Gas Detection Tape

Nahid Mohajeri, Advanced Polymer Technology GM, Nitto Inc., Merritt Island FL
Jen-Chieh Liu, Senior Product Development Chemist, Nitto Inc., Merritt Island FL
Anna Balenko, Chemist, Nitto Inc., Merritt Island FL

Introduction

Industrial gas detectors are crucial for ensuring the overall safety of the working environment with hazardous gases. These devices/systems can detect/monitor the leaks of hazardous gases and send out alarm signals to initiate safety responses. However, these devices can only detect the presence of a leak and are not very helpful with identifying the "Where". Examining and securing the leak location is always labor intensive and time-consuming, as well as a safety hazard. As a result, accurately detecting the leak source is very critical for reducing time, cost, and safety concerns.

Hydrogen gas (H_2) which is colorless, odorless, non-toxic, and highly combustible is commonly used in power generation, chemical industry and serves as the leading option for storing renewable energy. Ammonia gas which is colorless corrosive, flammable, and toxic in a confined space is widely used as a refrigerant gas and is also under consideration as a renewable fuel. Both gases can cause severe fatal accidents when leaks occur. Two gas detection tapes have been developed to visually detect hydrogen and ammonia gas leaks in an industrial operating environment. These tapes consist of silicone-based adhesives blended with chemochromic pigments/reactants which change color during exposure to hydrogen or ammonia gas. Compared to conventional detection products, these tapes allow for more flexibility by being easily applied/wrapped around potential leak locations to allow for even small leaks to be detected. They are less influenced by wind, position, duration, and operation skills. This leak location can be easily identified with a visible color change. Moreover, these tapes are designed for both indoor and outdoor environments. The silicone adhesive allows for a wide operational temperature range. The lowest gas concentration which can be detected is 10,000 ppm (1%) for hydrogen, and 220ppm for ammonia gas, respectively. A lower operational temperature or low gas concentration results in a slower color change rate. The reaction (color change) is irreversible for hydrogen detection tape and long lasting (greater than 72 hours) for ammonia detection tape within the operational temperature.

Hydrogen gas (H_2) detection tape

Tape structure

The hydrogen detection tape was comprised of a polyimide backing film and a silicone adhesive layer blended with the H_2 gas detection pigment, as shown in Figure 1. The inorganic pigment, which has better UV resistance as compared to organic type pigments for outdoor application, was designed to react with H_2 gas and create color change.

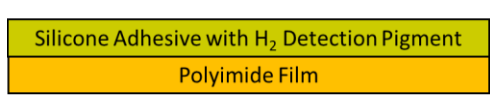

Figure 1. The hydrogen gas detection tape structure

Color change percentage

The tape provides a permanent color change from amber to black when is exposed to H_2 gas. The degree of color change was measured as L difference (CIE color space) before and after gas exposure by using the colorimeter (Color-Tec PCT+). A full, or maximum, color change (100% color change) was determined by having maximum L difference when exposing 100% hydrogen gas at ambient condition.

Gas concentration and flow rate effect on tape's color change

The tape's color change rate was influenced by hydrogen gas concentration and gas flow rate. The hydrogen gas concentration effect on color change rate was shown in the Figure 2. At fixed 6ml/min flow rate, the tape had full color change in less than 5min when exposed to 100% H_2 gas. However, after 30hr exposure, the tape only reached to 60% color change with exposing to 1% H_2 concentration air mixture at 100ml/min flow rate. The higher color change rate was due to the pigment had higher contact (interaction) rate at higher hydrogen gas concentration. On the contrary, there was less chance having H_2 to interact with pigment in adhesive layer when the gas concentration is lower which resulted in longer time to observe the color change.

The percentage of color change also indicted how easily the color change can be visually detected after hydrogen gas exposure. A full color change can provide an obviously visual contrast as shown in the blue box amber/black contrast for 100% H_2 gas in the Figure 2. There was also a clear visual contrast at 60% color change (amber/black contrast) (Figure 2 yellow box) for 1% H_2 gas in air after 30 hrs of exposure time. Based on the lower visual contrast of color change and required long exposure time with even lower H_2 concentration, the detection limit of the hydrogen detection tape can be defined as 1% H_2 concentration.

