# The AS4059 Hydraulic System Cleanliness Classification System; Replacement of NAS1638

마이크 데이 · 홍정희
Mike Day and Jeong-Hee Hong

**Abstract:** The NAS 1638 cleanliness classification system was originally developed in 1966 by the US Aircraft Industries of America to both simplify reporting of particle count data and to control the introduction of dirt during the assembly of aircraft fluid systems. The numbers of particles at stated sizes are represented by broad bands where the interval was generally a doubling of contamination. A number of systems have been introduced since this to suit differing requirements. NAS 1638 and AS4059 are used in other industrial sectors such as the Off-shore & Sub-Sea and the Primary Metal Industries.

The changes to ISO contamination measurement standards controlled by ISO/TC131/SC6 in 1999 meant that a revision of most of these classification systems was necessary. The body responsible for NAS 1638 decided to withdraw it for new installations and replace it with an update of an existing standard, SAE AS 4059.

This paper details the philosophy behind the contamination coding systems, the reasons for the changes to the ISO contamination standards and explains the workings of AS 4059, the replacement for NAS 1638. It goes on to detail the latest changes to this standard.

## 1. Background to Cleanliness Classification Systems

Particulate contamination (or cleanliness) classification systems are designed to simplify the communication of data from particle counters, where particle concentrations can range from single particles to many millions, with data at many sizes being available. The particle counts at various sizes are converted into convenient broadly based classes and the interval between the classes or codes follows a power series (usually a doubling of the numbers) to cover the large number range with a convenient number of classes.

The first of these was the **N**ational **A**erospace **S**tandard (NAS) 1638 [1] and was developed in the 1960s, primarily to control the amount of contamination being delivered in aircraft hydraulic *components* and became an American Aerospace standard in 1964. As no other classification system existed at the time for fluid *systems*, it was logical that NAS 1638 would be applied in this area. NAS 1638 saw widespread acceptance in the 70's and 80's by other industries where reliability was a pre-requisite, e.g. Off-shore & Sub-sea and Iron and Steel Industries. It led to the development of other Coding systems, the most notable being ISO 4406 [2].

If you obtain the latest issue of NAS 1638 you will find the following statements:-

"Inactive for new designs after May 30$^{th}$ 2001, see AS 4059 C" and

"6.1.3 This standard should not be used with Automatic Particle Counting".

This was a result of the changes to the ISO

홍정희 이사: 한국폴㈜ 응용기술연구소
E-mail:Jeong-hee_Hong@Pall.com,Tel.02-560-8791
ISO/TC131/SC6 & ISO/TC20/SC10 KATS
Mike Day: Pall Europe Consultants Ltd, UK
E-mail: Mikejday31@gmail.com
ISO/TC131/SC6 & ISO/TC20/SC10 BSI

standard for Automatic Particle Counter (APC) calibration [3] and this also made it necessary to up-issue AS4059 C to AS4059 D. Since then, AS4059 has gone through a further review to account for the wishes of the Aircraft Industry and, at the time of writing, is at Issue E.

This article gives the background to these systems, explains the changes at ISO that precipitated the change in the standards and explains how to use the new system.

## 2. NAS 1638 Cleanliness Classes

The concept of the system can be seen in Table 1 and it is based upon a fixed particle size distribution of the contaminant over a size range from >5 to > 100 μm. This distribution was based upon the contaminant contained within delivered aircraft hydraulic components in the '60's. From this basic distribution, a series of 14 classes was built up covering "very clean" to "dirty" levels, where the interval between each class was a doubling of the contamination level. This principle is a feature of many of the classes that have been developed since.

The method of counting the particles recommended was using the optical microscope defined in ARP 598 [4], simply because this was the only method of existence at the time! With foresight, the standard allowed the use of whatever counting method the user liked provided that the data was presented in the format stated in ARP 598 (see Table 1). Thus, it may be interpreted that the use of APCs was acceptable. The standard also allowed another method of measuring the concentration of particles: that of gravimetric analysis, i.e. the weight per volume (mg/100 mL) and nine codes are defined. This technique is rarely applied.

As stated earlier, NAS 1638 was used to define the cleanliness of system based samples because no other system was available at the time. As the success of the Aircraft Industry in controlling contamination was realised, NAS 1638 was applied in other industrial areas, like the Offshore and Primary metals Industries.

