A Practical Method for Interpreting Breathing Curves in the Selection of Negative Pressure Respirators

Leif A Ekman

EZE Communications
PO Box 528 Wahroonga NSW 2076, AUSTRALIA
Tel: +61-41-82-82-500 e-mail: the.ekmans@swipnet.se

Abstract

Certain aspects of a spirograph breathing curve may seem obscure even to professionals in the field of respiratory protection. Yet, a solid understanding of the spirograph can be highly useful in the evaluation of negative pressure respirators.

A few factors form the basis of such insight. Firstly, the difference between minute flow and peak flow, and the relationship between them. Secondly, the extra load the pressure drop over the filter places on the wearer, and the consequent increase in energy consumption.

Armed with a good understanding of how a spirograph test is conducted and what the breathing curve actually shows, the safety professional can glean much more information from a single curve than seems possible at first sight. The usefulness of the spirograph becomes all the more evident when comparing the curves for two different respirators.

This paper presents a new method designed to demonstrate, in a practical way, the long-term impact a negative pressure respirator has on the wearer. By taking basic data from a spirograph curve, the user can rapidly gain a clear idea of the difference between respirators during actual work. This new method can be of great use in equipment comparison and selection.

Introduction

Many respiratory protection professional will be aware of spirograph curves, their purpose, and the fundamental information contained in them. However, the usefulness and scope of breathing curves can be substantially increased if a few basic factors are worked into the interpretation of the graphs.

The curve is generated by a spirograph machine (fig. 1). The central part of the machine is a pump that simulates a lung. The mechanical lung can be adjusted to ‘breathe’ quickly or slowly, deeply or with shallow breaths. The pump is connected to the mouth of an artificial human head, onto which a respirator can be fitted.

Fig. 1 — Spirograph machine

Such a mechanical device is able to approximate human breathing, albeit in a robot-like manner — for instance, it cannot reproduce the irregularities in human breathing, nor can it simulate the way human breathing is affected by speech, laughter, coughing, shouting, stretching, bending or any other influences on the lung function.

As mentioned before, even ‘normal’ human breathing, unaffected by any internal or external factors, can only be approximated by the machine. As the spirograph ‘lung’ comprises a piston on a rotating wheel, the ‘breathing’ is exactly regular and sinusoidal, that is, the inhalation phase is exactly mirrored by the exhalation phase. In humans, the duration of the inhalation is generally of 30–40% of the exhalation phase, meaning that humans breathe in faster than they breathe out. This phenomenon is not reproducible in the spirograph machine.

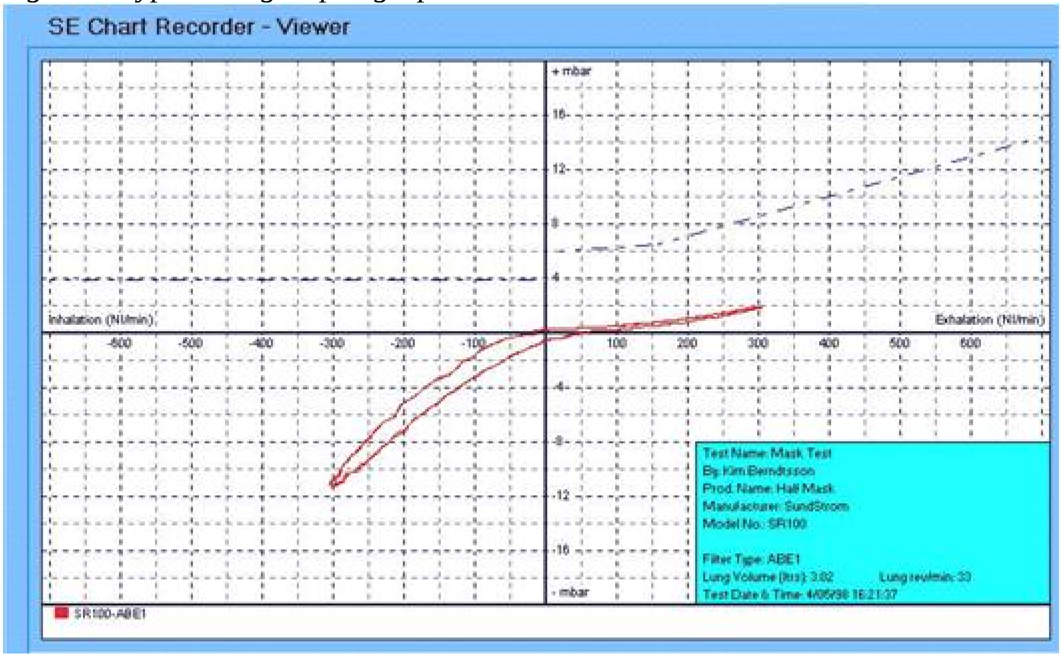
In other words, a spirograph is not useful for studying human breathing. However, it is an ideal way to examine the characteristics of a respirator when used by a human, and, in particular, for comparing different respirators and filters.

