Labthink Instruments Co., Ltd.
144 Wuyingshan Road, Jinan, P.R.China
Phone: +86 531 85068566
FAX: +86 531 85812140

Effect of Pressure Difference on Permeability Test for Plastic Film

Yuan Su[1], Merken Zhang[2], Jiang Zhao[2], Ping Yao[1],

1. Hunan University of Technology, Zhuzhou 412008, Hunan, China
2. Labthink Instruments Co. Ltd. Jinan 250031, Shandong, China

Abstract: t The barrier properties of packaging material play an important role in food and pharmaceutical packaging. Up to now, differential pressure method has the longest application history in barrier properties testing and been used in worldwide. With the development of testing and highly accurate pressure sensor technology, differential pressure method has become much more consummate than before. But there are still the doubts that differential pressure maybe has some influence on film structure，finally on permeability. In order to clear this effect, this article will explain the relation between differential pressure and barrier properties based on the actual test data.

Key Words: **differential pressure, barrier property, permeability, plastic film, packaging**

Barrier properties of packaging material play an important role in food and pharmaceutical packaging. Barrier properties include the gas permeation and water vapor permeation. There are different methods to test these properties. The differential pressure method to test gas permeability has the longest application history and been used in worldwide. But there are still the doubts for this method, one of them is that the pressure difference between two sides of test sample maybe destroy the structure of some fragile material and produce the cracks and perforations; also maybe let the material distortion and become thinner, so the surface of sample will be greater. All these factors will influence the tested permeability. We were more concerned about these factors particularly when the equal pressure method has been used in USA. But what, if any, is the influence on permeability by the pressure difference? Are the data tested by differential pressure method credible? These problems are still not verified by experimental data. So we arrange a series of experiments to clear these problems.

I Basic Principle

According to the theory of mass transfer [2], the driving force that let gas molecules penetrate through a plastic film is chemical potential. When the molecules are absorbed by polymer and then dissolved in it, they will move from a higher chemical potential to a lower one. But the chemical potential is determined by chemical activity. The chemical activity is proportional to the concentration of molecules. In gas phases, the concentration *Ci* can be expressed as partial pressure of molecules *pi*:

$$pi = kCi \qquad (1)$$

Where, k is a constant. That means the gas flux will be determined by the partial pressures between the two sides of sample. If there is a quantity *Q* of gas that penetrated through an area *A* in a time *t*, we have the permeability coefficient *P*:

$$P = \frac{Ql}{At(p_1 - p_2)} \qquad (2)$$

Where, p_1, p_2 are the partial pressures between the two sides of sample. The partial pressure difference $\Delta p = p_1 - p_2$. *l* is the thickness of film. We can see that the Permeability Coefficient, P, is the quantity of gas passing

through a plastic material of unit thickness, per unit area per unit time, under unit partial-pressure difference between the two sides of the material

We need to know the partial pressures between the two sides to determine the permeability. So, the first method was partial pressure difference method. There are many test standards in different countries for this method, such as GB/T 1038, ASTM D1434, ISO 2556, ISO 15105-1, JIS K 7126 (method A), etc. All these methods should maintain a difference of 1 atmospheric pressure (101.33 kPa) between the two sides of sample and test the permeability under this pressure.

Generally, there are three parameters were used to express the permeability of a polymer. Besides the Permeability Coefficient P, there are still two followings:

1 Transmission Rate, TR: the quantity of gas passing through a plastic material, per unit area per unit time; expressing as (Quantity)/[(Area)(time)]

2 Permeance, R, is the quantity of gas passing through a plastic material, per unit area per unit time, under unit partial-pressure difference Δp between the two sides of the material; expressing as $Q/(A\,t\,\Delta p)$

There are following relations for these three parameters:

$R=TR/\Delta p$， $P=R\times l$ （3）

From equation (3), we can see that R and P theoretically should not change with Δp. But what is real situation? The following is our arrangement to clear this problem.

II Experiment Arrangement

We used the gas permeability tester VAC-V1, made by Labthink Instruments Co., LTD, Jinan, Shangdong, China. This is an instrument basic on partial pressure difference. The test range is 0.1～100000 cm^3/m^2·24h·0.1MPa and can be extended to 600000 cm^3/m^2·24h·0.1MPa. The vacuum resolution is 0.1Pa，the vacuum in test cell can be assured below 20 Pa. The temperature can be controlled from ambient temperature to 50℃, precision of temperature is ±0.2℃. This instrument can measure the Permeance R, Permeability Coefficient P, Diffusion Coefficient D and Solubility Coefficient S. In the standard test, a perforate paper was used to support the sample and balance the effect of pressure difference.

Besides, the computer system for data treatment, a vacuum pump with a capacity 0.1Pa and the gas oxygen (99.9%) were used in the experiments. The figure 1 showed the arrangement.