Since each cleanliness class in NAS1638 specifies the particle size distribution over all particle size ranges to be counted, a dilemma resulted in assigning the overall cleanliness class if the actual particle counts for the required particle size ranges correspond to different NAS 1638 cleanliness classes, A convention was generally adopted to represent the overall cleanliness class of the sample in terms of the highest measured cleanliness class, i.e., a conservative cleanliness rating. However, practical experience showed that, often, the highest cleanliness class corresponded to the larger particle size ranges. In addition, since the concentration of particles in the larger size ranges is low, the presence of background contamination due to sampling errors, especially when using sample bottles, could contribute significantly, resulting in spuriously high cleanliness classes (low fluid cleanliness levels). This is discussed further in 4.1 and also in a paper by Day & Rinkinen [5]

Table 1 NAS 15638 Cleanliness Classification System

| Class | Max particles/ 100 mL. specified size ) | | | | |
|---|---|---|---|---|---|
| | 5 to 15μm | 15 to 25μm | 25 to 50μm | 50 to 100μm | > 100μm |
| 00 | 125 | 22 | 4 | 1 | 0 |
| 0 | 250 | 44 | 8 | 2 | 0 |
| 1 | 500 | 89 | 16 | 3 | 1 |
| 2 | 1,000 | 178 | 32 | 6 | 1 |
| 3 | 2,000 | 356 | 63 | 11 | 2 |
| 4 | 4,000 | 712 | 126 | 22 | 4 |
| 5 | 8,000 | 1,425 | 253 | 45 | 8 |
| 6 | 16,000 | 2,850 | 506 | 90 | 16 |
| 7 | 32,000 | 5,700 | 1,012 | 180 | 32 |
| 8 | 64,000 | 11,400 | 2,025 | 360 | 64 |
| 9 | 128,000 | 22,800 | 4,050 | 720 | 128 |
| 10 | 256,000 | 45,600 | 8,100 | 1,440 | 256 |
| 11 | 512,000 | 91,200 | 16,200 | 2,880 | 512 |
| 12 | 1,024,000 | 182,400 | 32,400 | 5,760 | 1,020 |

For this reason and to improve the standard generally, the SAE A6 Aerospace panel developed AS 4059 [6] in 1988 for aircraft hydraulic systems. This subsequently became ISO 11218 [7], a defacto standard based upon AS 4059 Issue A, but this has not been updated since its introduction. AS 4059 is currently at Issue E. It is unfortunate, but a reality, that few aircraft companies have taken these two standards on-board and, equally, very few industrial companies knew of the existence of AS 4059! This standard overcame many of the deficiencies of NAS

1638, extended the data to smaller sizes (>2 µm) and also added a lower numbered class (Class 000) to account for cleaner systems.

Before discussing AS 4059 it is necessary to explain certain changes to ISO Contamination standards in 1999 that have had an impact on the development of AS4059

## 3. Changes to Automatic Particle Counter (APC) Calibration Method

Earlier, it was stated that NAS 1638 referenced particle counting using the optical microscope, however in the '60s and '70s the development of APCs revolutionised the measurement of the size distribution of particles in hydraulic systems. Their accuracy, repeatability and speed of analysis meant that it became the main and preferred method of analysis. They also enabled substantial research activity into the effects of dirt on components and systems. Oklahoma State University (OSU), under the direction of Prof. E. Fitch, was the main force at the time and one of the many standards that they produced was ISO 4402 [8], the method for calibrating APCs. This was based upon the size distribution of A.C. Fine Test Dust (ACFTD), a silica based test dust used in the Automotive and Hydraulics industry for testing components. The size distribution was derived in 1964 using the optical microscope, so, in effect; the APC was set-up to record identical numbers of ACFTD particles as the microscope.

The notice of termination of supply of ACFTD in 1996 prompted a need for a replacement. It also gave the ISO committee overseeing the project (ISO/TC131/SC6) the opportunity to obtain traceability for the particle size distribution (PSD) of the calibration material. The lack of traceability was proving to be a problem in the 1990's as more and more companies strove to achieve ISO 9000 type quality systems and it was a constant embarrassment for laboratories involved with contamination testing to have to explain why there was no traceability and control over the calibration dust!

