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Influence of Ambient Temperature on TVOC Released from Polyurethane Athletics Track †

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Abstract: The athletics track consists of multiple organic hydrocarbons and their derivatives, which are easy to release TVOC under specific conditions such as high temperature. Taking polyurethane athletics track as the research object, the TVOC release of an athletics track is carried out in a 0.1 m^3 environmental chamber, and TVOC mass concentration detection is performed using a TVOC gas detector. The results show that the increase in ambient temperature will promote the release of VOCs from a PU athletics track, and the increase rate and decline rate of TVOC mass concentration will increase with the increase in ambient temperature. The increase in ambient temperature will result in a significant shortening of the rapid release of VOCs released from a PU athletics track and a prolonged slow-release period. The ambient temperature rises, the maximum and 24 h value of TVOC mass concentration of the PU athletics track are steadily increasing, and this trend is more significant in the high-temperature section. The research conclusions can provide a basis for the improvement of athletics tracks.

Keywords: athletics track; TVOC; ambient temperature; environmental chamber; influence

1. Introduction

A good sports environment will greatly inspire the enthusiasm of sportspeople to participate in sports activities. As one of the common sports venues, the sporty and beautiful appearance of the athletics track provides a good sports environment [1].

The pavement material of the athletics track consists of multiple organic hydrocarbons and their derivatives, such as polyurethane (PU) prepolymer, PU rubber particles or Ethylene Propylene Diene Monomer (EPDM) rubber particles, thinner, and adhesive. It is prone to various chemical reactions under specific environment such as high temperature and high humidity, thereby releasing volatile organic compounds [2]. When people exercise on the athletics track, the total volatile organic compounds (TVOC) released from the athletics track can be absorbed by the human body through breathing, skin contact, etc., causing various discomforts of the human body [3–6].

At present, the research on athletics track mainly focuses on toluene diisocyanate, polycyclic aromatic hydrocarbons, TVOC, etc., and the research on TVOC released from athletics track is only on the establishment of a detection method [7–9]. Although some scholars' research methods can detect more than 90 kinds of athletics track VOCs, the release mechanism and influencing factors of TVOC released from athletics track have not been systematically and deeply studied [10,11]. The TVOC released from athletics track is not a single compound, and the composition is not only related to the release source, but is also influenced by environmental factors such as ambient temperature, relative humidity and air exchange rate to a large extent.

Taking the PU athletics track as the research object, this study aims at simulating the real environment to release the TVOC of athletics track and detecting TVOC mass concentration under different temperature conditions by using a small environmental chamber and the TVOC gas detector respectively, so as to clarify the influence of ambient temperature on TVOC released from PU athletics track.

2. Materials and Methods

2.1. Materials

The PU athletics track used in the experiment is a parallel sample from the actual paved athletics track. The surface area is 300.00 × 300.00 mm. The color is reddish brown, and the PU athletics track has a double layer structure with the total thickness (13 ± 2) mm. The lower layer is PU rubber-bonded black rubber particle with the thickness of (10 ± 1) mm, and the upper layer is the mixed spray layer of EPDM particles and PU with the thickness of (3 ± 1) mm. It was sealed in a PTFE film with a thickness of 0.20 mm and stored at (23 ± 2) °C, (50 ± 5)% RH for testing.

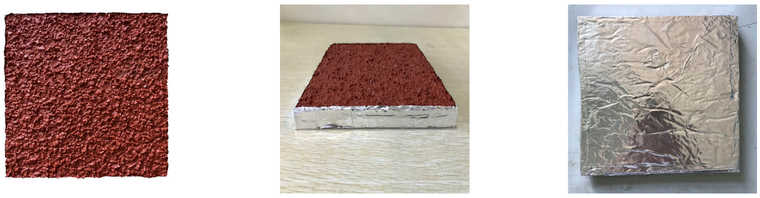
2.2. Main Instrument

1. 0.1 m^3 environmental chamber: QP 21-H4L100 small TVOC release environmental chamber produced by Shanghai Qinpei Environmental Protection Technology Co., Ltd. (Shanghai, China) The environmental chamber release studio size is 400.00 × 500.00 × 500.00 mm (width × depth × height), which uses a stainless steel inner wall, fully enclosed chamber, high-density insulation layer, self-contained temperature, humidity control device and an air purification and cycle intelligent control system;
2. TVOC gas detector: ppbRAE 3000 TVOC gas detector produced by American RAE Company. Using RAE's third-generation Photo Ionization Detector, the ionization potential of the UV lamp source is 10.6 eV, the detection resolution is 1 ppb (part per billion, one billionth), and the detection accuracy is 10–2000 ppm (part per million) of isobutylene calibration point ±3.00%, detection range 1 ppb–10000 ppm;
3. Experimental reagents: deionized water (conductivity is 0.1 $\mu S \cdot cm^{-1}$, Shanghai HUSHI) and alkaline cleaning agent (pH ≥ 7.5, Shanghai HUSHI).

