Applied Occupational and Environmental Hygiene
Volume 14(10): 691–695, 1999

1047-322X/99 $12.00 + .00

A Study on the Relative Breakthrough Time (RBT) of a Respirator Cartridge for Forty-Six Kinds of Organic Solvent Vapors

Shigeru Tanaka,[1] Yoko Nakano,[2] Kazuo Tsunemori,[2] Masahiro Shimada,[2] and Yukio Seki[1]
[1]School of Allied Health Sciences, Kitasato University, Kanagawa, Japan; [2]Sanko Chemical Ind. Co., Ltd., Kanagawa, Japan

The breakthrough time of a commercially available respirator cartridge was measured for 46 kinds of organic solvents. The condition of the test air flow was set according to the Japanese government standard for the National Approval Test: at 300 ppm of an organic solvent vapor concentration, a temperature of 20°C, a relative humidity of 50 percent, and a flow rate of 30 L/min. The interval between the start of passing the test flow through a cartridge and the time when the concentration of organic solvent vapors at the downstream of the cartridge reached 5 ppm was measured. The ratios of breakthrough times of organic solvents to that of cyclohexane which is designated as the standard test vapor in Japan, were calculated to obtain the relative breakthrough times (RBTs). Nine of the 46 organic solvents had breakthrough times shorter than that of cyclohexane, and these organic solvents with shorter RBTs were characterized by low boiling points and small molecular weights. The RBTs of 34 organic solvents were compared with the breakthrough times reported by Nelson et al. The relationship between the RBTs of this experiment and those reported by Nelson correlated well (correlation coefficient: 0.861).

Keywords Breakthrough Test, Organic Solvent, Respirator Cartridge, Cyclohexane, Relative Breakthrough Time

The National Approval Test of the Japanese government requires that a respirator cartridge should have a breakthrough time longer than 50 minutes until the concentration of 5 ppm at the downstream of the respirator cartridge is detected, while the test airflow was conditioned at 30 L/min with 300 ppm of cyclohexane vapor, a temperature of 20℃ and 50 percent relative humidity. The data on the breakthrough time of the respirator cartridge for removing cyclohexane is attached to the commercial cartridges, but no breakthrough times of the respirator cartridges for other organic solvent vapors are provided. This lack of information may be one of the major reasons for improper use.(1) There have been numerous studies on breakthroughs in respirator cartridges,(2–5) but there have been only a few reports on Japanese products.(6–8)

The present study was intended to confirm the efficiency of a commercially available respirator cartridge for the 46 kinds of organic solvents defined by the Ordinance on the Prevention of Organic Solvent Poisoning in Japan. The breakthrough test was examined under the same conditions as those defined by the National Approval Test of the Japanese government. The ratio of the breakthrough time of each organic solvent to that of cyclohexane was calculated to obtain the relative breakthrough time (abbreviated as RBT). The present results were compared with the RBTs for the same organic solvents reported by Nelson et al.(2)

MATERIALS AND METHODS

A commercially available respirator cartridge filled with 22 g of activated carbon, G-31 (Sanko Chemical Ind. Co., Tokyo) was used for this experiment. The schematic diagram of the apparatus for measuring the breakthrough time of the respirator cartridge is illustrated in Figure 1. The solvent vapor was generated by bubbling nitrogen in the scrubbers while controlling the flow rate of nitrogen with a mass flow controller (400MARK II, SEC Co., Tokyo), then was introduced into the mixing chamber. The diluted gas was adjusted to a temperature of 20℃ and relative humidity of 50 percent by means of a humidity controller (AHC-1, Ace Kenkyujo Co., Tokyo) before being sent to the mixing chamber. The concentration of the organic solvent vapor was adjusted to 300 ppm by controlling the bubbling flow rate for

