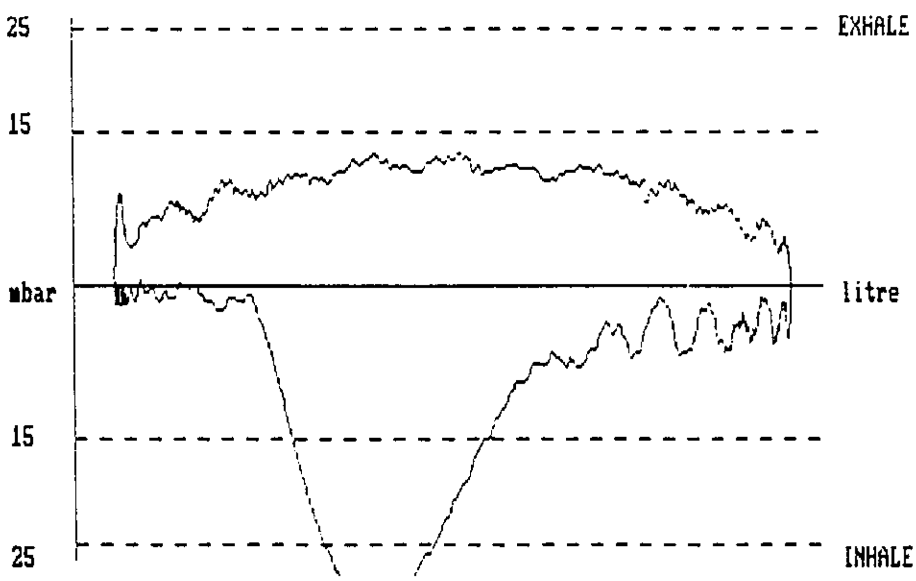
DATE : 18-03-1998 TIME : 17:02:52

EQUIPMENT
REGULATOR TYPE :
SERIAL NUMBER :
INTERSTAGE PRESSURE : 9.8 bar.g (STATIC/SURFACE)

CONDITIONS OF TEST
ROOM TEMPERATURE : 20.0 C
WATER TEMPERATURE : 11.0 C
HP SUPPLY PRESSURE : 50 bar.g (STATIC/SURFACE)
TIDAL VOLUME : 2.50 litre BREATH RATE : 24.98 bpm
VENTILATION RATE : 62.5 lpm

RESULTS
INHALE PRESSURE = 31.33 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE = 0.98 mbar (LIMIT = 5 mbar)
EXHALE PRESSURE = 13.16 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING = 2.02 J/l (LIMIT = 3.0 Joules/litre)
INHALE WORK = 1.06 J/l
POS INHALE WORK = 0.00 J/l (LIMIT = 0.3 Joules/litre)
EXHALE WORK = 0.97 J/l

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 35.6 msw (117 fsw)



REMARKS :

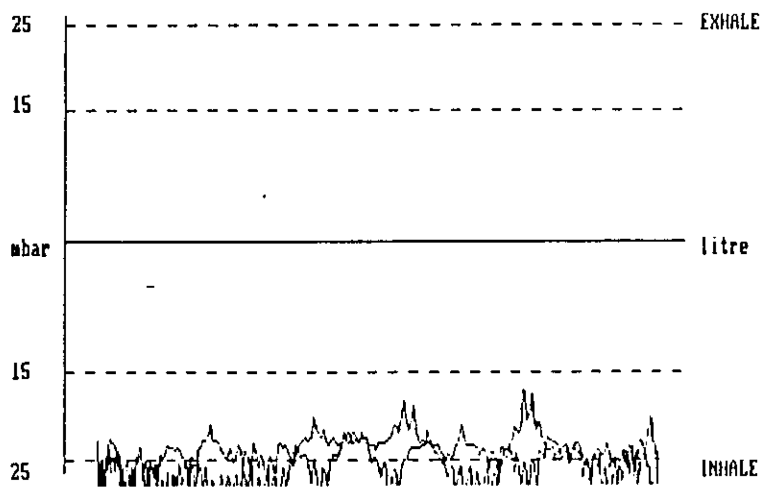
——— ANSTI ———

Contents

MAXIMUM SURFACE FLOW

```
INHALE PRESSURE        =  32.90 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE    =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE        =   0.00 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING  =   2.50 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK        =   2.50 J/l
POS INHALE WORK        =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK        =   0.00 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : -0.3 msw (-1 fsw)



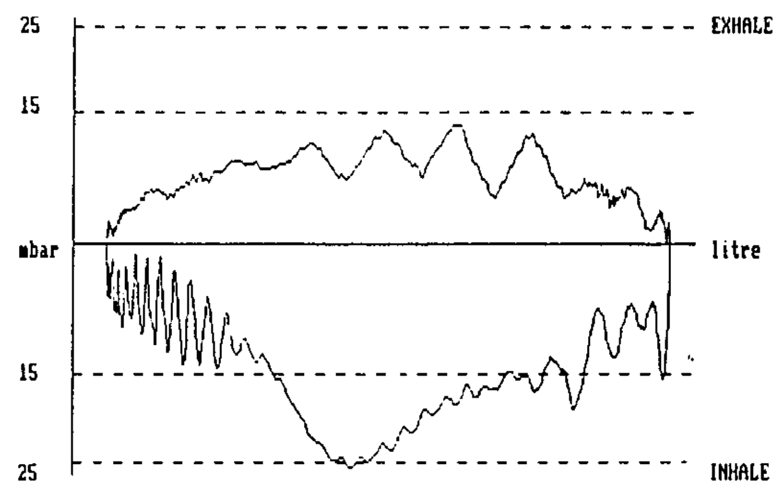
REMARKS : 660 LPM /47 bar

ANSTI

DEPTH PERFORMANCE