2.3. Experimental Method

2.3.1. Sample Pretreatment

Take out the PU athletics track sample to be tested and cut a square of 200.00 × 200.00 mm from 50.00 mm from the periphery of the sample block pre-equilibrated (24 ± 1) h in a clean environment of (24 ± 3) °C, (50 ± 5)% RH. Then, the pre-balanced sample is sealed and covered with aluminum foil in the thickness direction and the bottom. At the same time, ensure that the bare area of the tested sample exposed in the environmental chamber working room is 0.04 m^2. The sealed and coated PU athletics track samples are shown in Figure 1. Subsequently, the environmental chamber release of the PU athletics track TVOC can be carried out.



(**a**) (**b**) (**c**)

Figure 1. The front (**a**), side (**b**), back (**c**) of a PU athletics track sample sealed and covered with aluminum foil.

2.3.2. Instrument Pretreatment

Pretreatment of the environmental chamber: clean the inner surface of the environmental chamber with alkaline cleaner and water, and then wash it twice with deionized water. Subsequently, close the door and warm the chamber to 160 °C to fully resolve and drain the chemical on the surface of the bulkhead, and then cool the environmental chamber to the predetermined temperature. The background value of single VOCs in the cleaned environmental chamber is less than or equal to 2 $\mu g \cdot m^{-3}$ and the background value of TVOC is less than or equal to 20 $\mu g \cdot m^{-3}$.

Pretreatment of ppbRAE 3000 TVOC gas detector: use high purity nitrogen and 10.00 ppm isobutylene (air as carrier gas), respectively, for zero calibration and extended calibration of ppbRAE 3000 TVOC gas detector. Then, set the detector's sampling flow rate to 500.00 $mL \cdot min^{-1}$ after the calibration is completed, sampling pump duty cycle 100%. The ppbRAE 3000 TVOC gas detector performs zero calibration every time it is turned on for formal testing.

2.3.3. Release the Athletics Track TVOC by the Environmental Chamber

Set environmental parameters such as the temperature, relative humidity and gas exchange rate of the environmental chamber. Specific working conditions are shown in the following Table 1. After the environmental chamber is operated under no-load conditions to the set conditions, the pre-processed athletics track sample block is placed in the center of the parameter-stabilized environmental chamber for TVOC release.

Table 1. The table of Experimental parameter.

Group No.	Temperature (°C)	Relative Humidity (%RH)	Air Exchange Rate ($Times \cdot h^{-1}$)
1	23	55	1.0
2	30	55	1.0
3	35	55	1.0
4	40	25	1.0
5	45	25	1.0
6	50	25	1.0

2.3.4. Measure the TVOC Mass Concentration Released from the PU Athletics Track

Use silicone hose to connect the air outlet of environmental chamber to the air inlet of TVOC gas detector and record TVOC mass concentration after the detector reading is stable.

According to GB 36246-2018 [12], the entire test time of this experiment is determined to last for 24 h. During the whole test process, as the number of VOCs released from the PU athletics track gradually decreased, the measurement time interval gradually increased. During the first 3 h of the test, the TVOC mass concentration is recorded every 0.5 h, which is recorded every 1 h from 3 to 8 h, every 2 h from 8 to 16 h and every 4 h from 16 to 24 h.

3. Results

The influence of temperature on the change of TVOC release over time is mainly caused by the change in the thermal motion and vapor pressure of VOCs released from the athletics track during the temperature changes. Simultaneously, the adsorption capability and capacity of the athletics track for VOCs are also changing. As time goes by, the TVOC mass concentration is constantly changing, which further leads to the change in the above factors, which eventually causes the TVOC mass concentration of PU athletics track to change with time.

