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Patrick Coughlan
Chemours Fluoroproducts, United States of America, patrick.r.coughlan@chemours.com

Nina Gray
Chemours Fluoroproducts, United States of America, nina.e.gray@chemours.com

Mary Koban
Chemours Fluoroproducts, United States of America, mary.e.koban@chemours.com

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Patrick Coughlan[1]*, Nina Gray[2], Mary Koban[3]

[1,2,3] The Chemours Company
974 Centre Road, Wilmington, DE, 19805, USA, [1]Patrick.E.Coughlan@chemours.com
[2]Nina.E.Gray@chemours.com, [3]Mary.E.Koban@chemours.com

* Corresponding Author

ABSTRACT

Transitioning to low global warming potential (GWP) refrigerants will be critical as the world rises to solve the issues of climate change. Finding low GWP alternatives for HVAC equipment which can be safely used and serviced in varying applications is the new challenge. An interesting class of low GWP alternatives is the “mildly flammable” or class 2L refrigerants. ISO 817 and ANSI/ASHRAE Standard 34 both employ the “mildly flammable” or “2L” refrigerant classification (1,2). Class 2L refrigerants are not easily ignited due to their relatively high minimum ignition energy (MIE) and high lower flammability level (LFL) compared to class 3 refrigerants (3,4). Therefore, the traditional autoignition test (AIT), which has been used for standards and equipment design may not be the appropriate parameter to define mildly flammability refrigerants (5). A more relevant test may be the hot surface ignition test (HSIT), where the 2L refrigerant is released onto a hot surface and monitored for subsequent ignition or non-ignition under dynamic conditions (6). HSIT data was presented in earlier papers using Annex KK of the IEC 60335-2-40 standard as a framework (7,8). This current study builds on previous information and further expands that work (7,8,9,10,11). Specifically, the HSIT test was updated by adding a cylindrical tube to confine refrigerant after releasing onto the hot surface. The cylindrical tube was added to simulate the confinement found in HVAC ductwork. Additionally, the planchet designed was improved and heat insulation board specified.
Data are presented for different A2L refrigerants in this updated HSIT design. The updated HSIT method shows more differentiation between refrigerants, particularly as temperatures, are observed between 800°C and 850°C.

1.INTRODUCTION

Previously, work was conducted to review potential hot surface ignition/non-ignition events for various A2L refrigerants (7,8,9,10,11). From that work, a preliminary refrigerant hot surface ignition test (HSIT) method was developed for use in the IEC and UL standard frameworks (12,13). The preliminary refrigerant HSIT test method is found in “Annex KK” of both standards (12,13).

Since the HSIT test method is newly developed and based on information found in equipment standards, IEC 60335-2-40 and UL 60335-2-40, there is no commercial equipment readily available. Therefore, it is important to understand how design parameters can impact test result and correctly define the required parameter without over specifying equipment design.

Therefore, the objective of this study was to:

1) investigate hot surface equipment parameters
2) implement potential equipment improvements and then
3) generate data for several A2L refrigerants based on the improved HSIT design

2. HOT SURFACE IGNITION TEST EQUIPMENT

As discussed in several technical papers (7,8), this hot surface ignition experimental test set-up was designed to simulate a sudden, catastrophic leak of liquid refrigerant onto an exposed heating element. The heated surface portion of the test apparatus consisted of a 35.6 cm by 35.6 cm (14 in by 14 in) ceramic heating element (MHI HP220-HIGHBO-1250) with a 5 cm (2 in) 316 stainless steel round planchet placed on top of the ceramic heating element. Even though the ceramic heating element has a 22.9 cm by 22.9 cm (9 in by 9 in) metal surface and can theoretically reach temperatures up to 1250°C (2280°F), it is difficult to keep this area at a constant temperature during the testing. Therefore, the ceramic heating element was used to provide uniform heat to the much smaller 5 cm (2in) round metal planchet which was in contact with the ceramic plate. Heat loss is controlled by adding insulation boards to the ceramic heating surface. Gemcolite® ASM FG30-165050 ceramic insulation board covered the hot plate except for the area cutout for the planchet. A quartz chimney is placed directly above the planchet at a determined gap setting.