```
INHALE PRESSURE        =  26.12 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE    =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE        =  13.75 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING  =   2.30 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK        =   1.50 J/l
POS INHALE WORK        =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK        =   0.81 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 26.1 msw (86 fsw)



REMARKS : IMMERSED /HEAD UPRIGHT /CP 47 BAR

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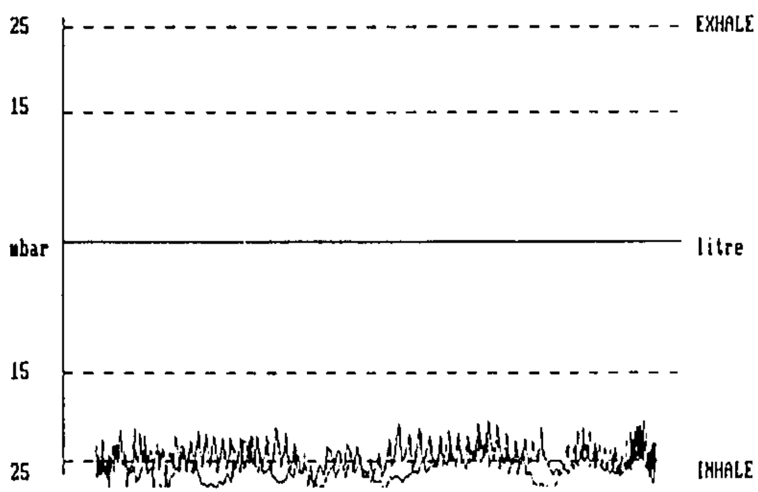
FIGURE 3

Contents

MAXIMUM SURFACE FLOW

INHALE PRESSURE	=	28.97 mbar	(LIMIT = 25 mbar)
INHALE POS PRESSURE	=	0.00 mbar	(LIMIT = 5 mbar)
EXHALE PRESSURE	=	0.00 mbar	(LIMIT = 25 mbar)
EXT WORK OF BREATHING	=	2.53 J/1	(LIMIT = 3.0 Joules/litre)
INHALE WORK	=	2.53 J/1	
POS INHALE WORK	=	0.00 J/1	(LIMIT = 0.3 Joules/litre)
EXHALE WORK	=	0.00 J/1	

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 0.0 msw (0 fsw)



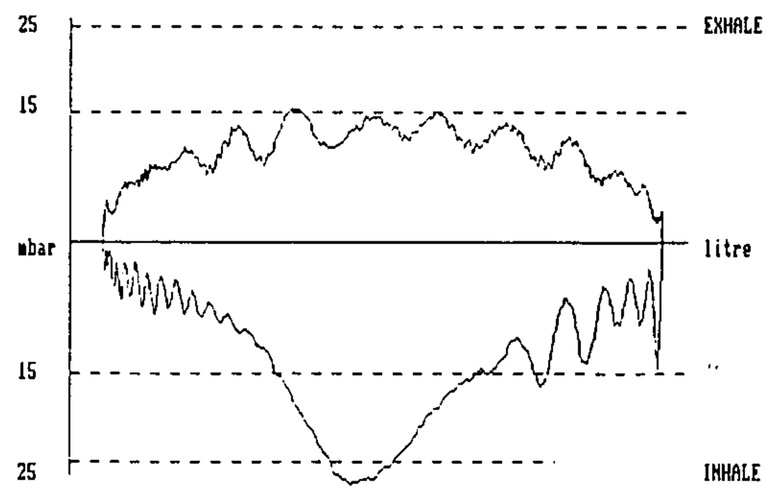
REMARKS : 6801pm/SURFACE/DRY

ANSTI

DEPTH PERFORMANCE

INHALE PRESSURE	=	28.08 mbar	(LIMIT = 25 mbar)
INHALE POS PRESSURE	=	0.00 mbar	(LIMIT = 5 mbar)
EXHALE PRESSURE	=	15.61 mbar	(LIMIT = 25 mbar)
EXT WORK OF BREATHING	=	2.44 J/1	(LIMIT = 3.0 Joules/litre)
INHALE WORK	=	1.38 J/1	
POS INHALE WORK	=	0.00 J/1	(LIMIT = 0.3 Joules/litre)
EXHALE WORK	=	1.06 J/1	