The replacement chosen was ISO Medium Test Dust (ISOMTD), who's PSD was certified by the National Institute of Standards and Technology (NIST) in the USA. They used a Scanning Electron Microscope (SEM) with an Image Analysis software package to precisely identify the size and numbers of particles down to 1µm. The parameter chosen for determining the size of the particle was the "Equivalent Spherical Diameter" which is the diameter of a sphere which has the same projected area as the particle and relates to APCs and automatic microscope counting. This will give a different count to data from a manual microscope, where the size is related to the longest particle dimension.

Unfortunately the size distribution obtained for ISO MTD differed from that in ISO 4402 (size for size), and showed that the earlier data greatly underestimated the numbers of particles less than about 10 µm. The net result was that if the APC was set to the *same size* (e.g. > 2µm, > 5µm etc), the APC with the new calibration would record more particles than one calibrated to ISO 4402 on the same sample for particle sizes less than about 10 µm (which was roughly the same for both calibrations); this is discussed in more detail in ISO TR 16386 [9]. Such a situation would cause uproar in industry, as companies would have to change specifications. The ISO committee chose the least disruptive path and selected new size descriptors which would give the 'same' particle counts, rounded off to the nearest integer size, shown in Table 2.

Table 2 Equivalent APC sizes relating to Calibration method

Particle Sizes

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ISO 11171 SIZE -µm (c ) | >4 | >6 | >10 | >14 | >21 | > 38 | > 70 |
| ISO 4402 SIZE -µm | >1 | >5 | >10 | >15 | >25 | >50 | > 100 |

In order to differentiate data obtained using the two methods the term "µm(c)" is used for data obtained using an APC calibrated to ISO 11171. The only major difference in particle counts is likely to be at the 4µm(c) size, which effectively has no previous equivalent. As few organisations had cleanliness specification based upon this size at the time, it was considered that the change would be minimal.

## 4. AS4059 - The Replacement for NAS 1638

As mentioned earlier, AS 4059 was developed from NAS 1638 in 1988 to overcome the limitations of NAS 1638 and has undergone five revisions and is now (at the time of writing) at issue “E”. The change to Issue D in 2001 was made in response to the changes in the ISO contamination standards and it is considered to be a significant advance over NAS 1638 as it offers many benefits. Although it was used by the Offshore industry, particularly in Europe and in Asia, it did not gain acceptance with the US Aircraft industry and they initiated a change in 2004 resulting in Issue E.

As AS4059 Issue D is being used by a number of Offshore companies and is in the process of being adopted by others, both versions are described below.

### 4.1 AS 4059 Issue D -2001

Issue D was initiated to account for the changes to the size ‘label’ of APCs as stated above and the following features were additional to NAS1638:-

- Gives options for analysis method:
  - 11171 calibrations for APCs giving improved precision of data, better repeatability and reproducibility and a traceable calibration..
  - Allows continued use of ISO 4402, the earlier method of calibrating APCs, although now this is considered to be a feature not necessarily a benefit (see later).
  - Microscopic methods, manual and automatic.
- Develops a Numeric-Alpha system for defining maximum contamination levels.
- Has an additional smaller size (previously > 2μm, now > 4μm(c))
- Has a cleaner class – Class 000
- Uses the same data as NAS 1638 to enable easy transition for existing specifications.
- Allows flexibility in the specification of cleanliness.
- Gives information on how to apply the standard.
- Gives the background to the changes in ISO standards.
- Gives guidance for sample bottle cleanliness and sampling.

Issue D features a single Table of Classes (see Table 3) with the data presented as cumulative counts (e.g. >5μm) whereas the data in NAS1638 is presented as differential or interval counts (e.g. 5 to 15μm). The cumulative method of presentation is the most common method of presenting data and is the way that particle counting methods presented it before transformation. AS4059 data was obtained by transforming the NAS 1638 data into cumulative counts; to see how this works, try subtracting the > 15 from > 5 μm numbers and comparing it with the 5-15 μm in NAS 1638. Note that the AS4059 Issue D data is rounded to the nearest third digit, for example the particle count at >6μm(c) for AS 4059 Class 6 should be 622,792 particles and this has been rounded up to 623,000.

