

EFFECTS OF WATER VAPOUR ON THE PERFORMANCE OF RESPIRATOR
GAS AND VAPOUR FILTERS

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INTRODUCTION

The efficiency of a gas filter for removal of gases or vapours depends on the following factors:

1. The physico-chemical properties of the filling.
2. The physico-chemical properties of the gases and vapours to be removed.
3. The amount of filling.
4. The concentration of the contaminant(s).
5. The air-flow rate.
6. The humidity of the air.
7. The water content of the filling.
8. Temperature.

The importance of each of these factors can be thoroughly described in quantitative terms, at least after some laboratory experiments have been carried out, but as a whole the filtration process is a complex one and the following requirements should be fulfilled if a proper assessment of the service time of a filter should be given:

1. The contaminant(s) should be identified as well as the level of concentration.
2. The air-flow rate through the filter (i.e., the breathing rate of a user) should be known exactly.
3. The humidity and temperature of the air should be known.
4. The efficiency of the filter as a function of concentration air-flow rate, humidity and temperature should be exactly known.
5. The air-flow rate, concentration, humidity and temperature should be constant during use.

In practice these requirements are only partly fulfilled and it is highly unlikely that they would be under normal working conditions.

Wherever respirators are worn and used with gas and vapour filters, these filters are exposed to the ubiquitous water vapour of the atmosphere. This gives rise to the important question of how the performance of the commonly used filters is affected by moisture.

The amount of water vapour in the air is far from negligible. It is generally expressed in terms of percent relative humidity (%R.H.) and the absolute concentration of water vapour can be calculated from the relative humidity if the temperature is known. Some examples are given in Table 1. These figures show that in terms of concentration water vapour will generally be present in amounts at least comparable to the amount of contaminants or exceed it by several orders of magnitude.

Charcoal filters are capable of taking up substantial amounts of water at higher relative humidities as exemplified in Fig. I, which shows sorption and desorption isotherms obtained during dynamic testing of a commonly used A-filter.

It can be seen that at equilibrium conditions the water uptake at the higher relative humidities amounts to about fifty percent by weight. Consequently it can be concluded that filters are exposed to substantial amounts of water vapour and that substantial amounts of water vapour can be taken up by filters.

TABLE 1

R.H. %	CONCENTRATION OF WATER VAPOUR AT 20°C	
	mg/m ³	ppm
10	1730	2307
20	3460	4613
30	5190	6920
40	6920	9227
50	8650	11533
60	10380	13840
70	12110	16147
80	13840	18453
90	15570	20760
100	17300	23067

SORPTION OF WATER VAPOUR

Static and Dynamic Sorption

Sorption of water vapour by charcoal filters can take place under static or dynamic conditions. Static sorption can take place during production and later on if a filter is left more or less open e.g., during intermittent use. In these cases the atmosphere has ready access to the filling and water vapour diffuses into it. As the rate of uptake is governed by rate of diffusion of the water vapour the process is slow and the resulting uptake only amounts to a few percent by weight.

Dynamic sorption takes place during use when air is arawn through the filter. In this case tne rate of uptake is much faster and strongly dependent on the size of the air flow rate. Under these conditions a filter can be heavily loaded within a few hours, depending on the size of the filter, the humidity of the air and the air flow rate.

Rate of Uptake

During dynamic sorption of water vapour the rate of uptake is approximately constant during the first hours as can be seen from Fig. 2 where the uptake is given as a function of time for Five European filters (B-type). The loading conditions were: $75 \pm 5\%$ R.H., 20 ± 2 °C and 30 ± 0.5 l/min.

The amounts of water sorbed during the first hour is given in Table 2 together with the calculated filter efficiencies and the equilibrium sorption capacities. Right from the beginning of the tests the filter efficiencies were low ranging from 15 to 30%, and with increasing time the efficiencies decreased further. The time required to reach the state of equilibrium sorption differed from 15 to 25 hours under the test conditions used.