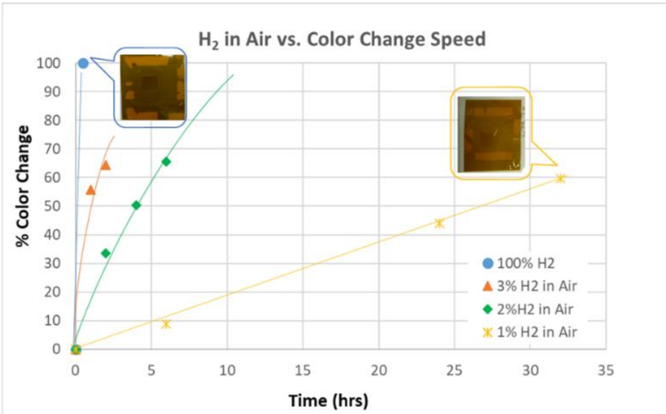

Figure 2. The hydrogen tape color change rate as the function of hydrogen concentration

The 3% H_2/air mixture was selected for studying the gas flow rate influence on tape color change rate. As shown in Figure 3, after two hours exposure, the tape had 65% color change with 100ml/min flow rate as compare to 35% color change with 25ml/min flow rate. Higher flow rate means higher flux of hydrogen gas can diffuse in the adhesive layer and interacted with the pigment which resulted in a fast color change rate.

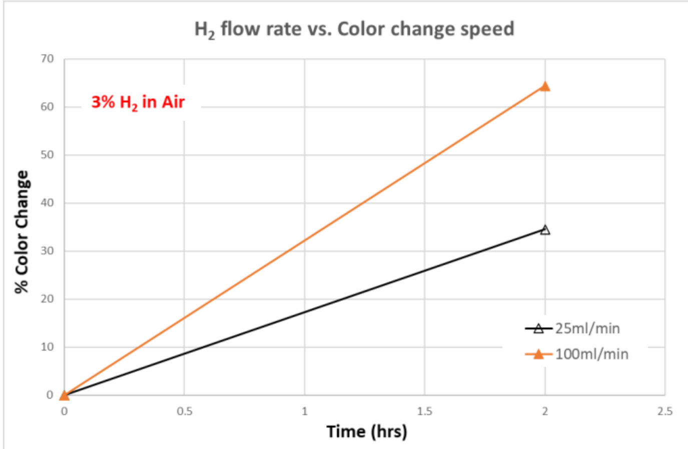

Figure 3. The hydrogen tape color change rate as the function of flow rate at 3% H_2/air mixture gas

Temperature effect on tape color change

The tape color change rate was also influenced by the environment temperature. The tape's rate of color change was tested by being exposed 100% H_2 gas with 6ml/min flow rate. The required time for 85% tape color change was recorded as the function of temperature as shown in Figure 4, which was a non-linear correlation between tape color change and temperature. The color change rate was higher at higher temperature. The tape only required 1.7min to reach 85% color change at 80^{o}C, but it took 30hrs at -70^{o}C. This can be explained as the hydrogen gas had higher reaction rate to pigment at higher temperature. The reaction rate was slow down at low temperatures.

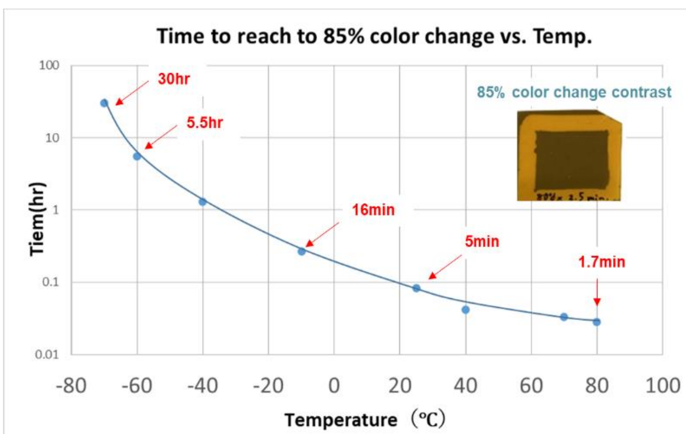

Figure 4. The hydrogen tape color change rate as the function of temperature at 6ml/min flow rate with 100% H_2 gas

Ammonia gas (NH_3) detection tape

Tape structure

The ammonia detection tape was comprised of a polyester backing film, a silicone adhesive layer blended with the pigment and polyester liner, as shown in Figure 5. Ammonia detection tape also used an inorganic pigment for reacting with ammonia gas to create color change.

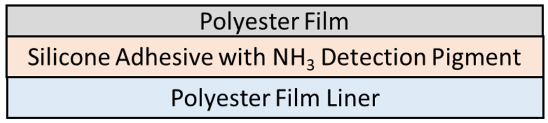

Figure 5. The ammonia gas detection tape structure

Ammonia detection tape color change percentage

The tape has color change from white to blue/green when exposed to NH_3 gas. Unlike hydrogen detection tape, the color change of ammonia tape is reversible. The color change retention time is over 24hrs, typically over 3 days, depending on exposure condition. Instead of measuring L, the degree of color change was measured as b* difference (CIE color space) before and after gas exposure by using the colorimeter (Color-Tec PCT+). A full, or maximum, color change (100% color change) was determined by having maximum b* difference when the tape exposed to 7.5% ammonia gas at ambient conditions.