TABLE 3. AS4059 Issue D Cleanliness Classification System

| Size, ISO 4402 calibration, or optical microscope | | Maximum Contamination limits (particles/ 100 mL) | | | | | |
|---|---|---|---|---|---|---|---|
| | | > 1 μm | > 5 μm | > 15 μm | > 25 μm | > 50 μm | > 100 μm |
| Size, ISO 11171 Calibration or Electron Microscope | | > 4 μm(c) | > 6 μm(c) | > 14 μm(c) | > 21 μm(c) | > 38 μm(c) | > 70 μm(c) |
| Size Code | | A | B | C | D | E | F |
| Classes | 000 | 195 | 76 | 14 | 3 | 1 | 0 |
| | 00 | 390 | 152 | 27 | 5 | 1 | 0 |
| | 0 | 780 | 304 | 54 | 10 | 2 | 0 |
| | 1 | 1,560 | 609 | 109 | 20 | 4 | 1 |
| | 2 | 3,120 | 1,220 | 217 | 39 | 7 | 1 |
| | 3 | 6,250 | 2,430 | 432 | 76 | 13 | 2 |
| | 4 | 12,500 | 4,860 | 864 | 152 | 26 | 4 |
| | 5 | 25,000 | 9,730 | 1,730 | 306 | 53 | 8 |
| | 6 | 50,000 | 19,500 | 3,460 | 612 | 106 | 16 |
| | 7 | 100,000 | 38,900 | 6,920 | 1,220 | 212 | 32 |
| | 8 | 200,000 | 77,900 | 13,900 | 2,450 | 424 | 64 |
| | 9 | 400,000 | 156,000 | 27,700 | 4,900 | 848 | 128 |
| | 10 | 800,000 | 311,000 | 55,400 | 9,800 | 1,700 | 256 |
| | 11 | 1,600,000 | 623,000 | 111,000 | 19,600 | 3,390 | 512 |
| | 12 | 3,200,000 | 1,250,000 | 222,000 | 39,200 | 6,780 | 1,020 |

From this table it will be seen that the particle counts are defined by a number (relating to the quantity of particles) and a letter (relating to their size). The size 'label' depends on the method of analysis.

The numeric-alpha concept gives AS 4059 much more flexibility than was possible with NAS 1638 both in specifying and reporting data. Those who specify cleanliness levels often require improved control over the cleanliness level at critical sizes rather than work to a fixed distribution, e.g. they can specify improved control over these critical sizes or relax controls over those that are not. Equally, sizes that are not critical, can be relaxed and even omitted;

There are three options for specifying cleanliness:-

- *Specifying cleanliness over multiple sizes* e.g. AS4059 8B to F which means that 1μm/4μm(c) has no specification and a fixed distribution as defined by Class 8 is required over the complete size range. Any combination of two or more sizes can be used. The "*B-F" convention will duplicate the NAS 1638 specification.
- *Specifying cleanliness for specific sizes,* e.g. AS 4059 6B/ 6C/ 5D/ 4E/ 4F, which means that 1μm/4μm(c) has no specification and tighter controls are required over the larger size. Any combination of two or more sizes can be used.
- *Specifying at single sizes*, e.g. AS 4059 6B, which means that only the > 5 μm/> 6μm(c) is subject to a cleanliness specification, and the maximum number of particles per 100 mL is 19,500.

Note that if a class in not specified, then size B is taken as the default so that there is continuity with previous issues of AS 4059 where the Cleanliness reported was for size B.

The reporting of data has also improved with the introduction of AS4059. There has been a tendency to quote a single highest NAS code in the data as being the result for all, although there is no statement in NAS 1638 to do so. This invariably occurs at the larger sizes (>25 μm/21μm (c)) and is usually a result of cross contamination during the sampling or analysis processes. This is illustrated by the example in Table 4 below. This is the result of the analysis of a sample taken from a sub-system fitted to a Subsea module after 2 days continuous flushing with a "3μm" filter. Data was verbally reported by the lab and the highest NAS 1638 was given because this was "the correct way to do it". So flushing continued until advice was sought. Clearly the results were affected by a combination of sampling error and using sample bottles that were not sufficiently clean. With AS 4059 reporting all of the data is mandatory and had all of the data been reported then the reason for 'failure' would have been obvious and either corrective actions taken or a concession gained.