The difference between the rates of uptake under dynamic and static conditions can be seen from Table 3. Six different filter types were humidified in a two-step procedure:

1. Humidification under dynamic conditions for 4 hours at $75 \pm 5\%$ R.H., 20 ± 2 °C and 30 ± 0.5 l/min.
2. Humidification under static conditions for 24 hours in a climatic chamber at 90% R.H. and 20 ± 2 °C.

In the climatic chamber circulating air was used and the filters were placed in such a way that the air had free access to the fillings.

In spite of the fact that during the dynamic experiments the relative humidity used was smaller and the exposure time shorter than in the static tests, the resulting dynamic uptakes far exceed the static ones.

TABLE 2

FILTER TYPE	UPTAKE OF WATER VAPOUR DURING THE FIRST HOUR (DYNAMIC CONDITIONS)	EFFICIENCY OF FILTER DURING THE FIRST HOUR %	EQUILIBRIUM SORPTION CAPACITY 6
I (B)	3.51	15.0	25.9
II (B)	4.32	18.5	33.5
III (B)	3.51	15.0	36.0
IV (B)	6.76	28.9	50.8
V (B)	7.57	32.4	37.3

TABLE 3

FILTER TYPE	UPTAKE OF WATER VAPOR	
	DYNAMIC CONDITIONS	STATIC CONDITIONS
	G	G
I (A)	11 .50	0 .90
II (A)	13 .33	1 .95
II (B)	12 .44	5 .38
III (A)	14 .44	2 .53
IV (A)	9 .50	3 .31
VI1 (B)	5 .09	2 .06

EFFECTS OF MOISTURE ON FILTER PERFORMANCE

Filtration Mechanisms

Depending on the type of filter (A, B, E or K) one or more of the following filtration mechanisms are effective in removing the contaminants from the air:

1. Physical sorption.
2. Chemical interaction.
3. Catalytic interaction.
4. Hydrolysis.

The effect of water vapour on these filtration mechanisms can lead to increased, unchanged or decreased efficiency of a filter depending on the type of filling, the chemical properties of the contaminant and to some extent the amount of water vapour sorbed in the filter. Some examples will be given in the following.

Qualitative Effects of Equilibration

A comparative study of the effects of equilibrating filters with water vapour before testing has been performed on a number of A, B, E and K filters from eleven European manufacturers. The results are given in Table 4. The following conclusions can be drawn from the results.

Type A-filters which contain unimpregnated activated charcoal decrease in capacity when equilibrated before performing a breakthrough test. The decrease is caused by the competitive sorption of water vapour and test substance.

For the type B filter positive as well as negative effects were found depending on the test substance used. Generally water vapour was found to have a deleterious effect on filter performance when hydrogen cyanide or hydrogen sulphide were used as test substances whereas when using chlorine improved performance was obtained.

For the type E filter mostly negative or no effects were found from equilibration and for the type K filter mostly positive effects were found.

Filters of type B, E and K contain impregnated charcoals, and chemical reactions and/or catalytic processes can take place between the contaminants and the impregnation.

Apparently some of these processes can be promoted by the presence of water while some are retarded.

TABLE 4
INFLUENCE OF EQUILIBRATION

FILTER TYPE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
A. CCL ₄	-	-	-	-	-		-			-	-
HCN	-	-	(-)	(-)	(-)		0			-	
B. CL ₂		+	0	+		+	(+)	+	+	(+)	-
H ₂ S				-		-			B		+
E. SO ₂	0		0							+	-
K. NH ₃	+		(+)	+						0	

+ INCREASED CAPACITY WHEN EQUILIBRATED

0 CAPACITY UNCHANGED BY EQUILIBRATION

- REDUCED CAPACITY WHEN EQUILIBRATED.

NO INFORMATION AVAILABLE AT PRESENT

() INDICATES ONLY MINOR CHANGES IN CAPACITY.

B EQUILIBRATED FILTER IGNITED SPONTANEOUSLY DURING TESTING.