3. REFRIGERANT SPRAY SYSTEM

The refrigerant spray system consisted of a 0.3175 cm (0.125 in) stainless steel cylindrical tube with an opening at the release end connected to refrigerant containing cylinder. The tubing had the following dimensions:

Length:	152 mm ± 5.0 mm	(6.0 in ± 0.20 in)
Outer dimension:	3.2 mm ± 0.2 mm	(0.125 in ± 0.01 in)
Inner dimension:	1.6 mm ± 0.1 mm	(0.06 in ± 0.005 in)

An opening was cut at the end of the tubing to create a refrigerant release point. The tubing was cut perpendicular to the axis making a right angle cut. The tip of the refrigerant spray system was placed inside the chimney and maintained 38 mm ± 13 mm (0.15 in ± 0.5 in) above the heated planchet and was directed at the center of the planchet. Figure 1 below shows the placement of the refrigerant spray nozzle, chimney, and planchet.

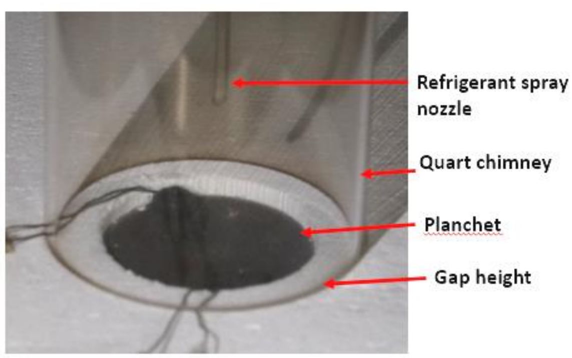

Figure 1- placement of several key components

4. ENCLOSURE

Testing was performed in a draft free enclosure contained within a laboratory fume hood. Ventilation was off during the testing. Dimensions of the enclosure were 14.5 cm (37 in) in length by 18.9 cm (48 in) in depth with a height of 22 cm (56 in). The enclosure was completely sealed except for the opening to the back of the hood which facilitates venting.

5. TEST METHOD

The planchet was heated until a steady test temperature of 800 °C (1472 °F) with +/- 10 °C (+/-18 °F) is maintained for 5 minutes. Approximately five grams of liquid refrigerant (at room temperature) was discharged directly onto an 800 °C (1472 °F) planchet which was contained within the static enclosure (i.e., the hood ventilation is off) at ambient pressure. The planchet surface was observed for an initial refrigerant (liquid) hot surface ignition and an additional two minutes for possible refrigerant vapor ignition. If the sample did not show visible ignitions (immediately or during the 2 minute observation time), the ventilation was turned on to clear the enclosure of refrigerant vapors. A corresponding "NO GO" result was also recorded for this refrigerant release. If the refrigerant ignited during any part of this test, the hood ventilation was immediately turned on, and a "GO" result was recorded. Ignition testing was done at a temperature of 800 °C (1472 °F) with +/- 10 °C (+/-18 °F) for a pass/fail response. Each refrigerant sample was tested five times to ensure that results were robust.

6. EXPERIMENTAL TEST DESIGN VALIDATION

6.1 Planchet Design

As mentioned in papers by Chemours, the original planchet design was a thin stainless steel circular disc with a small lip of about 3 mm and diameter of 25.4 mm (16,17). However, this design was noted to have some deficiencies concerning refrigerant impingement. Specifically, since the planchet was very light, during refrigerant discharge the planchet was very easily dislodged from placement causing the refrigerant to get underneath the insulation and create false ignition, i.e. an ignition at an unknown temperature. The "refrigerant trapping" issue was recognized during the development of the draft 5th edition of the IEC 60335-2-40 standard. Therefore, the published 6th edition of this standard notes a new planchet which is larger and incorporates a more robust lip design (12). While this planchet design was reviewed and tested, the Chemours team further modified the planchet.

The planchet used for this work had the over lip inverted (now on the bottom of planchet versus top). Images of the original and current planchet are shown below in figures 2a and 2b. A ceramic overlay is now used to aid in heat conduction which is seen in figure 3b. To aid in temperature reproducibility, the planchet was inverted versus the 6th edition of IEC 60335-2-40 (12). It should be noted that both normal and inverted positions of the planchet can be used for hot surface ignition experiments. However, the newly designed and final inverted planchet (ie, lip on bottom) a) increases the area in contact with heating element b) decreases free surface area where heat losses and occur, and c) provides a totally flat area where refrigerant cannot get trapped (see the lip in figures 3a and 3b). The important point to note is that the actual hot surface impingement area has remained the same through all of the improvements.

Figure 2a) **Figure 2b)**

Figures 2a showing original planchet (top view) and 2b) showing original planchet from side view. The small lip areas are seen in both figures. In both views, the planchet and k- type thermocouple leads are visible.