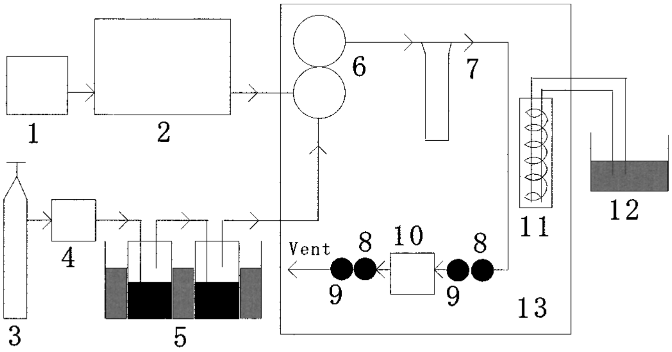

FIGURE 1
A schematic diagram of the apparatus for measuring the breakthrough times of respirator cartridges: 1. Compressor; 2. Humidity sensor controller (AHC-1); 3. N_2 cylinder; 4. Mass flow controller; 5. Scrubber (organic solvent); 6. Mixing chamber; 7. Flow meter; 8. Sampling point; 9. Temperature and humidity probe; 10. Testing cartridge; 11. Fan; and 12. Constant temperature box.

the organic solvent scrubbers and the diluting gas flow rate. The total airflow was passed through the respirator cartridge at the flow rate of 30 L/min. The vapor concentration was measured both upstream and downstream of the respirator cartridge using a gas chromatograph equipped with a hydrogen flame ionization detector (GC-8A Shimadzu Co., Kyoto) at five-minute intervals. The interval from the start of passing the test flow till the time when the vapor concentration at the downstream of the respirator cartridge reached 5 ppm was measured three times, and the average was calculated.

The ratio of the breakthrough time of each organic solvent to that of cyclohexane was calculated in order to determine the RBT. (RBT = [breakthrough time of the organic solvent (min)]/[breakthrough time of cyclohexane(min)].)

RESULTS AND DISCUSSION

Figure 2 shows the relationship between the boiling point (BP: ℃) and RBT of each organic solvent. The correlation was expressed by a regression equation of RBT = 0.0086BP + 0.3334 with a coefficient of 0.771. Nine of the 46 organic solvents had breakthrough times shorter than that of cyclohexane (124 minutes), i.e., a RBT of less than 1.0. The nine are: methanol (RBT: 0.02), dichloromethane (0.23), carbon disulfide (0.41), acetone (0.51), methyl acetate (0.63), ethyl ether (0.65), chloroform (0.78), n-hexane (0.88) and 1,2-dichloroethylene (0.89). These organic solvents are characterized by low boiling points and small molecular weights. The homologous organic solvents were classified as shown in Figure 3 to assess the correlation between the boiling point and RBT. The correlation coefficients were calculated to be 0.943 for aromatic hydrocarbons, 0.865 for chlorides, 0.834 for ketones, and 0.954 for cellosolves, and were higher than that of the total organic solvents (0.771). Figure 4 shows the relationship between the molecular weight (MW) and RBT of the organic solvents. The correlation was expressed as follows: RBT = 0.0056 MW + 0.7144 (correlation coefficient: 0.334). Freedman et al.[9] and Matsumura[10] found that compounds with lower boiling points and smaller carbon numbers exhibited shorter breakthrough times among homologous organic compounds. The present results were consistent with the findings reported so far.

Nelson et al.[2] tested an active carbon packed bed for a breakthrough test against the vapors of 121 organic solvents, and determined the breakthrough time of a respirator cartridge model containing 56 g of activated carbon for solvent vapors at a concentration of 1000 ppm at temperature of 22 ℃, relative humidity of 50 percent, and flow rate of 53.3 L/min. They reported the breakthrough times for the 34 organic solvents among the 46 organic solvents we examined in our study. To compare the results of the same kinds of vapors measured at different experimental conditions, RBTs of the 34 organic solvents of this study were calculated on the basis of the 10 percent breakthrough time obtained by Nelson et al. and compared with the RBTs obtained in Nelson's study. As shown in Figure 5, the regression equation for these two results was Y = 1.06X with a correlation coefficient of 0.861.

CONCLUSIONS

The breakthrough time-challenge gas concentration relation (abbreviated as breakthrough time curve chart) for cyclohexane is attached to all respirator cartridge currently available on the Japanese market. The present study suggests that it is reasonable for safety reasons to consult this breakthrough time curve to estimate the time when a respirator cartridge should be discarded. Caution is required, however, when respirator cartridges are used for organic solvents with breakthrough times shorter than that of cyclohexane. Respirator cartridge performance is particularly poor when removing methanol, dichloromethane, carbon disulfide, and acetone, which have extremely small RBTs, and the use of this respirator cartridge for those solvents is considered problematic. Developments of other adsorbents or collectors are suggested to solve this problem. This study also suggested that the breakthrough times for organic solvents not tested in the current study are predictable on the basis of the boiling points of the homologous organic solvents.