EZE Communications
Strategic Technology Management Consultant

The spirograph curve

A few factors are immediately evident in a typical spirograph curve (fig. 2):

Fig. 2 — Typical single spirograph curve



Test object:

Mask:	Sundström model SR100 half mask
Filter:	ABE1

Spirograph machine settings:

Lung Volume:	3.02 litres
Breathing rate:	33 breaths per minute

Even without looking at the actual curve, it is possible to calculate two additional values from the machine settings, namely:

Air consumption:	$3.02 \times 33 = 99.66$ litres per minute
Peak flow:	$99.66 \times \pi = 312.93$ litres per minute

The peak flow signifies the fastest speed the air reaches on its way into and out of the lungs. This calculation can be done simply by using the π-function, as the operation of the machine is generated by a rotating wheel and therefore sinusoidal.

the.ekmans@swipnet.se Mobile: 041 82 82 500
Po Box 528 Wahroonga NSW 2076 AUSTRALIAABN 70 078 495 597

Analysing the curve

The spirograph curve plots the air pressure in the mask at any moment as the air is inhaled through the filter and then exhaled through the exhalation valve. The resulting graph is a closed curve, as it depicts the breathing cycle.

Vertically, the chart shows air *pressure* in the mask. Horizontally, it shows air *speed* through the mask. The part of the curve that lies below the middle line shows negative pressure, that is, the inhalation phase when air is drawn in through the filter. The part above the line shows positive pressure, that is, the exhalation phase when air is pushed out through the exhalation valve of the respirator. The centre of the graph is the point where the lungs stop and inhalation turns into exhalation and vice versa.

The extreme points of the curve each shows two values:

The bottom left extreme point shows the peak inhalation speed of air, and the inhalation resistance through the filter. The top right extreme point shows the peak exhalation speed of air, and the exhalation resistance through the exhalation valve of the respirator.

The reason why the curve is bent around the zero-point is that the inhalation resistance is higher than the exhalation resistance: it is harder to breathe in through the filter than to breathe out through the valve.

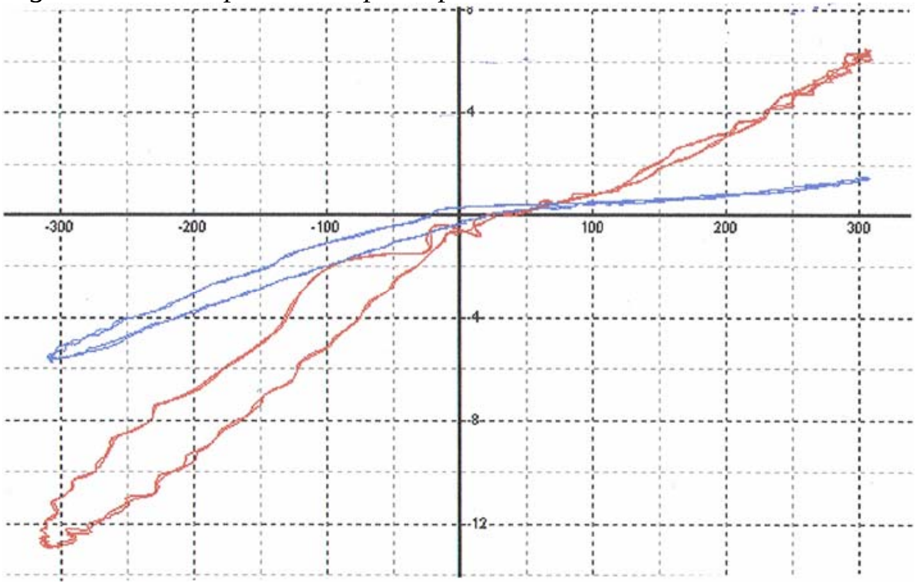
Consequently, what is of the greatest interest to safety professionals selecting respiratory protective devices is the *steepness* of both ‘arms’ of the curve. If there were no breathing resistance at all, the spirograph curve would be a perfectly horizontal line.

