Comparison Of HEPA/ULPA Filter Test Standards Between America And Europe

Bin Zhou, Jinming Shen

Heating, Ventilation, Air-conditioning and Gas Institute, Tongji University, Shanghai, China

Corresponding email: zhoubinwx@126.com

SUMMARY

This paper compares the difference of HEPA/ULPA filter test standards between America and Europe from test procedures, aerosol types and its size, to air filter classification. Both of them adopt MPPS method as their trend. According to EN1822, it is recommended to combine the test rigs for efficiency test and leakage test in practice. Influence of different scanning velocity on sampling accuracy, leakage and efficiency test accuracy need further studied and reasonable scanning velocity should be fixed. According to Rongyi Zhao's theoretical analysis, dilution method to test high test aerosol concentration may not be correct, and reasonable test methods instead of dilution need to be further studied.

INTRODUCTION

High efficiency particulate air filters (HEPA) and ultro-low penetrating particulate air filter (ULPA) are widely used in pharmacy, hospital, food processing and microelectronics, they are one of the most important terminals in clean space. In order to guarantee product quality and environmental control, every country makes its strict test standards.

During the late 1950s, China adopted oil mist method from USSR. At the early 1960s, oil mist method was improved to meet requirement of collective safeguard equipment and the development of atomic energy engineering. In 1963 and 1965, sodium flame test rig was successfully developed respectively to test filter media and HEPA. In 1970s, especially after the economic reform and opening-up policy, oil mist method and sodium flame method were used widely, therefore in 1980s national standard GB6165 was made using both methods.

As the development of microelectronics, the orginal standards using sodium salt and oil mist are old-fashioned. Before standard revising, review of test standards is very needed. This paper compares HEPA and ULPA filters between America and Europe from test procedures. Some problems and future development are proposed here for benefit of new standards.

DEVELOPMENT OF HEPA/ULPA FILTER TEST STANDRDS

America

In 1956, MIL-STD-282<Filter Unit, Protective Clothing, Gas-mask Components and Related Products: Performance-Testing Methods> using DOP method was published. DOP liquid is heated and vaporized, then condensate to become DOP particle with mean diameter 0.3μm, which is called thermal generation. It is used to test HEPA filters on Q-127, Q-76 and Q-107 test rigs. Till now it has been revised for 4 times and the latest one is MIL-STD-282:1995.

In 1959, Underwriters Laboratories Inc. published ANSI/UL 586:1959<Air Filter Units>. It is mainly used to test penetration under ambient environment and after hot air, wet air and low temperature treatment. After 8 times revision, the latest version is ANSI/UL 586:2004.
In 1975 and 1976, ANSI N45.8 committee published ASME N509 and ASME/ANSI N510 respectively, and revised them in 1980 and 1981. In 1976, this committee was recognized as "American Society of Mechanical Engineers Committee on Nuclear Air and Gas Treatment". In 1986, ASME AG-1-1986<Code on Nuclear Air and Gas Treatment> was issued. After several revisions, the latest version is ASME AG-1-2003.

In 1980s, Los Alamos National Laboratory (LNAL) reviewed various HEPA filter testing practices, and pointed out the pro and con of MIL-STD-282 method. LNAL proposed alternative method "High Flow Alternative Test System", which uses standardized Laskin nozzles and impactors instead of DOP generator to produce aerosols, and uses laser aerosol spectrometer instead of aerosol measuring instrument on Q-107. The test result is equivalent with that of MIL-STD-282 method, and notably efficiency corresponding to certain particle size is determined. However, because the long test time and increased data error caused by particle sizing instrument, it wasn't popular[1].

During 1992 and 1993, Institute of Environment Sciences and Technology (IEST) issues a series of HEPA/ULPA filter test standards for different requirements and applications, such as IEST-RP-CC007.1:1992<Testing ULPA Filters>, IEST-RP-CC001.3:1993<HEPA and ULPA Filters> and IEST-RP-CC-006.2:1993< Testing Cleanrooms>.

In 2005, IEST issued IEST-RP-CC001.4 <HEPA and ULPA Filters> and IEST-RP-CC034.2<HEPA and ULPA Filter Leak Tests>

Europe

In 1984, EUROVENT issued EUROVENT 4/4 < Sodium Chloride Aerosol Test for Filters Using photometers>. This standard tests efficiency and pressure drop of HEPA filters using sodium flame methods, and then filters are classified. The method was originated from BS3928-1969, which uses mass mean diameter 0.6μm NaCl aerosols. Different concentration of salt mist will cause different color from hydrogen gas flame, so according to the sodium flame color from upstream and downstream samplings, efficiency is determined.