ACKNOWLEDGMENTS

The authors are deeply indebted to Dr. Yoshimi Matsumura, the Technology Institution of Industrial Safety, for her valuable advice during the preparation of this report, and Ms. Miho Nakazawa, Occupational Health Service Center, Japan Industrial Health and Safety Association, for her technical advice.

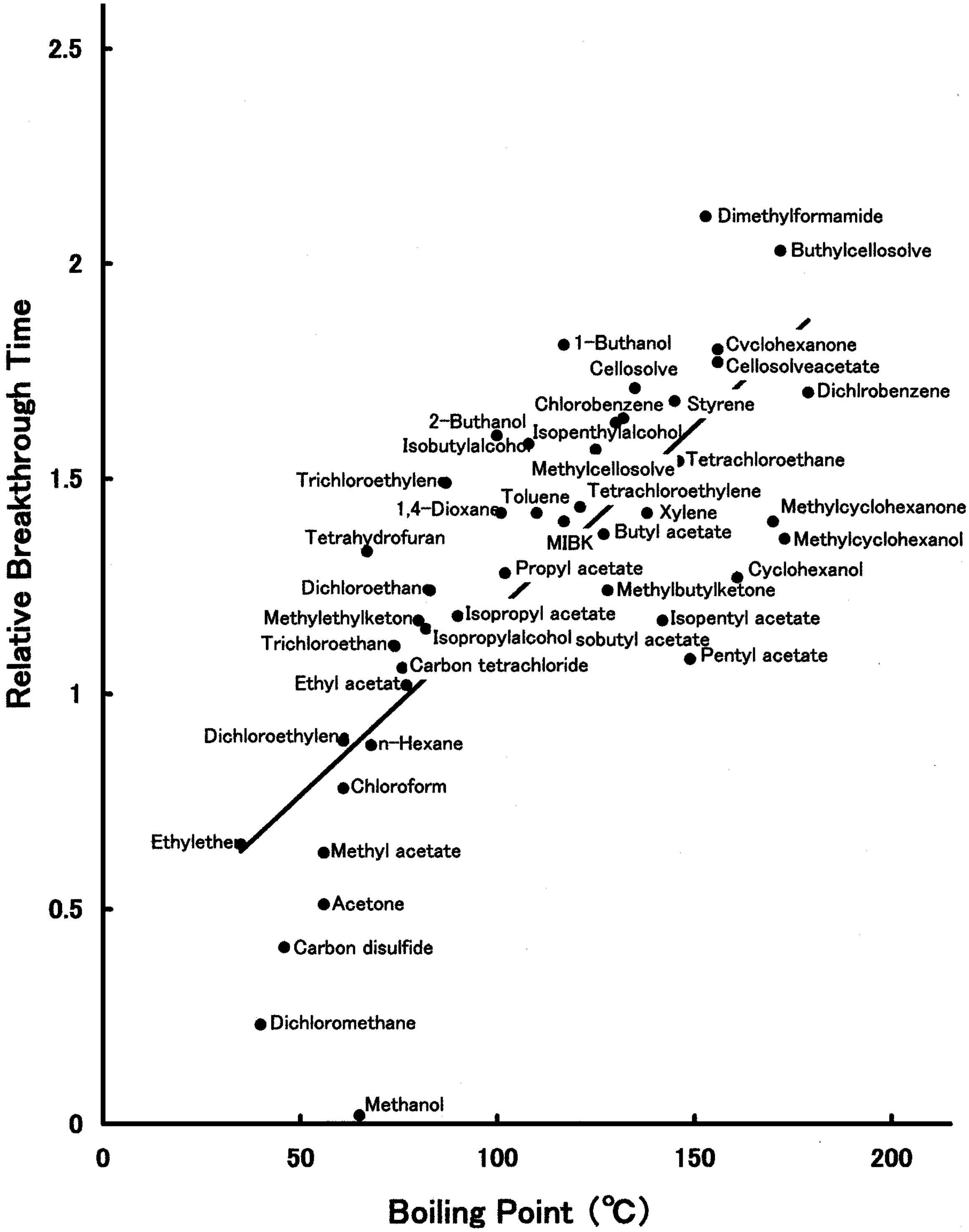

FIGURE 2

The relationships between the boiling point and RBT of each organic solvent.