The bottom-left quarter gives information on the filter, and the top-right quarter gives information on the mask.

This becomes all the more evident in a spirograph curve featuring two different respirators (fig. 3):

the.ekmans@swipnet.se Mobile: 041 82 82 500
Po Box 528 Wahroonga NSW 2076 AUSTRALIA ABN 70 078 495 597

Fig. 3 — Two respirators superimposed



In this case, the spirograph settings have remained unchanged. Consequently, both respirators have been tested under the same conditions, which is evidenced by the horizontal extension (volume/speed of air) of both the red and the blue curves. However, the vertical extension, showing the breathing resistance through the filter (left side) and the exhalation valve (right side) differ markedly between the two masks.

Effects

The effects of breathing resistance on the body are well known. By placing a negative pressure, air purifying filter respirator on the face, an extra work load is also placed on the lungs. This additional work load almost inevitably results in a variety of physiological effects, including:

- Fatigue/exhaustion
- Raised body temperature
- Increased heart rate
- Rise in blood pressure

It can also generate psychological stress, such as anxiety, claustrophobia, or, in rare cases, panic.

The greater the extra work load, the greater the detrimental effects on the body, as well as on work performance and ability to conduct strenuous tasks or even moderate work.

It is important to keep in mind that the spirograph curve is a representation of an on-going, cyclical process that is repeated over and over again. What is not immediately

 the.ekmans@swipnet.se Mobile: 041 82 82 500
Po Box 528 Wahroonga NSW 2076 AUSTRALIAABN 70 078 495 597

evident from the curve is its own continuousness: it may be difficult to appreciate the effect of a small difference in breathing resistance over a long time — in fact, for as long as the respirator in question is worn.

For this purpose, it could be useful to translate the information contained in a spirograph curve into actual physical work.

Converting breathing resistance to work load

It is clear from fig. 3 that the inhalation resistance of one filter is about twice that of the other, and the exhalation valve of the same mask imposes more than three times the breathing resistance compared with the other mask.

However, breathing resistance as expressed as a plot on a breathing curve might not be quite as meaningful as having a more tangible appreciation of the added work load on the body.

A method was developed to demonstrate work of breathing in the form of a practical exercise.

Methodology

The first step was to convert the breathing resistance imposed by the filter and exhalation valve into physical work. This could be done in at least two ways:

1. The difference in breathing resistance between two different respirators could be recalculated as a function of minute volume, i.e. the amount of air breathed during the span of one minute. This means, for instance, that the work of inhaling 50 litres per minute through the high-resistance filter in fig. 3 would be equal to breathing 100 litres per minute through the other filter.
2. A formula could be devised in order to calculate the actual energy required to breathe through any respirator and to equate that energy into an easily demonstrable type of physical work.

Although the first method appeared simple and convenient, it did not provide an acceptable level of demonstrability. Consequently, the second option was chosen.

Calculating power and energy

Using data shown in the breathing curve, it is possible to calculate the power it takes to pull air through the filter and push it through the exhalation valve. This power is expressed in Watt (W).

Since the number of breaths per minute is known, the total power of breathing can be split into inhalation and exhalation. Furthermore, the respective inhalation and exhalation resistance can be applied, and the time element can be factored in, giving energy as an end result. The energy can be quantified in watt-seconds (Ws) or, in compliance with the SI system, in Joule (1 Ws = 1 J).

the.ekmans@swipnet.se Mobile: 041 82 82 500
Po Box 528 Wahroonga NSW 2076 AUSTRALIAABN 70 078 495 597

Calculating work

The objective of this exercise was to find a way of demonstrating the extra work of breathing required to use a respirator as opposed to breathing without a respirator.