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 34.9 msw (115 fsw)



REMARKS : IMMERSED/HEAD UPRIGHT

ANSTI

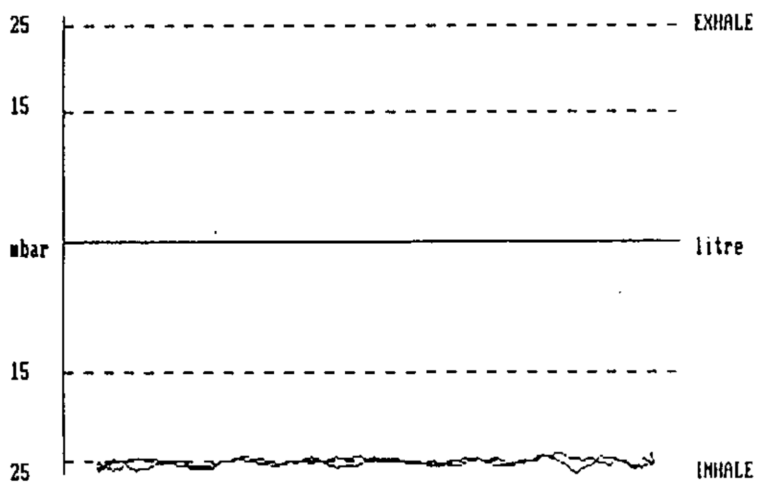
FIGURE 4

Contents

MAXIMUM SURFACE FLOW

INHALE PRESSURE = 26.91 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE = 0.00 mbar (LIMIT = 5 mbar)
EXHALE PRESSURE = 0.00 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING = 2.56 J/l (LIMIT = 3.0 Joules/litre)
INHALE WORK = 2.56 J/l
POS INHALE WORK = 0.00 J/l (LIMIT = 0.3 Joules/litre)
EXHALE WORK = 0.00 J/l

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 0.0 msw (0 fsw)

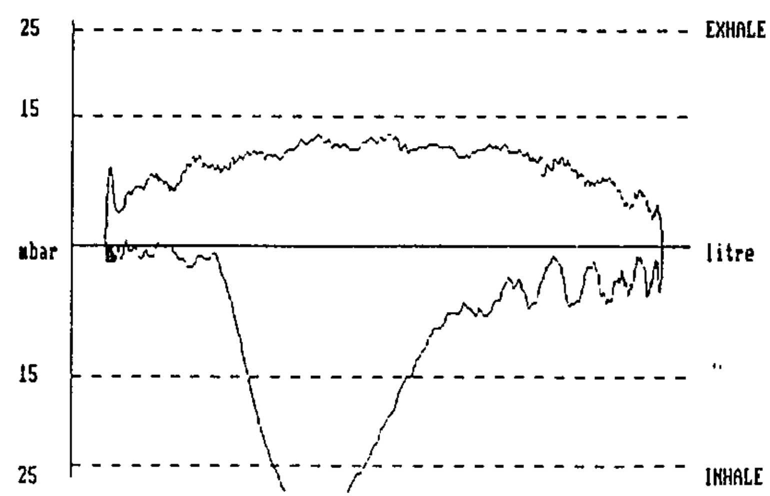


REMARKS : 720 lpm / INT 7.55 BAR /CP 49.3 BAR
ANSTI

DEPTH PERFORMANCE

INHALE PRESSURE = 31.33 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE = 0.98 mbar (LIMIT = 5 mbar)
EXHALE PRESSURE = 13.16 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING = 2.02 J/l (LIMIT = 3.0 Joules/litre)
INHALE WORK = 1.06 J/l
POS INHALE WORK = 0.00 J/l (LIMIT = 0.3 Joules/litre)
EXHALE WORK = 0.97 J/l

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 35.6 msw (117 fsw)