Fig. 1 Gas Permeability Tester VAC-V1

Tests were taken in the standard laboratory. The ambient temperature in laboratory was 23℃，50%RH。The test cell was at a temperature of 40℃，the humidity of test gas was 0％RH. The tested materials were 8 types

with different thickness for some materials. These materials were most used in flexible packaging, such as: PC (125μm), PC (175μm), PET (12μm), PET(23μm), PET (25μm), PET (70μm), PA(35μm), PE (40μm), CPP (40μm), OPP (38μm). Besides, there were some multiplayer material, PE/EVOH/PE (55μm), PA/PE (80μm) were used. The permeance range of samples was from 1.49 cm^3/m^2·24h·0.1MPa to 7030 cm^3/ m^2·24h·0.1MPa. Each sample was tested under a series of partial pressure difference of: 30kPa, 50 kPa, 70 kPa, 90 kPa, 110 kPa, 130 kPa and 150 kPa. There were more than 3 times tests at each point of pressure difference.

III Date Analysis

The table 1 gave the data of Transmission Rate TR for different materials at different partial pressure difference; table 2, of Permeance R and table 3, of Permeability Coefficient P.

Table 1 Transmission Rate (cm^3/m^2·24h) for different materials with pressure difference

Materials (Thickness at μm)	Partial Pressure Difference (kPa)						
	30	50	70	90	110	130	150
PE (40)	1875.43	3154.45	4391.56	6071.05	7204.33	8418.80	9919.87
CPP (40)	1045.74	1763.57	2416.90	3010.48	3642.43	4437.63	5029.70
OPP (38)	526.69	922.04	1332.30	1686.89	2032.81	2344.06	2718.35
PC (125)	177.01	299.86	415.44	546.37	662.45	782.83	908.68
PC (175)	123.61	217.15	306.77	398.42	489.72	584.72	664.50
PET (12)	42.64	68.56	96.50	122.45	158.16	187.90	218.34
PET (23)	23.18	38.16	53.82	69.16	82.35	97.41	109.71
PET (25)	20.43	33.87	47.30	67.56	75.28	90.68	102.88
PET (70)	8.45	13.18	18.28	23.64	29.67	34.26	39.20
PA (35)	10.12	16.10	22.75	28.12	32.95	39.29	44.65
PE-EVOH-PE (55)		1.29	1.45	1.75	1.79	2.07	2.60
PA-PE (80)	27.95	48.47	66.03	86.97	107.92	128.9	149.5

Table 2 Permeance R(cm^3/m^2·24h·0.1MPa) for different materials with pressure difference

Materials (Thickness at μm)	Partial Pressure Difference (kPa)						
	30	50	70	90	110	130	150
PE (40)	6251.45	6308.90	6273.67	6745.61	6549.39	6476.79	6613.25
CPP (40)	3406.16	3487.85	3375.64	3310.01	3285.18	3417.68	3431.51
OPP (38)	1774.76	1818.71	1901.35	1860.38	1831.37	1793.22	1837.20
PC (125)	590.01	599.72	593.48	590.07	604.99	602.84	607.98
PC (175)	412.02	434.29	438.24	442.69	445.20	449.79	443.73
PET (12)	142.14	137.65	136.77	136.18	143.47	145.96	145.56
PET (23)	75.28	77.98	75.37	75.07	74.66	75.17	74.48
PET (25)	68.10	67.74	67.57	67.28	67.10	69.76	68.59
PET (70)	28.18	26.35	26.12	26.27	26.97	26.35	26.13
PA (35)	33.68	32.22	32.04	31.24	29.70	30.75	30.69
PE-EVOH-PE (55)		2.57	2.07	1.94	1.63	1.59	1.73
PA-PE (80)	94.30	94.57	92.22	96.34	97.80	100.21	101.99

Table 3 Permeability coefficient P [(E-11) cm^3·cm/cm^2·s·cmHg] for different materials with different partial pressure difference

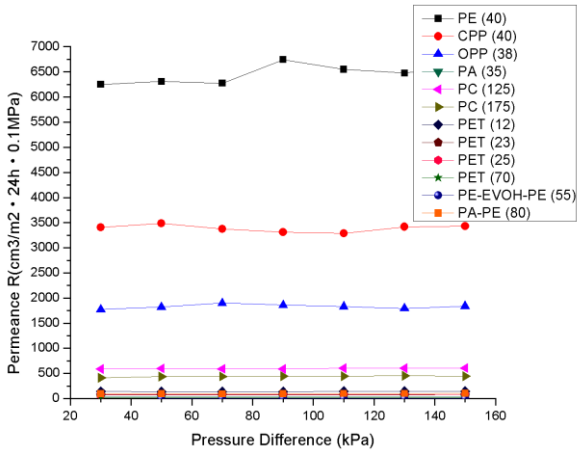
Materials (Thickness at μm)	Partial Pressure Difference (kPa)						
	30	50	70	90	110	130	150
PE (40)	38.1	38.4	38.2	41.1	40.0	41.1	40.3
CPP (40)	20.8	21.2	20.6	20.2	19.8	20.8	20.9
OPP (38)	10.3	10.5	11.0	10.8	10.6	10.4	10.6
PC (125)	11.2	11.4	11.3	11.2	11.5	11.5	11.6
PC (175)	11.0	11.5	11.7	11.8	11.9	12.0	11.8
PET (12)	0.260	0.252	0.250	0.249	0.262	0.267	0.266
PET (23)	0.264	0.273	0.264	0.263	0.262	0.263	0.261
PET (25)	0.259	0.258	0.257	0.256	0.256	0.266	0.261