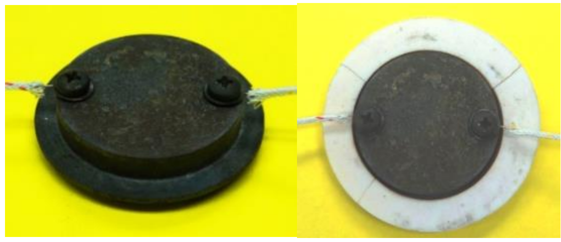

Figure 3a) **Figure 3b)**

Figures 3a) showing new planchet (side view) and 3b) showing new planchet with ceramic overlay (top view). In both views, one can see the planchet and k- type thermocouple leads.

6.2 Insulation

As mentioned in previous papers, the insulation board is a non-refractory ceramic fiber (non-RCF) board with a minimum density of 0.01273 lb/in^3 and maximum density of 0.01620 lb/in^3. The insulation board should have a minimum thickness of 8mm +/-0.5 mm (0.315in +/-.02 in) with a 2 inch hole cut out in the center to allow room for the planchet.

The density of the insulation board plays a key role in the HSIT test. It was found that a less dense board will break down faster due to the extreme test parameters (temperature and thermal shock resulting from refrigerant discharge) and a more dense board will not allow the planchet to seat properly while conducting the test, which results in the planchet not reaching maximum temperature for test protocol.

Boards that break down rapidly let refrigerant get trapped between the planchet and the hot plate, creating erroneous data readings. On the other hand, boards that are too dense, are difficult to correctly place into position and also lead to refrigerant getting trapped between the planchet and the hot plate. Incorrect board density leads to test failures with no valid hot surface ignition readings. Therefore, it is recommended that the insulation board is restricted to the 0.01273- 0.01620 lb/in^3 min/max density measurement.

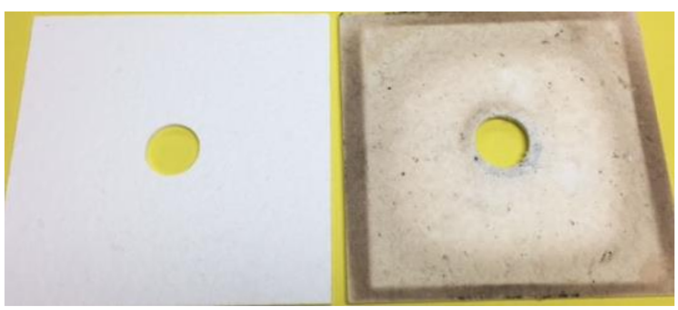

Figure 4a) **Figure 4b)**

Figure 4a) shows a robust board ready for testing. Figure 4b) shows a board that is breaking down under the testing. As can be seen from figure 4b the boards start to break apart and then refrigerant can get trapped between the planchette and the hot plate leading to testing errors.

6.3 Chimney Height

The recently published 6th edition of IEC 60335-2-40 and proposed 3rd edition draft of UL 60335-2-40 Annex KK HSIT have been updated (12,13). Specifically, the HSIT method includes a cylindrical quartz tube, called a chimney, to make the test more conservative and to better reflect actual refrigerant releases within ductwork. It has been noted that HSIT more appropriately reflects a refrigerant release in equipment and adding the chimney further mimics refrigerant release, hot surface impingement and directional flow and movement along the ductwork.

This work analyzed the chimney height from the planchette surface. It was found that chimney height could impact the data. A minimum chimney height of 4 mm was found to be reproducible giving good information and delineation for ignitions/non-ignitions. As the chimney height was increased, ignition incidence rate decreased. At 6.35 mm it was found that ignitions did not occur, even at temperatures of 850C. While it may be possible to achieve ignitions if the temperature is increased, it may require a significantly higher planchet temperature of 900C or higher. Currently there are significant challenges to maintaining 900c planchet temperature. Therefore, it is recommended to use a maximum 4mm chimney gap height. Decreasing the gap height to less than 4mm is also possible, but this small gap height has practical limitations. It is difficult to accurately re-set the chimney height uniformly after cleaning the chimney as shown in figure 5.

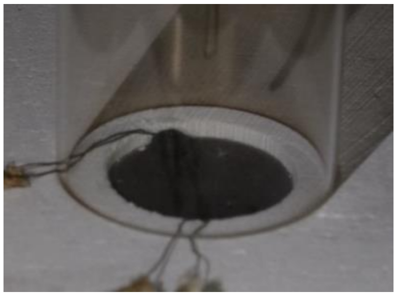

Figure 5- Image showing chimney above planchette at a specified gap height

7. Ignition/Non-Ignition Test Results

7.1 Chimney Height

To understand the impact of chimney gap height three different 2L refrigerants with varying LFL ad BV were tested; R-32, R-1234yf, and R-454C which is a blend of R-32 and R-1234yf. When the refrigerants are tested at the 6 mm chimney gap height, there is no differentiation between refrigerants, i.e., there were no observed ignitions for any refrigerant. When the refrigerants are tested at the 4 mm chimney gap height, there is differentiation found between refrigerants. As was discussed earlier, a gap height less than 4 mm was discounted as viable gap height due to the difficulty setting up the equipment.