TABLE 4. Particle Count Data from Flushing a Sub-sea System

| NAS 1638 Data – Code reported NAS 1638 Class 9<br>NAS 1638 Specification – Class 6 | | | | | |
|---|---|---|---|---|---|
| AS 4059 Data | | | | | |
| Size | >5 μm | >15 μm | >25μm | >50 μm | >100 μm |
| Counts | 7,666 | 1,576 | 536 | 176 | 65 |
| Codes | 5B | 5C | 6D | 7E | 9F |

### 4.2 AS 4059 Issue E: 2005

Issue D, despite its obvious benefits, did not gain the acceptance of the US Aircraft industry as it was considered to be too complex and did not allow an easy conversion from NAS 1638. The revision was issued on 2005/05/02 and the following changes were made to Issue D:

- Inclusion of NAS1638 data (differential counts) as AS4059 Table 1 (see Table 5) with exactly the same numbers.
- Retention of the Cumulative method of data presentation as AS4059 Table 2 but true conversion of data from NAS1638 i.e. no rounding up/down of data, (see Table 5).
- New instructions for specifying and reporting cleanliness data; this effectively incorporates those in Issue D for the cumulative counts as AS4059 Table 2 and gives better guidance for the 'NAS1638' data (Table 1). It also has new reporting tables to reflect these changes.
- It explains the differences between NAS1638 and AS4059.

■ Interestingly, it allows the use of microscope counting at 100µm if the APC is not calibrated at 70µm(c).

Table 5. AS4059 Table 1 Cleanliness Classification System (Interval Counts)

| Size, ISO 4402 Calibration, or optical microscope | | Maximum Contamination limits (particles/ 100 mL) 5 to 15 µm | 15 to 25 µm | 25 to 50 µm | 50 to 100 µm | > 100 µm |
|---|---|---|---|---|---|---|
| Size, ISO 11171 Calibration or Electron Microscope | | 6 to 14 µm(c) | 14 to 21 µm(c) | 21 to 38 µm(c) | 38 to 70 µm(c) | > 70 µm(c) |
| Classes | 00 | 125 | 22 | 4 | 1 | 0 |
| | 0 | 250 | 44 | 8 | 2 | 0 |
| | 1 | 500 | 89 | 16 | 3 | 1 |
| | 2 | 1,000 | 178 | 32 | 6 | 1 |
| | 3 | 2,000 | 356 | 63 | 11 | 2 |
| | 4 | 4,000 | 712 | 126 | 22 | 4 |
| | 5 | 8,000 | 1,425 | 253 | 45 | 8 |
| | 6 | 16,000 | 2,850 | 506 | 90 | 16 |
| | 7 | 32,000 | 5,700 | 1,012 | 180 | 32 |
| | 8 | 64,000 | 11,400 | 2,025 | 360 | 64 |
| | 9 | 128,000 | 22,800 | 4,050 | 720 | 128 |
| | 10 | 256,000 | 45,600 | 8,100 | 1,440 | 256 |
| | 11 | 512,000 | 91,200 | 16,200 | 2,880 | 512 |
| | 12 | 1,024,000 | 182,400 | 32,400 | 5,760 | 1,020 |

Table 6. AS4059 Table 2 Cleanliness Classification System (Cumulative Counts)

| Size, ISO 4402 Calibration, or optical microscope | | Maximum Contamination limits (particles/ 100 mL) > 1 µm | > 5 µm | > 15 µm | > 25 µm | > 50 µm | > 100 µm |
|---|---|---|---|---|---|---|---|
| Size, ISO 11171 Calibration or Electron Microscope | | > 4 µm(c) | > 6 µm(c) | > 14 µm(c) | > 21 µm(c) | > 38 µm(c) | > 70 µm(c) |
| **Size Code** | | **A** | **B** | **C** | **D** | **E** | **F** |
| Classes | 000 | 195 | 76 | 14 | 3 | 1 | 0 |
| | 00 | 390 | 152 | 27 | 5 | 1 | 0 |
| | 0 | 780 | 304 | 54 | 10 | 2 | 0 |
| | 1 | 1,560 | 609 | 109 | 20 | 4 | 1 |
| | 2 | 3,120 | 1,217 | 217 | 39 | 7 | 1 |
| | 3 | 6,250 | 2,432 | 432 | 76 | 13 | 2 |
| | 4 | 12,500 | 4,864 | 864 | 152 | 26 | 4 |
| | 5 | 25,000 | 9,731 | 1,731 | 306 | 53 | 8 |
| | 6 | 50,000 | 19,462 | 3,462 | 612 | 106 | 16 |
| | 7 | 100,000 | 38,924 | 6,924 | 1,224 | 212 | 32 |
| | 8 | 200,000 | 77,849 | 13,849 | 2,449 | 424 | 64 |
| | 9 | 400,000 | 155,698 | 27,698 | 4,898 | 848 | 128 |
| | 10 | 800,000 | 311,396 | 55,396 | 9,796 | 1,696 | 256 |
| | 11 | 1,600,000 | 622,792 | 110,792 | 19,592 | 3,392 | 512 |
| | 12 | 3,200,000 | 1,245,584 | 221,584 | 39,184 | 6,784 | 1,024 |