When temperature is 23–35 °C and relative humidity is 55%, the TVOC mass concentration of PU athletics track under the temperature conditions changes with the test time, as shown in Figure 2. Under normal temperature conditions, the maximum TVOC mass concentration and 24 h value of PU athletics track increased with the increase in temperature. At 23, 30, and 35 °C, the maximum TVOC mass concentration of PU athletics track is 1390, 1899, and 2522 $\mu g \cdot m^{-3}$, respectively, and the

24 h value is 1317, 1667, and 2149 μg·m−3, respectively. The time when the TVOC mass concentration of PU athletics track reach the maximum at 23, 30 and 35 °C is 6, 6, and 5 h, and the time to balance is 12, 16, and 16 h, respectively.

When temperature is 40–50 °C and relative humidity is 25%, the TVOC mass concentration of the PU athletics track under various temperature conditions changes with the test time, as shown in Figure 3. Under high temperature conditions, the maximum TVOC mass concentration and 24 h value of PU athletics track also increased with temperature. At 40, 45, and 50 °C, the maximum TVOC mass concentration of the PU athletics track is 2686, 3253, and 3836 μg·m−3, respectively, and the 24 h values are 2197, 2600, and 2796 μg·m−3, respectively. When the temperature is 40, 45, and 50 °C, the time taken to reach maximum is 5, 4, and 4 h, and the time to balance is 16, 20, and 20 h, respectively.

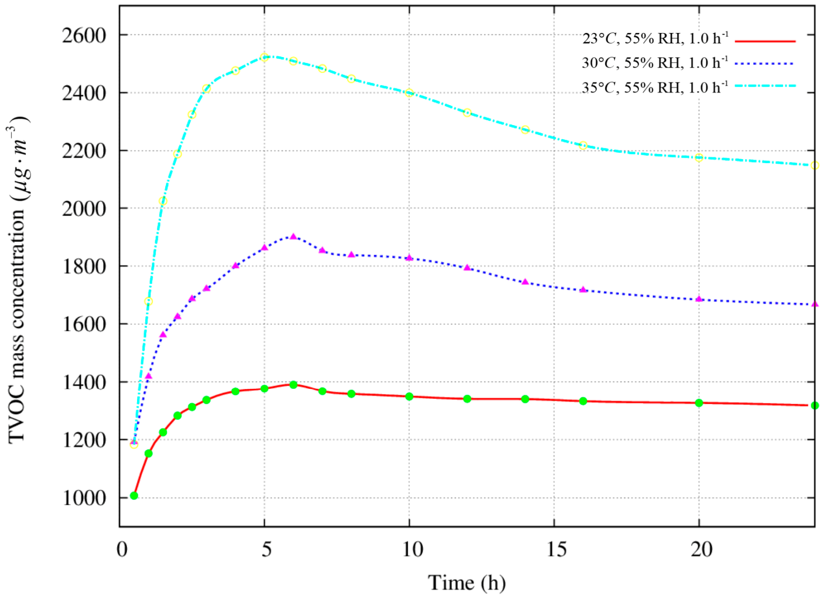


Figure 2. The total volatile organic compounds (TVOC) mass concentration of polyurethane (PU) athletics track changes with time from 23 to 35 °C.

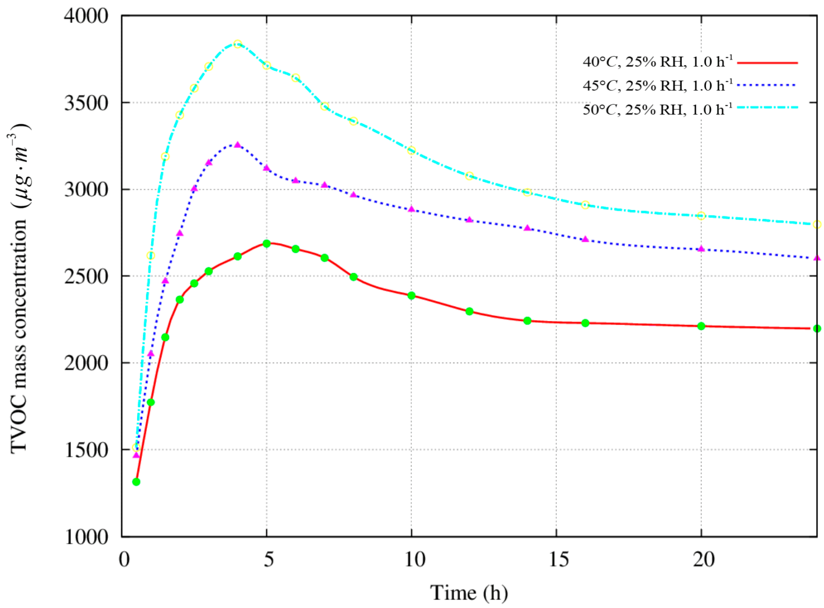


Figure 3. The TVOC mass concentration of PU athletics track changes with time from 40 to 50 °C.