7.2 Chimney Height Results

Results in table 1 below show ignition/ non-ignition results for the chimney gap heights of 4 mm and 6 mm. The trends are as expected for ignitions for R-454C based on the content of R-1234yf in R-454C and the ignition trends with R-1234yf.

Table 1- Results for ignition/non-ignition versus chimney gap height

Refrigerant	Chimney Height above planchet, mm	Number of Ignition @ 850 C	Comment
R-32	4	0/5	Differentiation between refrigerants
R-454C (78.5 wt% 1234yf/ 22.5wt% 32)	4	2/5	
R-1234yf	4	5/5	
R-32	6	0/5	No differentiation between refrigerants
R-454C (78.5 wt% 1234yf/ 22.5wt% 32)	6	0/5	
R-1234yf	6	0/5	

Since 4 mm was found as the optimum gap height; several 2L refrigerants were tested at that chimney gap height. Data are presented in table 2. It is interesting to note that spot ignitions (ignitions that occur when refrigerant immediately hits the surface) do not occur for any of these refrigerants. Ignitions occurred during the two-minute waiting time as the refrigerant concentration had time to reach the LFL to UFL region. This seems to imply that the maximum hot surface temperature can increase as long as there is additional airflow or movement within the chimney to eliminate potential for LFL to UFL regions. This observation may be useful for equipment design. No differentiation was noted between R-454 A and R-454C. This could be due to various reasons such as the test variability, test sample size, refrigerant mixing/delivery system, refrigerant buoyancy effects, etc. These observations will be investigated in successive studies.

Table 2-Ignition/Non-ignition Data for 2L refrigerants with improved HSIT methods

HSIT METHOD- Incorporating Redesigned Planchet and Chimney Chimney Gap Height at 4mm					
2L Substance	Number of Reps	Test Temperature (800C)		Test Temperature (850C)	
		Spot Ign (liq on surf), Y/N	Two Min Ign (LFL- UFL), Y/N	Spot Ign (liq on surf), Y/N	Two Min Ign (LFL- UFL), Y/N
R-1234zyf	5	0/5	0/5	0/5	5/5
R-1234ze	5	0/5	0/5	0/5	5/5
R-32	5	0/5	0/5	0/5	0/5
R-452B	5	0/5	0/5	0/5	0/5
R-454A	5	0/5	0/5	0/5	2/5
R-454C	5	0/5	0/5	0/5	2/5

8. SUMMARY

This current study builds on previous HSIT information and further expands that work. Specifically, three different equipment parameters were investigated 1) planchet design, 2) insulation density and 3) addition of chimney at optimum gap height.

The planchet was inverted versus the 6th edition of IEC 60335-2-40 and now includes a ceramic overlay to aid in heat conduction. The newly designed and final inverted planchet (ie, lip on bottom) a) increases the area in contact with heating element b) decreases free surface area where heat losses and occur, and c) provides a totally flat area where refrigerant cannot get trapped. A ceramic overlay is now used with the planceht to aid in heat conduction.

The density of the insulation board also plays a key role in the HSIT test. Incorrect board density leads to test failures with no valid hot surface ignition readings. Less dense boards that break down rapidly let refrigerant get trapped between the planchet and the hot plate, creating erroneous data readings. Boards that are too dense are difficult to correctly place into position and also lead to refrigerant getting trapped between the planchet and the hot plate. Optimum board density was specified to range between 0.01273 lb/in^3- 0.01620 lb/in^3.

The HSIT test was updated by adding a cylindrical tube to confine refrigerant after releasing onto the hot surface. The cylindrical tube was added to simulate the confinement found in HVAC ductwork. Chimney height was determined to impact ignition/non-ignition data. A minimum chimney height of 4 mm was found to be reproducible giving good information and delineation for ignitions/non-ignitions. As the chimney height increased, ignition incidence rate decreased, reducing test utility. Smallest chimney height tested proved impractical to replicate.

Finally, data is presented for different A2L refrigerants in this updated HSIT design. The updated HSIT method shows more differentiation between refrigerants particularly as the hot surface temperature is increased from 800°C to 850°C.

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