## 5. Specifying Cleanliness and Reporting Cleanliness data

Two separate but similar processes are involved, depending on whether the data has to be expressed in terms of AS4059 Table 1 or AS4059 Table 2 and these are presented below. In both, the Class number is defined by the maximum particle concentration for that size and all the data has to be reported.

For AS 4059 Table 1 (differential counts):

Cleanliness is defined by a single class in a similar manner that was unofficially applied to NAS 1638, e.g. AS4059 Class 6and the particle counts in each size range must not exceed number given for each size range in that class.

When reporting, the cleanliness class for each size range is tabulated in a suitable result sheet (one is suggested in the standard) and the highest class in any particle size is reported without specifying that size.

For Table 2 (cumulative counts):

Specifying cleanliness is unchanged from Issue D using the Numeric (Cleanliness Class) Alpha (size) convention, either:

- Basing the class on the highest class of multiple size ranges e.g., AS4059 Classes 6B-F
- Total number of particles larger than a specific size, e.g. AS4059 Class 5B,
- Designating a class for each size range e.g. AS4059 Classes 7B/6C/5D, in this example there is no cleanliness requirement for sizes A, E & F

Although there is no requirement to report the highest class, if this is done it is recommended that the size at which it occurs is given e.g. AS4059 Class 8F.

## 6. Comments

Is NAS 1638 dead? Well not quite, it has arisen in two different forms!! From the statement on the NAS 1638 web site it can still be used for existing systems where correlation with earlier data is considered necessary, but this lacks traceability. For those who prefer to use the NAS 1638 system, they should migrate to AS4059 Table 1.

The other form is AS4059 Table 2 and this has all the flexibility in both specifying and reporting Cleanliness data that was introduced when Issue D was developed.

One aspect of the change which may be a little unclear is that of component cleanliness – the scope of the original NAS 1638 document! As NAS 1638 is inactive for new components/ systems and AS4059 is really meant for hydraulic systems, how is the cleanliness of components defined? The SAE Committee have been made aware of this and are deliberating. The authors recommend the use of AS4059 system using sizes B to F for commonality and relating the particle counts to 100mL of the components wetted volume.

The SAE committee responsible for this standard has complied with the requirements of the US Aircraft industry and it is hoped that this industry adopts this standard. It should be noted that both NAS 1638 and AS4059 are used in other industrial sectors such as the Off-shore & Sub-Sea and the Primary Metal industries, but the SAE committee have not taken into account the views of these users. This is understandable but unfortunate as modern quality systems demand the use of up-to-date standards and these other industries will either have to adopt procedures that are controlled by the aircraft industry and accept any changed that the owners desire. Alternatively, if this is untenable, they will have to develop their own standards.

## 7. References


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### [Authors Introduction]


Mike Day
E-Mail: mikejday@gmail.com
Tel: +44 (0)2392 251658
Born on July 31, 1946.
Mechanical Engineering at Staffordshire University, Bachelor's degree on July 1970, Cranfield University, Master's degree on July 1984.
Worked for BHR Group Research 1974-1984, worked for Pall Europe Ltd., Scientific & Laboratory Serviced, 1984- 2005 and Technology Group 2005-2011, Now managing director CMS Consultants Ltd.
Represents UK on ISO/TC131/SC6 and ISO/TC20/SC10. Convener of ISO/TC131/SC6/WG1.



Jeong-hee Hong(홍정희 理事)
E-Mail:Jeong-hee_Hong@pall.com
Tel.:02-560-8791, 010-9070-0669
Born on December 10, 1968.
Precision Mechanical Engineering in Busan National University, Bachelor's degree, on Feb. 1991. Precision Mechanical Engineering in Busan National University, Master's degree, on Feb.1993.
Worked at Research & Development Center in Doosan Infracore; 1993-2000. Now working for Scientific &Laboratory Service in Pall Korea Limited; 2000～2012. Represents Korea, ISO/TC131/SC6 & ISO/TC20/SC10 Technical Committee Member in KATS