Fig.3 Relationship between permeance and pressure difference

PET (70)	0.30	0.28	0.278	0.280	0.287	0.281	0.279
PA (35)	0.180	0.172	0.171	0.167	0.158	0.164	0.164
PE-EVOH-PE (55)		0.0215	0.0174	0.0163	0.0137	0.0132	0.0145
PA-PE (80)	1.15	1.15	1.12	1.17	1.19	1.22	1.24

The relationships of table 1, 2 and 3 were shown in figures 2, 3 and 4 respectively. We can see the interesting phenomena from these tables and figures: The transmission rate TR increased proportionally with partial pressure difference; but the permeance R and permeability coefficient P did not changed with partial pressure difference.

Note: In figure 2, we only illustrated the



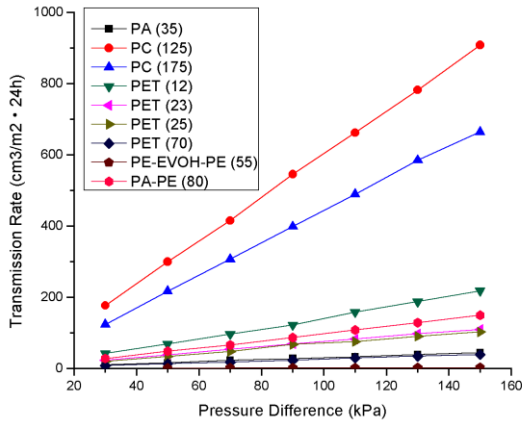


Fig. 2 TR as a function of pressure difference

Fig.3 Relationship between permeance and pressure difference

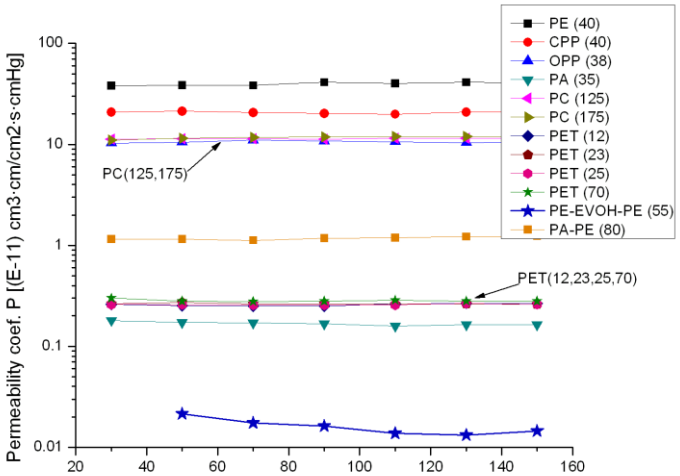


Fig. 4 Relationship between permeability coef. and pressure difference

From the basic principle in the section I, the transmission rate is the quantity of gas passing through a plastic material, per unit area and per unit time. This variable normally was determined by two factors:

1) the proper permeability of material
2) the difference of concentration between the two sides of material.

When the proper permeability of material was not changed, the greater the difference of concentration, the easier is the transmission of gas. That means the TR will increase with the partial pressure difference from equation (1). This was just certified by our experiments. But if we only concern the permeability of material, we should eliminate this external factor, that's to say, eliminate the partial pressure difference. So we have the R in equation (3). The experimental data had shown that R (and so P) did not changed with partial pressure difference. Like in an electrocircuit, if the greater the difference of
electrical potential between the two points of a resistance, the greater passes the current through this resistance. But the resistance did not changed with the difference of electrical potential.

Moreover, for the same material we saw that the permeances were different for the different thickness. But we cannot say that the thinner material has a greater capacity of permeation than the thicker. Because for the same material, it should have the same permeability for the same type of gas. So, we normalized the R by multiplying it with the thickness *l* as in the equation (3) and then, we have the permeability coefficient P. Checking the PC (125) and PC (175) in table 2 and table 3, we can see the R (125) is greater than R (175), but P (125) is same as P (175). There are same results for PET (12), PET (23), PET (25) and PET (70) (see the figures 3 and 4). It is clear that the same material have same permeability coefficient for same type of gas, even if its R will change with its thickness. Generally, the permeability coefficient is a basic value for the permeability of material.

IV Conclusion

The method of partial pressure difference has taken an efficient solution for the effect of pressure difference and can assure that the structure of samples has not significant deformation under the pressure difference. In our testing range, that's to say, in the range of partial pressure difference method, the tested data conformed with theoretical prediction, R and P did not changed with pressure difference between two sides of material. The test results were stable and reproducible.

Reference:

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