Quantitative Effects of Humidification

Under the conditions of practical use filters will seldom reach the state of equilibrium, but only take up water vapour corresponding to e.g., 50 percent of this value. The influence of the amount of water sorbed on the breakthrough times for a number of filters is shown in Table 5. The test conditions were: Concentration of test gas - 0.5%, 50 ± 0.5 l/min, $75 \pm 5\%$ R.H. and $20 \pm 2^\circ\text{C}$.

In the tests with hydrogen cyanide the penetration of this substance as well as the penetration of cyanogen (C_2N_2) were detected separately, as it has been shown ¹ that in some B-filters cyanogen is formed by oxidation of hydrogen cyanide in the filters. In Table 5 the breakthrough times based on cyanogen are given in brackets. Generally cyanogen appeared in the effluent air before hydrogen cyanide.

The filters were tested in three different states:

1. As received from the manufacturer.
2. Humidified according to the above-mentioned two-step procedure.
3. Equilibrated with water vapour at 75% R.H. at $20 \pm 2^\circ\text{C}$.

As the amount and quality of the charcoals and impregnants differ widely among the filter types also the amounts of water vapour taken up during the above-mentioned humidification procedures differ.

TABLE 5
EFFECT OF HUMIDIFICATION

FILTER TYPE	TEST SUBSTANCE	BREAKTHROUGH TIMES MIN.			BREAKTHROUGH CONCENTRATION PPM
		AS RECEIVED	HUMIDIFIED	EQUILIBRATED	
I (A)	CCL ₄	70	59	22	10
I (B)	HCN		40 (35)	23 (5)	10
I (B)	HCN	46 (18)	54 (8)		10
II (A)	CCL ₄	62		16	10
II (B)	HCN		45 (42)	33 (28)	10
II (B)	HCN	59 (48)		52 (32)	10
III (A)	CCL ₄	47	15	4	10
IV (A)	CCL ₄	62	50	9	10
IV (B)	SO ₂	19	26	32	05
IV (B)	H ₂ S	170	129	136	10
IV (E)	SO ₂	16	25	11	5
VI (B)	SO ₂	21	22	27	5
VI (B)	H ₂ S	126	16	17	10

DISCUSSION AND CONCLUSIONS

As can be seen from Table 5 extremely poor results were obtained in some cases,

In the humidified state where approximately only 25 percent of the equilibrium sorption capacity has been reached, breakthrough times could be lowered by several orders of magnitude. The lowering effect of moisture on the sorption capacity of type A-filters is caused by the competition between sorption of water and sorption of the organic vapour. By using an organic test substance with a higher boiling point than carbon tetrachloride the effect of moisture would be relatively smaller. On the other hand, it has been found that the sorption capacity of a charcoal filter can be increased by the presence of water vapour if the sorbate is water soluble. This has been found with methanol as the sorbate and some types of charcoal.² A similar effect could be expected if the sorbate is readily hydrolyzed by water.

The effects of moisture in filters of the B, E and K types are difficult to predict for several reasons.

These filters contain activated charcoal impregnated with inorganic salts of heavy metals e.g., Cu, Ag and Cr. The impregnants either react chemically with the contaminants or act as catalyst giving rise to oxidation or decomposition processes. Impregnation is carried out by treating the charcoal with an aqueous solution of proper salts followed by more or less extensive drying.

Each manufacturer has his own mixture and its composition is known, at least by the manufacturer himself, but the exact chemical composition of the impregnation on the surface of the more or less dried charcoals is unknown.

Consequently the chemical reactions and the role played by moisture cannot be predicted.

In some cases minor amounts of water are of vital importance for the chemical or catalytic reaction between the contaminant and the impregnation e.g., in case of hydrogen cyanide³ and cyanogen chloride.⁴

If, however, the water content is too high the capacity of the filter is considerably lowered for the same contaminants. It can be concluded that the efficiency of a respirator filter for taking up water vapour is rather low right from the beginning. However, due to the high content of water vapour in the air substantial amount of water can be taken up and the predominant effect is a lowering of the breakthrough time (and hence capacity) resulting in many cases in a dangerously low level of protection.