However, since sodium flame methods are not suitable for testing filters with large air flow rate and high-tech requirement, working group 2 of the Technical Committee 195 from CEN began to draft a new standard from 1990. At first many people inclined to accept BS 3928 for its wide use, but at last a completely new test method was preferred. The reasons are[2]:

(1) A consistent and logical classification system covering HEPA/ULPA filters is needed;
(2) The method can satisfy the need of clean room users, where room classes always differ by a factor of 10;
(3) The relationship between leak sizes and efficiency of a specified class is required;
(4) The correlation between different test rigs and fewer errors should be met.

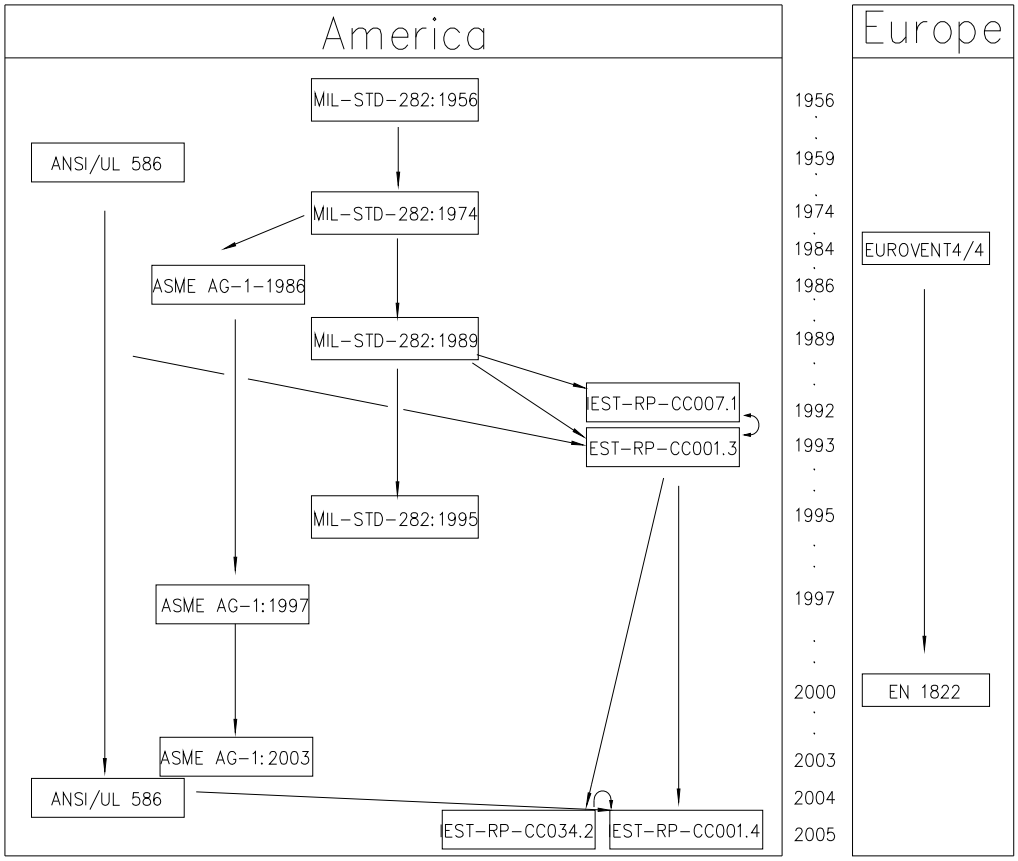

Figure 1. Development of standards for HEPA/ULPA filters.

Through about 10 years' endeavor, during 1998 and 2000, CEN issued EN 1822 in succession. Since EN 1822 is issued, disorder situations have been change in Europe. Compared with former standards, the biggest feature is that Most Penetrating Particle Size[3] (MPPS) efficiency is measured for filter medium and filters.

COMPARISON AND DEVELOPMENT TENDENCY

At present, main HEPA/ULPA filter test standards among Europe and America are MIL-STD-282:1995, IEST-RP-CC001.3:1993, IEST-RP-CC007.1:1992, ANSI/UL 586:2004, IEST-RP-CC001.4:2005, IEST-RP-CC034.2:2005, EN 1822. In the following standards from IEST and CEN will be compared.

Table 1. Comparison of main HEPA/ULPA filter test standards.