For ammonia detection tape, because the ammonia gas and pigment interaction is reversible, the tape may present different shades of color from blue/green (100% color change) to light blue (~20% color change) as shown in Figure 6.

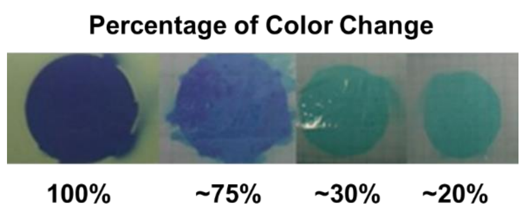

Figure 6. The ammonia gas detection tape color change reference guide

Gas concentration effect on tape color change

Ammonia gas was blended with air to prepare various ammonia gas concentration from 7.5% to 25ppm. Tape color change was tested at fixed 110ml/min gas flow rate. In the Figure 7, the tape had full color change at 7.5% and 0.27% NH_3 concentration after gas exposure 15min and 7hr, respectively. At 220ppm NH_3 concentration, the tape did not reach full color change, but only had ~ 20% color change after 16hr exposure. There was no obvious visual color change when the tape exposed to 50ppm and 25ppm NH_3 gas concentration even after long 16 – 18hrs exposure. As a result, the detection limit of the ammonia detection tape was determined at 220ppm gas concentration. Similar to hydrogen detection tape, at lower ammonia gas concentration, ammonia gas has less chance to interact with pigment in the adhesive layer which resulted in longer color change time.

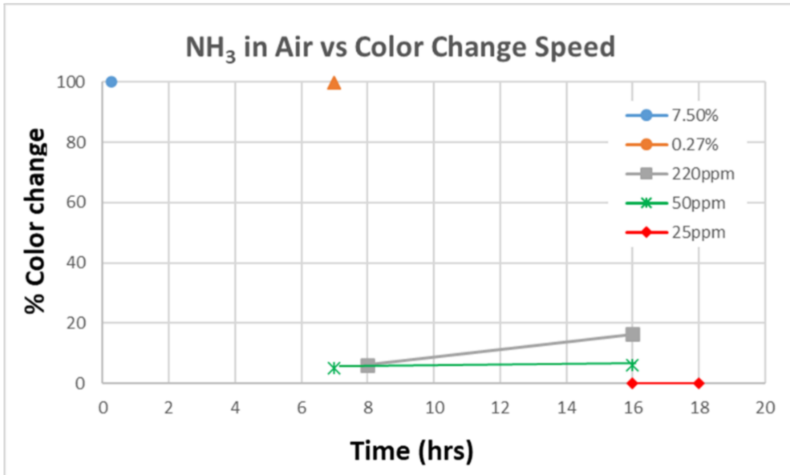

Figure 7. The ammonia tape color change rate as the function of ammonia/air mixture at 110ml/min flow rate.

Temperature effect on tape color fading

Since the interaction between ammonia gas and pigment is reversible, the changed color starts to fade away when the gas exposure is stopped. The test samples were exposed to ammonia gas to reach the full color change, and then measured the color fading at various temperature environments. The color fading rate as the function of temperature is shown in the Figure 8. At higher temperature environment, the color changed tape had faster color fading rate. The tape's color reversed back to ~20% color change after 4hrs at 100^{o}C and 120^{o}C environment. The tape still maintained ~60% color change at 40^{o}C environment after 72hrs.

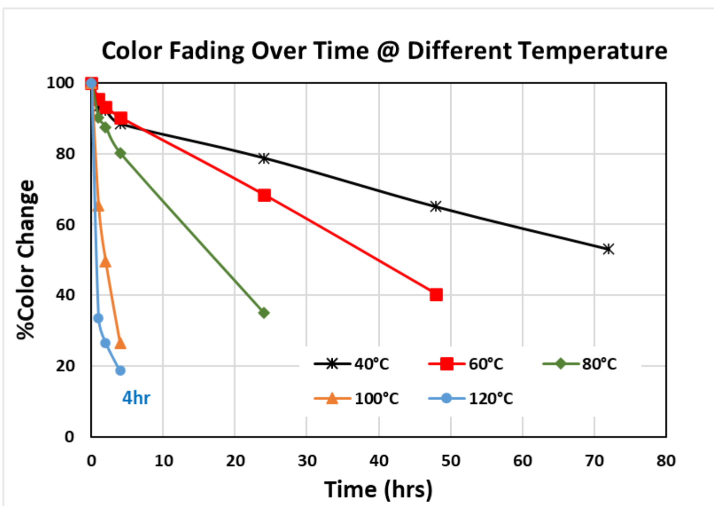

Figure 8. The ammonia tape color fading rate as the function of the temperature after tape reached to 100% color change and then stopped gas exposure.