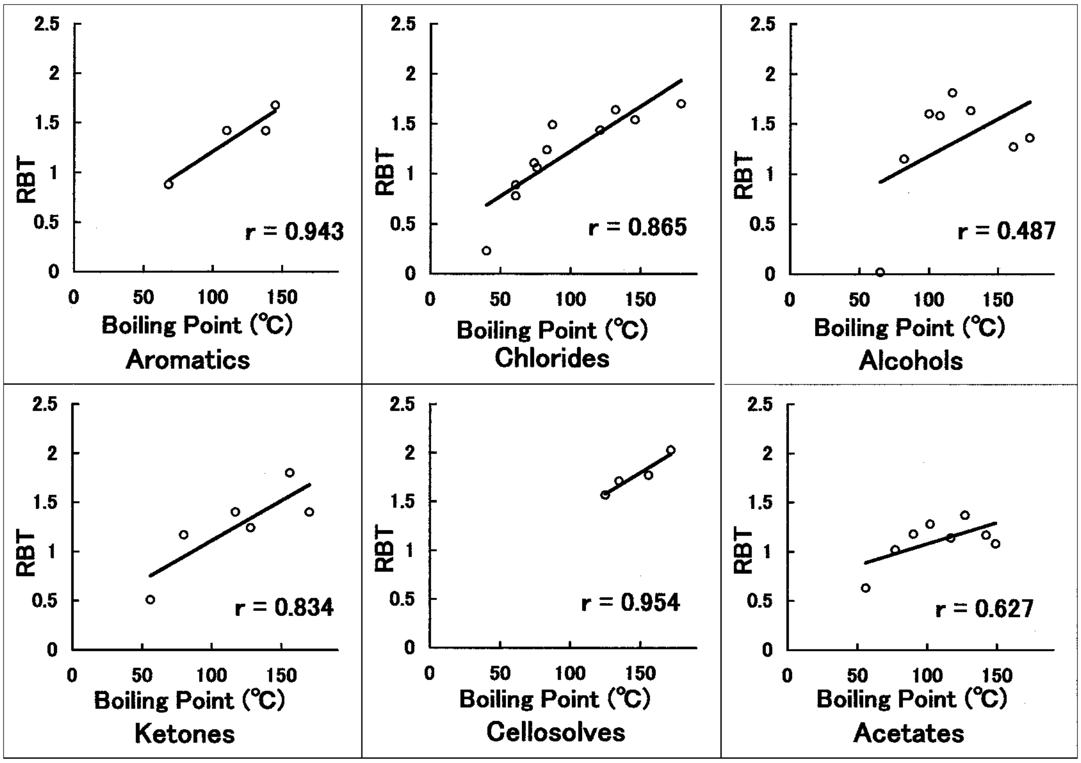

FIGURE 3
The relationship between the boiling point and RBT of homologous organic solvents.

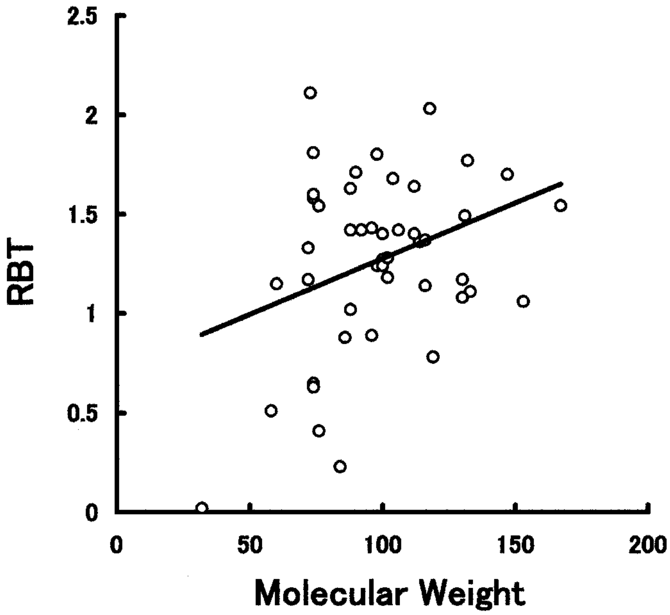

FIGURE 4
The relationship between the molecular weight and RBT of each organic solvent.