	IEST-RP-CC001.3	IEST-RP-CC007.1	IEST-RP-CC001.4	IEST-RP-CC034.2	EN 1822
Test Aerosol	Thermal DOP (HEPA filters) or any aerosol of IEST-RP-CC007(F type filters)	Mineral oil, corn oil, olive oil, oleic acid, DOP, DOS or PSL	Thermal DOP (HEPA filters) or any aerosol of IEST-RP-CC007 (F~K type filters)	DOP, DOS, mineral oil, oleic acid, PAO or PSL	DOS, DOP or paraffin oil
Aerosol size	0.3μm (HEPA filters), 0.1~0.2μm (F type filters)	Polydisperse or 90% in 0.1~0.2μm	0.3μm (A~E filters), MPPS (G type filters), others 0.1~0.2μm and 0.2~0.3μm	n/a	MPPS
Sampling Instrument	Photometers (HEPA filters), particle counter(F type filters)	Optical counter, electrical mobility particle sizer, diffusion separation instrument	n/a	n/a	Optical counter or condensation nucleus counter
Temperature and relative humidity	n/a	10～37.8°, 30～70%	n/a	n/a	23±5°, <75%
Pressure	n/a	Positive pressure	n/a	n/a	n/a
Qualification Requirement	(1)air velocity uniformity across duct cross*; (2)aerosol uniformity across duct cross**; (3)pressure drop under rated air flow; (4)test duct leakage test; (5)inlet HEPA filters; (6) velocity uniformity measures; (7)cleanliness of test air; (8)aerosol concentration of upstream; (9)scanning velocity; (10)sampling rate; (11)particle loss; (12)system response time; (13)correlation ratio; (14)aerosol neutralizer;				
	(1)(2)(3)(4)(8)(9)(10)	(1)(2)(4)(5)(6)(7)(11)(12)(13)(14)	(1)(3)	(1)(2)(9)(10)	(2)(7)(10)(11)

* air velocity uniformity of IEST-RP-CC001.3 and IEST-RP-CC001.4 is ±20%, while that of IEST-RP-CC007.1 is ±10%;
** aerosol uniformity of IEST-RP-CC007.1 and IEST-RP-CC034.2 is ±20%, while that of EN1822 is ±10%.

Test Procedure Comparison

IEST-RP-CC001.3 uses thermal DOP method for A~E type filters and "laser test" for F type filter. DOP method uses photometers while the latter uses particle counters. IEST-RP-CC001.4 determines penetration in the same way and are both suitable for testing submicron particle efficiency≥99.97%. By comparison, the main difference includes:

(1) IEST-RP-CC001.3 includes scanning leakage test, while IEST-RP-CC001.4 doesn't and IEST-RP-CC034.2 is made for the leakage test only;
(2) The leakage test of IEST-RP-CC001.3 is used to test HEPA/ULPA filters in the lab, while IEST-RP-CC034.2 requires testing HEPA/ULPA filters during factory

manufacture, field installation, and after installed in the clean room and unidirectional air cleaners. The methods in IEST-RP-CC001.3 includes: photometer scanning method (for filters with penetration lager than 0.001%) and particle counter scanning method (for filters with penetration smaller than 0.001%), but the method is limited if the background counts are less than 10% of the maximum acceptable leakage count. IEST-RP-CC034 not only introduces the two different scanning methods, another special leakage test method is introduced for filters difficult to access: Aerosol photometer total leakage test method. By introducing aerosol into the test duct, concentrations of upstream and downstream and total leakage are determined.

(3) Compared with IEST-RP-CC001.3, A~F type filters classification are mainly the same. The differences are:
1. the test aerosol for C and D type filter can be PAO or DOP, because the traditionally used DOP poses potentially treat to health, and both the Food and Drug Administration and US Surgeon General have accepted PAO to replace DOP as a test aerosol.
2. Filters with 99.999% minimum efficiency related to 0.1~0.2μm particles are F type filters in IEST-RP-CC001.3, while the same minimum efficiency related to 0.1~0.2μm and 0.2~0.3μm particles are F type filters in IEST-RP-CC001.4.
3. Except for the particle counter, IEST-RP-CC001.4 allows photometers for F type filters.

(4) Compared with IEST-RP-CC001.3, super ULPA (G type)~ ULPA (A type) are added. In Europe, EN 1822 is used to test HEPA/ULPA filters upon MPPS efficiency. The procedures in the standard include 3 sections: filter medium test, filter leakage test and filter overall efficiency test. Firstly, the relationship curve between filter medium efficiency and particle size is established under rated air flow, then MPPS value is fixed; Secondly, under corresponding air velocity, monodisperse or multidisperse aerosols are used to test filters' local penetration, so as to determine whether the filter has leakage, but the precondition is that the particle size of monodisperse aerosols and the number mean size of multidisperse aerosols are MPPS; At last, static measuring method or scan method are used to test the overall efficiency, of which the static measuring method use stationary sampling probes to test the concentration of upstream and downstream, and the scan method uses a scanning probe on the downstream side together with a stationary sampling probe set upstream to get the local MPPS efficiency and then the overall efficiency.