REMARKS : IMMERSED/HEAD UPRIGHT/TURBO 6/MAX SENS
ANSTI

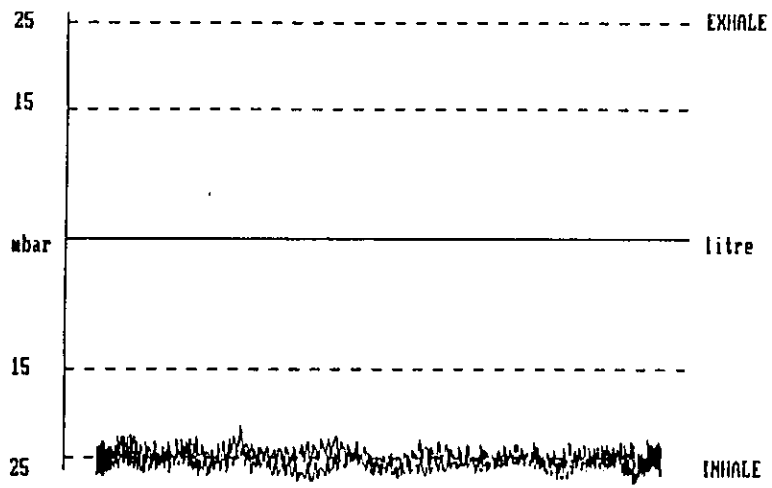
FIGURE 5

MAXIMUM SURFACE FLOW

RESULTS

INHALE PRESSURE	=	27.59 mbar	(LIMIT = 25 mbar)
INHALE POS PRESSURE	=	0.00 mbar	(LIMIT = 5 mbar)
EXHALE PRESSURE	=	0.00 mbar	(LIMIT = 25 mbar)
EXT WORK OF BREATHING	=	2.53 J/1	(LIMIT = 3.0 Joules/litre)
INHALE WORK	=	2.53 J/1	
POS INHALE WORK	=	0.00 J/1	(LIMIT = 0.3 Joules/litre)
EXHALE WORK	=	0.00 J/1	

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 0.0 msw (0 fsw)



REMARKS : 680 lpm/SUFACE/DRY

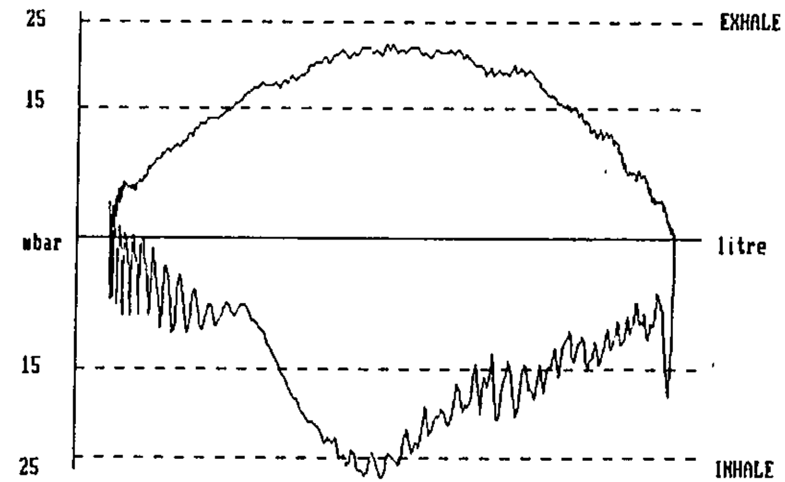
ANSTI

DEPTH PERFORMANCE

RESULTS

INHALE PRESSURE	=	27.79 mbar	(LIMIT = 25 mbar)
INHALE POS PRESSURE	=	4.22 mbar	(LIMIT = 5 mbar)
EXHALE PRESSURE	=	22.59 mbar	(LIMIT = 25 mbar)
EXT WORK OF BREATHING	=	3.05 J/1	(LIMIT = 3.0 Joules/litre)
INHALE WORK	=	1.48 J/1	
POS INHALE WORK	=	0.00 J/1	(LIMIT = 0.3 Joules/litre)
EXHALE WORK	=	1.56 J/1	

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 40.1 msw (132 fsw)



REMARKS : IMMERSED/HEAD UPRIGHT

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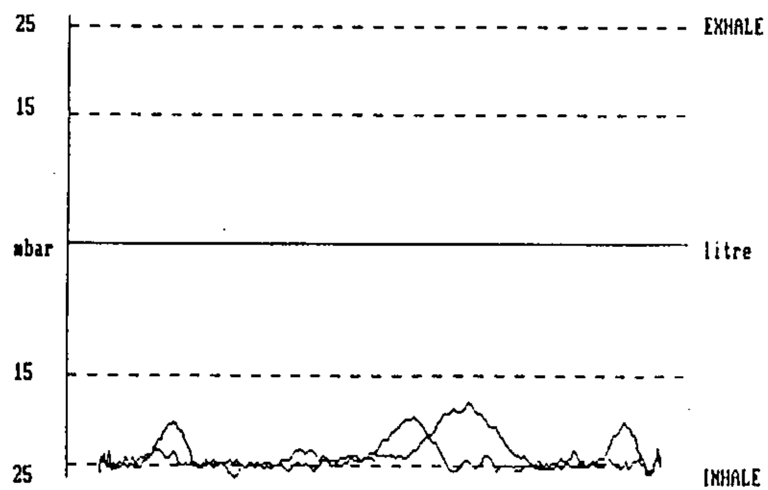
FIGURE 6

MAXIMUM SURFACE FLOW

RESULTS

INHALE PRESSURE	=	26.22 mbar	(LIMIT = 25 mbar)
INHALE POS PRESSURE	=	0.00 mbar	(LIMIT = 5 mbar)
EXHALE PRESSURE	=	0.00 mbar	(LIMIT = 25 mbar)
EXT WORK OF BREATHING	=	2.44 J/1	(LIMIT = 3.0 Joules/litre)
INHALE WORK	=	2.44 J/1	
POS INHALE WORK	=	0.00 J/1	(LIMIT = 0.3 Joules/litre)
EXHALE WORK	=	0.00 J/1	