IMPACT ON STANDARDIZATION

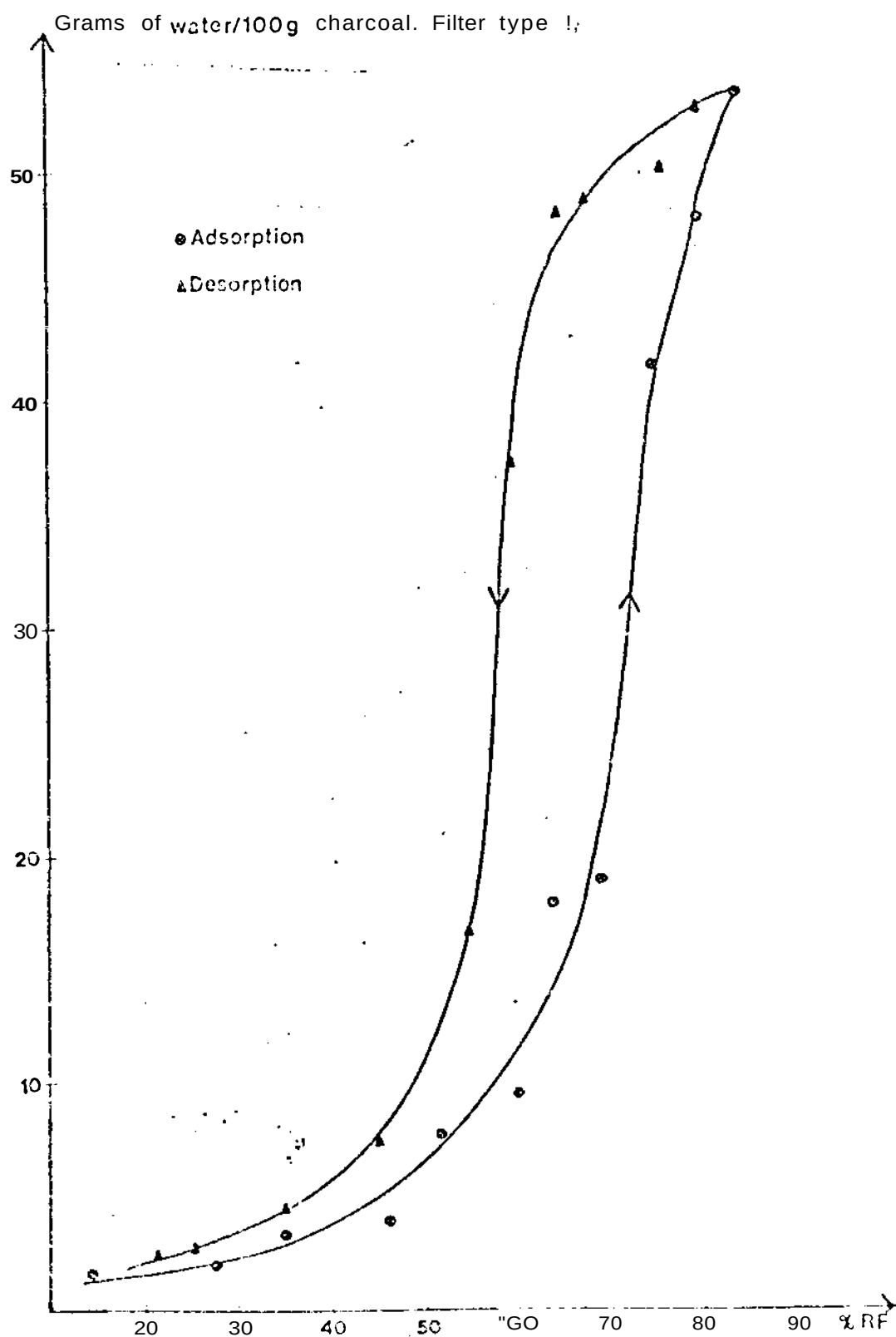
The test results presented here are part of a greater number which forms the basis for the new draft for a European Standard on gas vapour filters.⁵⁾

The results were communicated from the following countries: Denmark,³ England,⁶ Finland,⁷ France,⁸ Germany,⁹ Holland,¹⁰ and Italy.¹¹⁾

Based on the above-mentioned results it has been suggested in the new draft for a European Standard ⁵ that breakthrough tests on respirator filters shall be performed only after the filters have been equilibrated with water vapour at 30 ± 0.5 l/min., $70 \pm 2\%$ and $20 \pm 1^\circ\text{C}$.