Difference[1] between EN 1822 and IEST-RP-CC001.4 includes the following:

(1) Filters with efficiency≥99.95% in EN 1822 are tested for MPPS efficiency and leakage, while in IEST-RP-CC001.4 most filters should be tested using number mean diameter (NMD) 0.3μm thermal DOP which is approximately near MPPS.

(2) Filters with MPPS efficiency≥85% in EN 1822 are called HEPA filters (in total 7 types), while Filters with NMD 0.3μm thermal DOP efficiency≥99.97% in IEST-RP-CC001.4 are called HEPA filters (in total 14 types);

(3)IEST allows photometer and particle counters (both OPC and CNC), while EN1822 only accept particle counters (both OPC and CNC) and Different Mobility Analyzers (DMA).

(4) The test range for OPC in EN 1822 is 0.1~2μm, which is divided into 6 groups; and for CNC is 0.05~0.8μm; and for DMA is 0.01~0.8μm. In IEST-RP-CC001.4, the test range for OPC is 0.1~0.3μm, while for CNC is also 0.1~0.3μm.

(5) In EN 1822, the efficiency can be tested using scanning method of leakage test, so the efficiency test and leakage test can be one test, while in IEST they are two independent tests.
(6) In EN 1822, filters with MPPS efficiency≥99.95% must be tested through scanning method, while in IEST, whether to scan the filters depends on the performance: A and H type filter only need efficiency test, while B, E and I filters need be tested through dual flow rate leakage test, and the remaining are required to be tested both.
(7) In EN 1822, percentage is usually used to reflect penetration of filters, while in IEST introduces new Par Per Million (PPM).
(8) In EN 1822 MPPS efficiency is used, while in IEST only G type filter uses, and for A~E type filters, mass mean diameter 0.3μm aerosol is used, whose NMD is close to MPPS.

Type selection of test aerosol

Since DOP was first applied by MIL-STD-282, it has been popular and most standards recently use DOP, furthermore, definition of HEPA filter is based on the DOP efficiency.

However, the vapor of transparent liquid DOP is irritative for eyes and respiration channel. When high concentration of DOP vapor is inhaled, people may become uncomfortable, such as headache, nausea, and hypoesthesia. When exposed to DOP for a long time, people tend to be poisoned, or it may even be carcinogenic. Therefore people are concerned about DOP.

America and Europe are both active in seeking new substitute, for example, in IEST-RP-CC001.4 PAO will replace DOP. As for the toxicity and safety, PAO is affirmed to be noncorrosive, stable and cheap. Now it has been used in field filter test and present instrument can produce and deal with it. However, the remaining liquid on the filters will be released gradually after test like DOP and poses pollution. In some HEPA filter test standards of America, PSL is recommended to avoid the above situation. PSL is usually used for calibrating OPC, so it can satisfy the test requirement, but it’s expensive compared with PAO.

The most important properties of a possible aerosol substance are index of refraction, vapor pressure and density, so during the seeking process, the values of the substitute should not differ too much from Table 1 of EN 1822-2.

Filter classification

In IEST-RP-CC001.4, A~E type filters are classified using DOP method of MIL-STD282; F, H~K type filters are based on the method of IEST-RP-CC007.1; G type filter is classified according to the method of IEST-RP-CC021. In EN 1822 H10~U17 type filters are all based on MPPS efficiency. Different test methods, test aerosols and test conditions will bring about different performances for the same filter, which makes the comparison between different standards difficult. IEST-RP-CC001.4:2005 lists the comparative performance.

From comparison, performances of various types of filters in IEST-RP-CC001.4 are closer to each other. The overall efficiency of A type filter is 99.97%, the same as that of B, E, H, and I type filters, while that of C and J type filters is 99.99%, and that of D and F filters is 99.999%, but test aerosols and leakage test requirements are different. In EN 1822, except that the ratio of total penetration of H10 to that of H11 is 3, others between the neighboring type are 10. In

EN 1822, except that the ratio of local penetration to total penetration, of U17 is 20, others are 5. In IEST-RP-CC001.4, the local penetration ratios are different, because errors during scanning leakage test are very big, and the permitted leakage penetration during leakage test should be equal or larger than that of efficiency test.