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 0.0 msw (0 fsw)



REMARKS : 790 lpm/SURFACE/DRY

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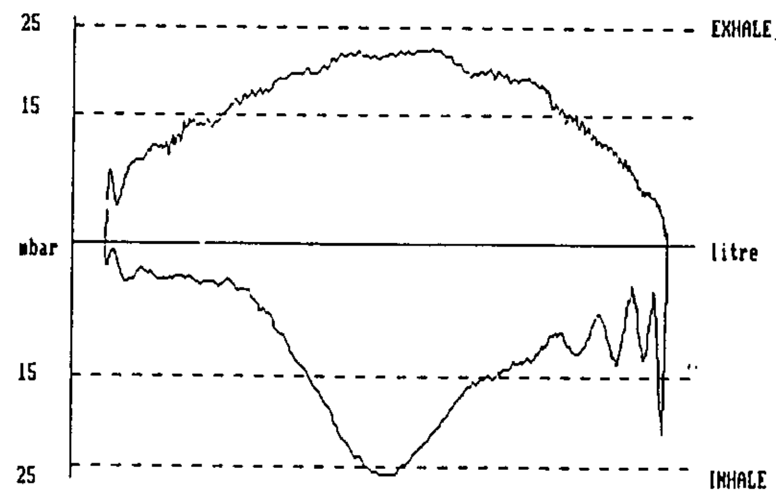
DEPTH PERFORMANCE

RESULTS

INHALE PRESSURE	=	26.42 mbar	(LIMIT = 25 mbar)
INHALE POS PRESSURE	=	0.00 mbar	(LIMIT = 5 mbar)
EXHALE PRESSURE	=	22.68 mbar	(LIMIT = 25 mbar)
EXT WORK OF BREATHING	=	2.88 J/1	(LIMIT = 3.0 Joules/litre)
INHALE WORK	=	1.26 J/1	
POS INHALE WORK	=	0.00 J/1	(LIMIT = 0.3 Joules/litre)
EXHALE WORK	=	1.63 J/1	

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 40.8 msw (134 fsw)



REMARKS : IMMERSED/HEAD UPRIGHT

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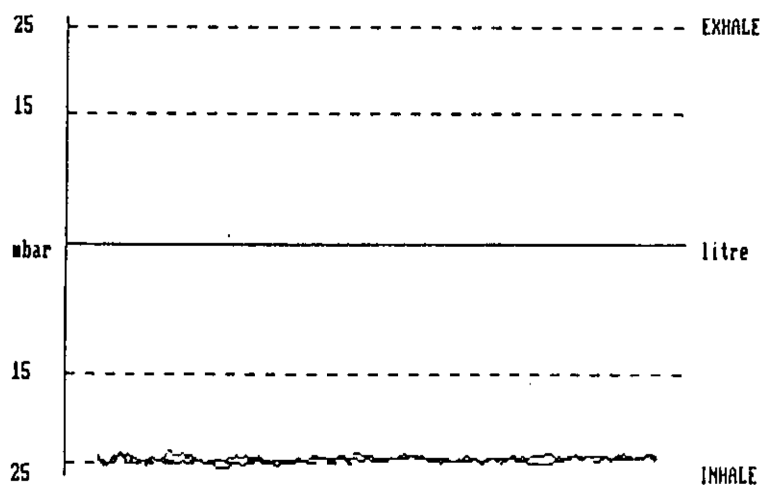
FIGURE 7

MAXIMUM SURFACE FLOW

```
INHALE PRESSURE         =  26.02 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE     =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE         =   0.00 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING   =   2.50 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK         =   2.50 J/l
POS INHALE WORK         =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK         =   0.00 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 0.0 msw (0 fsw)



REMARKS : SURFACE FLOW TEST/820 lpm/ INT 6.84 BAR

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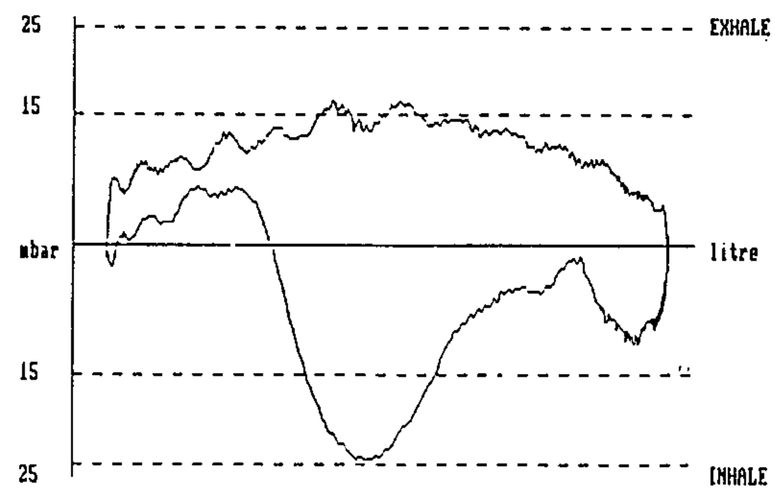
DEPTH PERFORMANCE