Temperature effect on tape color change

The tape color change ability was also influenced by the environment temperature. The tape was tested the color change percentage by being exposed 7.5% NH_3 gas with 15ml/min flow rate at various temperatures for 1hr. Figure 9 showed that the tape had 100% color change at ambient conditions (25°C). However, at same gas exposure time, the tape only achieved 90% and 65% color change at 80°C and 90°C, respectively. The highest temperature which the tape still had good visually detectable color change (20% color change) was at 120°C environment.

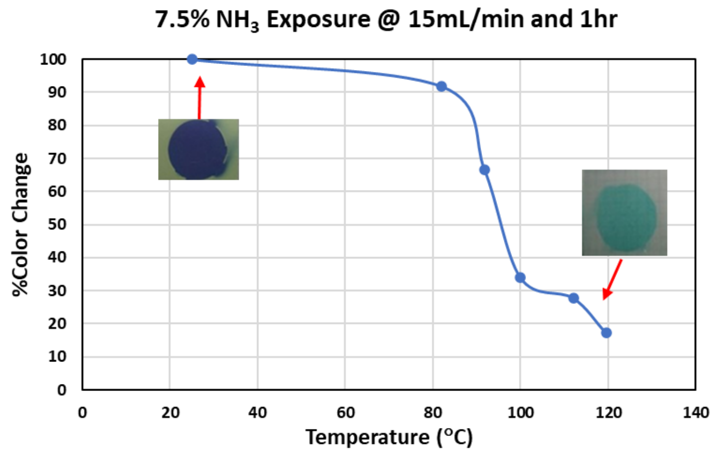

Figure 9. The ammonia tape color change ability as the function of temperature after exposed 7.5% NH_3 gas one hour with 15ml/min gas flow rate.

The tape was also tested for the color change ability at low temperatures. The tape was covered and sealed in a vial contained 30% aqueous ammonia solution and measured the time making the tape to have full color change by ammonia vapor in the vial, as shown in Figure 10. The tape still had the color change ability at -20°C which took 10min to have full color change. At higher temperature (60°C), only 1 min was required to make the tape have full color change.

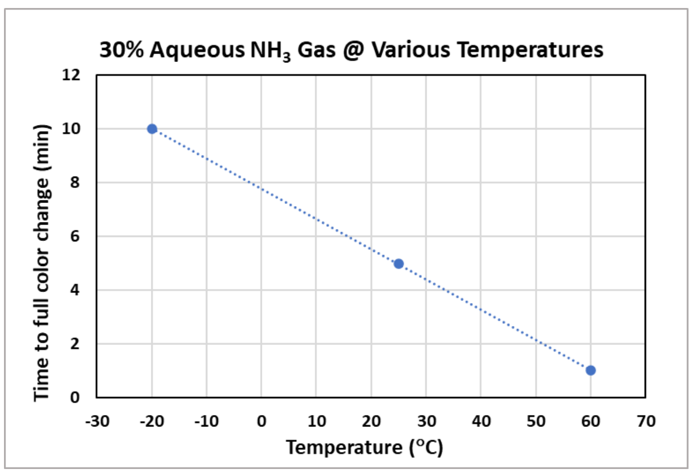

Figure 10. The ammonia tape color change ability as the function of temperature by testing with 30% aqueous ammonia solution.

Conclusion

Two gas detection tapes (hydrogen gas and ammonia gas) have been successfully developed. The inorganic pigments were used and well-mixed in the silicone adhesive which allowed the tapes to have wider operation temperature and good outdoor durability application. The hydrogen detection tape had permanent color change after exposed to hydrogen gas. The color change rate/ability was influenced by gas concentration, flow rate and environment temperatures. The tape can operate from -75^{o}C to 80^{o}C with an obvious visual contrast color change, and the gas concentration detection limit was at 1% hydrogen concentration at ambient conditions. As for ammonia detection tape, the color change was reversible (color fading), but the color change retention time was over 24hrs, typically over 3 days, depending on exposure condition. The tape still had a good visual color change contrast at operation temperature between -20^{o}C to 120^{o}C and the gas concentration detection limit was 220ppm ammonia concentration at ambient conditions.