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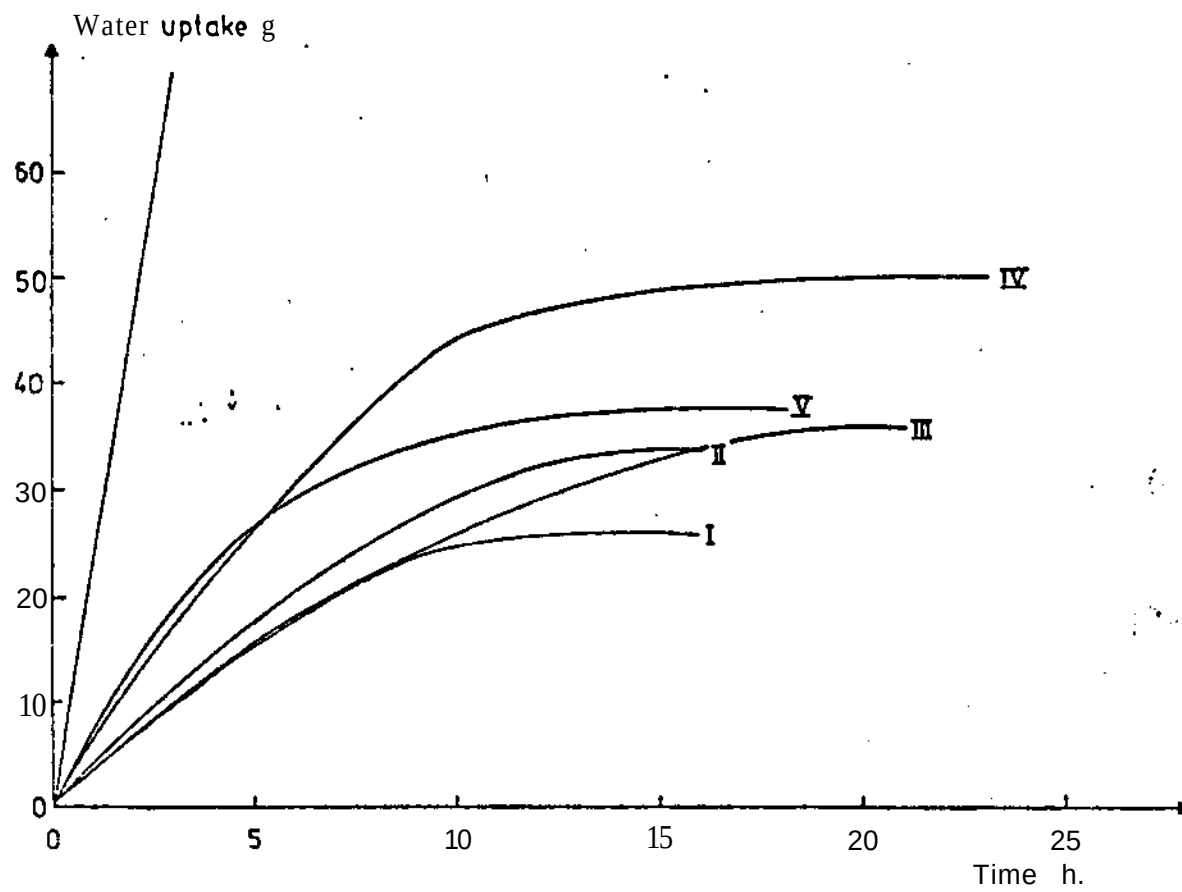


Fig. 2.