Existing problems and development tendency

(1) Former HEPA filter test standards were used to test 0.3μm particle efficiency, because it is believed that with the combined effect of diffusion and interception, 0.3μm particle is the most difficult one to collect, so it became the base size of DOP method. However, later research denied this conclusion, which shows that the MPPS range is 0.1~0.25μm and MPPS is different for different types of filters and air velocity [3]. From above comparison between EN1822 and IEST-RP-CC001.4, as test condition changes, MPPS efficiency and filter classification change according to EN1822, but not in IEST-RP-CC001.4. EN1822 has the characteristic of high sensitivity and accuracy, but the test procedure is complicated and test time is long, so a more efficient, simple and reliable test method should be exploited.

(2) In EN1822, both the stationary sampling probe or movable probe can be installed to test the overall efficiency, and for H13~H17 filters scanning probe is needed to test the local penetration, because the test rig and instruments between efficiency test and leakage test are alike, it is recommended to combine the two test rigs in practice for high resource utilization efficiency. C~K type filters in IEST-RP-CC001.4:2005 are the same.

(3) Rrequirements in EN1822 and IEST-RP-CC034.2 are different. In EN1822, the probe inlet air speed should less than 25% of filter face velocity, and be placed 10~50mm from the filter surface, while in IEST-RP-CC034.2, the corresponding values are±10% and 25mm. In EN 1822, the upper limit for scanning velocity is 10cm/s, while in IEST-RP-CC034.2, the value is 5cm/s for photometer scanning and 2.5cm/s for particle counter scanning. As different scanning velocity will influence sampling accuracy and then leakage and efficiency test accuracy, hence further study on reasonable scanning velocity is needed.

(4) EN1822 allows to use two counters simultaneously at upstream and downstream, or one counter with sequential sampling between upstream and downstream[4]. As for the former, the same types should be used and calibrated, and as for the latter, aerosol concentration, size distribution and uniformity in the test duct should be kept constant.

(5) Because particle counters have test range, aerosol concentration in the upstream should be controlled so as to avoid aerosol coagulation and overlap loss in particle counters. Both standards allow the use of dilution system. However, in order to verify the accuracy of tested concentration after dilution, theoretical analysis is made by Rongyi Zhao, showing that the result after dilution is incredible[5].Until now there’s no other methods to deal with high concentration test except, reasonable test methods need to be further studied.

(6) In order to control the sampling error of particle counter, non-isokinetic sampling error and particle loss due to diffusion, sediment, coagulation and impaction in the sampling tube, together with overlap loss should be reduced. Special probe should be designed to keep isokinetic, and the length of sampling tube should be shortened, and the electric performance of sampling tube should be improved, and no other parts are installed in the tube, and the sampling tube should be kept away from noise source[6].

(7) As for field leakage test for HEPA/ULPA filters, EUROVENT issued EUROVENT 4/8:1985 “In Situ Leak Test of High Efficiency Filters In Clean Spaces” using DOP method in early 1985. Because the process from manufacture, transportation and field installation is a system, each part will influence the cleanliness of clean room. Because field test is especially important for CMOS chip workshop and biosafety, IEST makes IEST-RP-CC034 specially, which covers the leakage test of each part, and it’s the complete leakage test standard now.

CONCLUSIONS

In America, DOP method has a profound influence, but now particle sizing method is the trend. In Europe, test method changes from Sodium Flame method to MPPS method. It is recommended to combine the test rigs for efficiency test and leakage test in practice.

Different scanning velocity between EN1822 and IEST-RP-CC034.2:2005 will influence sampling accuracy, leakage and efficiency test accuracy, hence, further study on reasonable scanning velocity is needed.

According to Rongyi Zhao’s theoretical analysis, reasonable test methods instead of dilution need to be further studied.

REFERENCES

1. IEST.(2005).HEPA and ULPA Filters. (IEST-RP-CC001.4:2005). Illinois. Institute of Environment Science and Technology
2. R. Wepfer. Characterisation of HEPA and ULPA Filters by Proposed New European Test Methods[J]. Filtration & Separation. 1995, 6: 545-550
3. Lee, K.W. and B.Y.H.Liu. On the Minimum Efficiency and the Most Penetration Particle Size for Fibrous Filters. Journal of the Air Pollution Control Association [J]. 1980. 30(4): 377-381
4. CEN.(2000). High efficiency air filters(HEPA and ULPA) -Part 5: Determining the efficiency of filter element. (EN1822-5). Brussels: European Committee for Standardization.
5. Rongyi Zhao. Technology research on 0.1μm particle (in Chinese). Cleaning and air conditioning technology. 1995, 1: 2-6
6. Zhonglin Xu, Jingming Shen, Changyong Chen. Errors for particle counters using aerosol (in Chinese). China powder technology. 2000, 6(1): 15-19