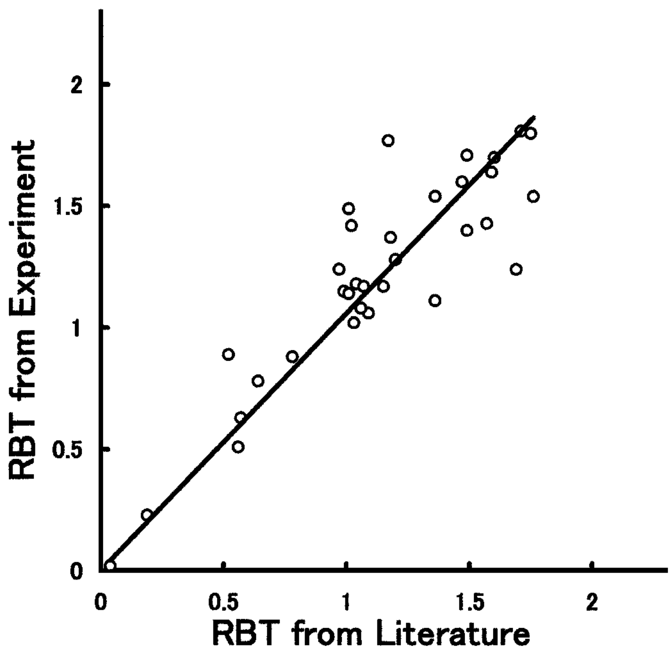

FIGURE 5
The relationship between RBT obtained from literature[(2)] and this experiment.

REFERENCES

1. Ministry of Labor Japan: General Guidebook on Industrial Health, pp. 202–206 (1993), pp. 216–222 (1994), pp. 226–231 (1995), pp. 236–239 (1996), pp. 234–237 (1997). Japan Industrial Safety & Health Association, Tokyo (in Japanese) (1993, 1994, 1995, 1996, 1997).
2. Nelson, G.O.; Harder, C.A.: Respirator Cartridge Efficiency Studies: V. Effect of Solvent Vapor. Am Ind Hyg Assoc J 35:391–399 (1974).
3. Nelson, G.O.; Harder, C.A.; Bigler, B.E.: Respirator Cartridge Efficiency Studies: VI. Effect of Concentration. Am Ind Hyg Assoc J 36:205–216 (1976).
4. Wood, G.O.: Estimating Service Lives of Organic Vapor Cartridges. Am Ind Hyg Assoc J 55:11–16 (1994).
5. Yoon, Y.H.; Nelson, J.H.: Breakthrough Time and Adsorption Capacity of Respirator Cartridges. Am Ind Hyg Assoc J 53:303–316 (1992).
6. Matsumura, Y.: Filtration Efficiency of Gas Mask Canisters. J Ind Hyg Jpn 19:25–35 (1980) (in Japanese).
7. Kimura, K.; Ito, A.; Tanaka, M.; Tanaka, S.: A Study on the Estimation of Breakthrough in a Respirator Cartridge. J Sci Labour 65:391–402 (1989) (in Japanese).
8. Tanaka, S.; Tanaka, M.; Kimura, K.; Nozaki, K.; Seki, Y.: Breakthrough Time of a Respirator Cartridge for Carbon Tetrachloride Vapor Flow of Workers' Respiratory Patterns. Ind Health 34:227–236 (1996).
9. Freedman, R.W.; Ferber, B.I.; Hartstein, A.M.: Service Lives of Respirator Cartridge Versus Several Classes of Organic Vapors. Am Ind Hyg Assoc J 34:55–60 (1973).
10. Matsumura, Y.: Breakthrough Times of Active Carbon Tubes for Sampling Organic Vapors. Jpn Ind Health 25:512–522 (1983) (in Japanese).