```
INHALE PRESSURE         =  24.94 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE     =   6.97 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE         =  16.60 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING   =   1.99 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK         =   0.83 J/l
POS INHALE WORK         =   0.12 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK         =   1.16 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 48.6 msw (159 fsw)



REMARKS : IMMERSED/HEAD UPRIGHT/MAX VENTURI/MAX SENS

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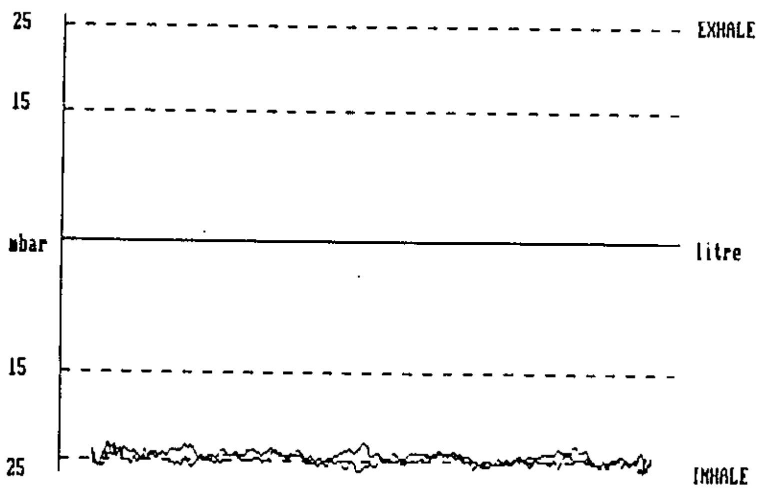
FIGURE 8

MAXIMUM SURFACE FLOW

```
INHALE PRESSURE          =  26.61 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE      =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE          =   0.00 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING    =   2.51 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK          =   2.51 J/l
POS INHALE WORK          =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK          =   0.00 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 0.0 msw (0 fsw)



REMARKS : SURFACE FLOW TEST/980 lpm/INT 6.65 BAR

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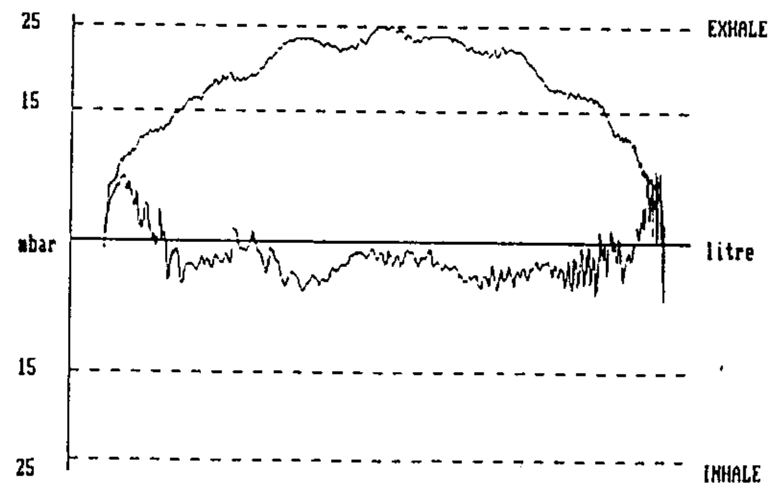
DEPTH PERFORMANCE

```
INHALE PRESSURE          =   6.58 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE      =   8.25 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE          =  25.14 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING    =   2.08 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK          =   0.23 J/l
POS INHALE WORK          =   0.06 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK          =   1.86 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 50.7 msw (166 fsw)



REMARKS : IMMERSED/HEAD UPRIGHT

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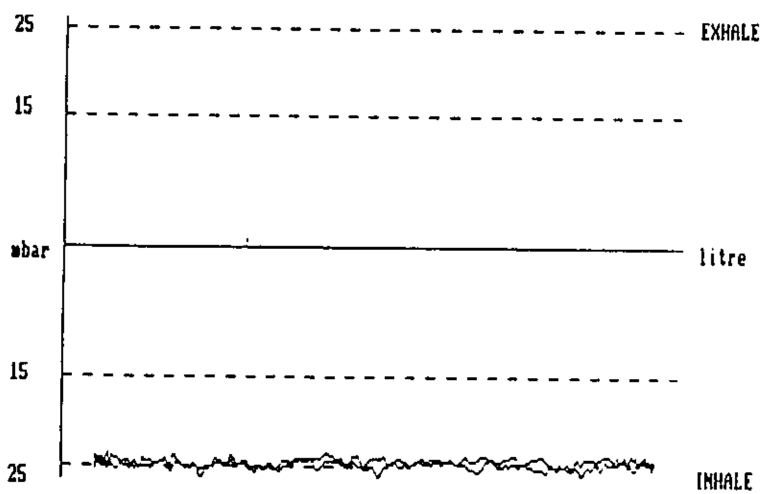
FIGURE 9