As work can be simply expressed as a function of energy and distance, a convenient method would be to equate the work of breathing to lifting an object a certain distance over a certain period of time.

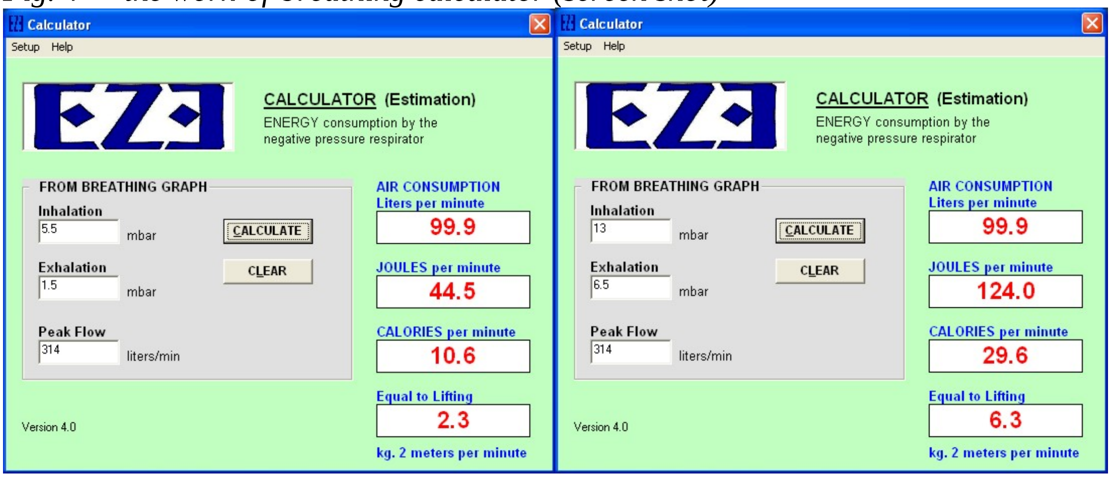
This can be easily done in the form of a formula that uses only three variables: inhalation resistance, exhalation resistance, and peak air flow.

The work-of-breathing calculator

A new software program was devised, comprising a simple user interface (fig. 4) and a calculator that applies the resistance/work formula to the input. When the three variables from the spirograph curve are entered into the computer form, the work of breathing is displayed in terms of lifting a certain weight from the floor and up over your head over one minute, every minute for as long as the respirator in question is worn.

Fig. 4 shows the recalculated results for the two filter respirators plots on the spirograph curve in fig. 3 above.

Fig. 4 — the work-of-breathing calculator (screen shot)



The software allows the use of various input units, for example, millibar, Pascal, psi, mm mercury, mm water and so on. Further, the output value is expressed in both Joule and calories, along with the lifting exercise.

The prime purpose of the software is that it can show, in a practical way, the real difference between various respirators in terms of work of breathing over time. In the sample case, the work of breathing through one respirator amounts to performing a one-minute lift of a weight of 2.3 kilograms from the floor to above one's head, every minute for as long as the mask is worn. This means 240 times during a 4-hour shift.

By comparison, the breathing resistance of the other respirator requires the same number of lifts, but with a weight of 6.3 kilograms.

The difference should be relatively simple to estimate, even without actually performing the physical exercise. For instance, it is possible to think of the weight to be lifted in terms of milk cartons or other everyday items.

Conclusion

It has been shown that the breathing resistance in a respirator plays a significant role in work performance as well as physical and mental comfort.

One important aid in the evaluation of respiratory protection equipment is the spirograph curve, which can be a useful method of comparing the inhalation and exhalation resistance of various devices.

The true magnitude of breathing resistance, or the difference in breathing resistance between two respirators, is difficult to grasp from the data shown on a spirograph plot — especially when considering the long-term effects of what may appear as a small difference.

It is hoped that the work-of-breathing calculator software may provide a demonstration of the extra work of breathing placed upon the lungs and body by a negative pressure air purifying filter respirator, in particular when comparing different respirators.

<END>

the.ekmans@swipnet.se Mobile: 041 82 82 500
Po Box 528 Wahroonga NSW 2076 AUSTRALIAABN 70 078 495 597