4. Discussion

1. As the temperature increases, the TVOC mass concentration release from PU athletics track gradually increases. At the same time, both the increase rate and the decrease rate increase with the increase in temperature during the increase or decrease in the TVOC mass concentration of the PU plastic track.
   According to the Antoine equation
   $$\lg P = A - \frac{B}{(T + C)} \tag{1}$$
   where *A*, *B*, *C* are physical property constants, which vary with the compound, and are greater than 0, *P* is the vapor pressure of compound, *T* is thermodynamic temperature, *T* = t °C + 273.10.
   In the Antoine equation, the *A*, *B* and *C* values of different substances are constant. As the temperature increases, the vapor pressure of VOCs also increases, which promotes VOCs' in PU athletics track release to the air, resulting in an increase in the TVOC mass concentration.
   At the same time, the diffusion coefficient of VOCs in the PU athletics track also directly affects the release of PU athletics track VOCs. According to the Arrhenius equation
   $$K = Ae^{-\frac{Ea}{RT}} \tag{2}$$
   where *K* is the reaction rate constant at a certain temperature, *R* is a molar gas constant, *T* is thermodynamic temperature, *T* = t °C + 273.10, *Ea* is the diffusion activation energy and can generally be regarded as a constant independent of *T*, *A* is pre-factor and the unit is the same as *K*.
   The increase in temperature in the environmental chamber leads to an increase in the thermal motion of VOCs, and the number of activated molecules involved in the reaction is significantly increased, resulting in a significant increase in the reaction rate. Thermodynamic temperature is the exponential term of the Arrhenius equation, resulting in a higher temperature the more the reaction rate increases. Therefore, as the temperature increases, either the increase rate or decrease rate increase in the process of the TVOC mass concentration released from the PU athletics track increasing or decreasing;
2. The release of TVOC from athletics track changed significantly over time in the early stages of testing, and it showed a rapid increase first and, after reaching the maximum mass concentration, it fell at a certain speed and eventually became balanced. In general, the release process of TVOC from PU athletics track can be divided into three phases: rapid release period, slow release period and stable release period;
3. As the temperature changes, the duration of the three phases of TVOC released from PU athletics track is obviously inconsistent. As the temperature rises, the TVOC mass concentration emission from athletics track will reach the maximum faster, and the period of equilibrium will be longer. This indicates that the increase in temperature will directly lead to the rapid release period being significantly shortened, and the slow release period being significantly prolonged;
4. At the end of the slow release period, the TVOC released from PU athletics track will reach a dynamic balance. That is, the TVOC released from PU athletics track is substantially equal to the TVOC mass concentration taken by the pure air cycle. The lower the temperature, the faster the TVOC released from PU athletics track will reaches dynamic balance, and the shorter the time needed to reach the stable release period;
5. The influence of ambient temperature on TVOC released from PU athletics track is very significant. The maximum mass concentration and 24 h value of TVOC steadily increased when ambient temperature increased. This is due to the fact that, during the process of ambient temperature increasing, the thermal motion of VOCs in the PU athletics track is gradually enhanced, while the adsorption capability and adsorption capacity of the VOCs in the PU athletics track are gradually reduced, causing a large release of VOCs in the PU athletics track and an increase the TVOC mass concentration released from PU athletics track.

5. Conclusions

In this study, the influence of ambient temperature on the TVOC mass concentration released from PU athletics track was analyzed. The main conclusions are as follows: the increase in ambient temperature will promote the release of VOCs and increase the mass concentration of TVOC on the PU athletics track. Both the increase rate and the decrease rate increase with the increase in ambient temperature during the increase or decrease in the TVOC mass concentration released from PU athletics track. The increase in ambient temperature will directly lead to the rapid release period being significantly shortened, and the slow release period being significantly prolonged. The maximum mass concentration and 24 h value of TVOC have steadily increased when ambient temperature increased, and this trend is more pronounced in the high temperature range.

Overall, the research conclusions can provide a basis for the improvement of the athletics track.

Author Contributions: G.L. and W.Z. conceived and designed the study. G.L. performed the experiments. H.W. performed the data analyses. W.Z. helped perform the analysis with constructive discussions. G.L. wrote the paper. All authors reviewed, edited and approved the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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