Contents

MAXIMUM SURFACE FLOW

```
INHALE PRESSURE           =  25.92 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE       =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE           =   0.00 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING     =   2.50 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK           =   2.50 J/l
POS INHALE WORK           =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK           =   0.00 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 0.0 msw (0 fsw)



REMARKS : 920 lpm/INT 6.18/SURFACE/DRY

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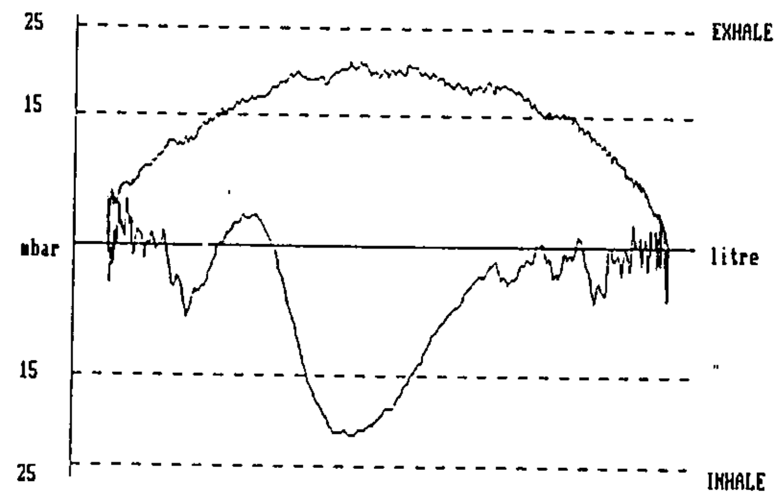
DEPTH PERFORMANCE

```
INHALE PRESSURE           =  22.00 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE       =   5.79 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE           =  21.21 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING     =   2.15 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK           =   0.63 J/l
POS INHALE WORK           =   0.04 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK           =   1.53 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 51.0 msw (167 fsw)



REMARKS : IMMERSED/HEAD UPRIGHT

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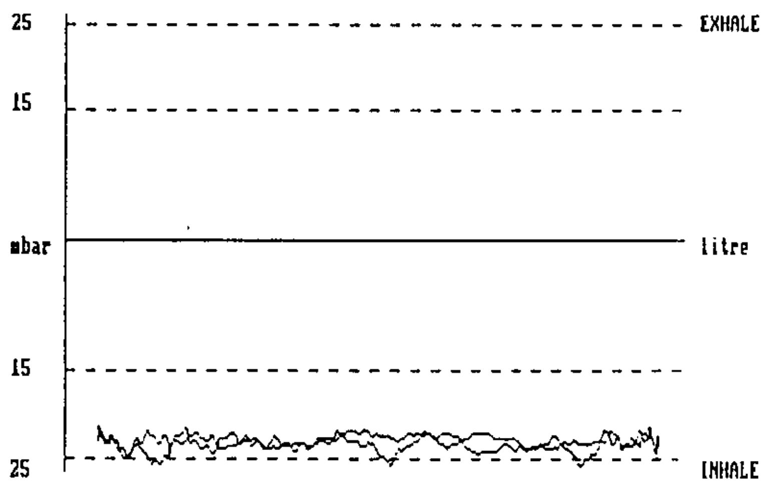
FIGURE 10

MAXIMUM SURFACE FLOW

```
RESULTS
INHALE PRESSURE         =  25.24 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE     =   0.00 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE         =   0.00 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING   =   2.34 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK         =   2.34 J/l
POS INHALE WORK         =   0.00 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK         =   0.00 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 0.0 msw (0 fsw)



REMARKS : 970 lpm / SURFACE /DRY/INT 8.16/CP 50 BAR/MAX VENTURI

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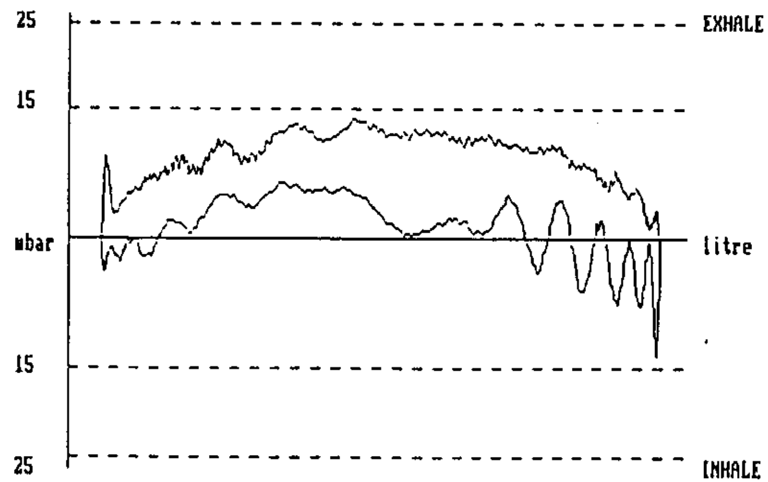
DEPTH PERFORMANCE

```
RESULTS
INHALE PRESSURE         =  13.55 mbar (LIMIT = 25 mbar)
INHALE POS PRESSURE     =   6.58 mbar (LIMIT =  5 mbar)
EXHALE PRESSURE         =  13.94 mbar (LIMIT = 25 mbar)
EXT WORK OF BREATHING   =   1.07 J/l  (LIMIT = 3.0 Joules/litre)
    INHALE WORK         =   0.09 J/l
POS INHALE WORK         =   0.23 J/l  (LIMIT = 0.3 Joules/litre)
    EXHALE WORK         =   0.98 J/l
```

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 51.2 msw (168 fsw)



REMARKS : IMMERSED/HEAD UPRIGHT/MAX VENTURI

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FIGURE 11

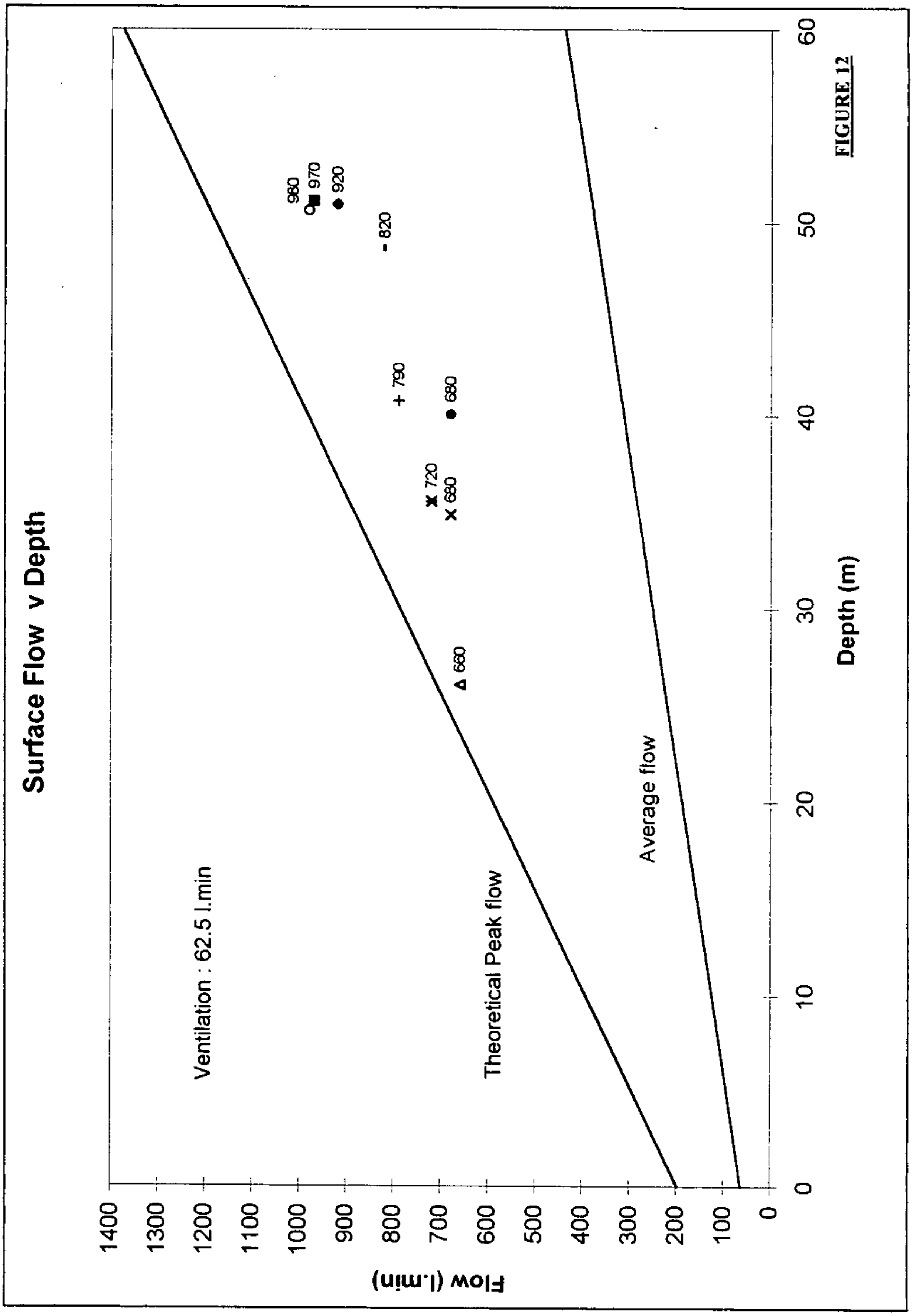

FIGURE 12

Contents