RECOMMENDATIONS AND BEST PRACTICE FOR HYDRAULIC HOSE ASSEMBLY CLEANLINESS

BFPA/P111

BFPA
REPRESENTING HYDRAULIC & PNEUMATIC INDUSTRIES

ISSUE 1

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FOREWORD

These Recommendations are intended to reflect the opinion of the British Fluid Power Association only and a User should also consider manufacturer's instructions before using any particular product.

This document has been prepared under the direction of the British Fluid Power Association.

These Recommendations reflect current practice within the industry and draw together information from a number of national and international specifications currently used.

Whilst the Association has taken all reasonable care to ensure the accuracy of these Recommendations, no liability or responsibility in negligence or otherwise whatsoever shall be accepted by the Association, its members, servants or agents as to the content or interpretation of these Recommendations.

BFPA would like to express its appreciation for the preparation to individuals and companies who prepared these Recommendations.

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NORMATIVE REFERENCES

ISO 4405:1991	Hydraulic fluid power – Fluid contamination - Determination of particulate contamination level by the gravimetric method
BS ISO 4406:1999	Hydraulic fluid power – Fluids - Method for coding the level of contamination by solid particles
BS ISO 4407:1991	Hydraulic fluid power – Fluid contamination – Determination of particulate contamination by the counting method using an optical microscope
BS 8465:2010	Hydraulic fluid power – Monitoring the level of particulate contamination – Comparison membrane technique
BS ISO 11171:2010	HFP - Calibration of automatic particle counters for liquids
BS ISO 11500:2008	Hydraulic fluid power - Determination of particulate contamination by automatic counting using the light interruption principle
BS ISO 11943:1999 *under revision*	Hydraulic fluid power - On-line automatic particle-counting systems for liquids - methods of calibration and validation
ISO/TS 12669 *under development*	Hydraulic fluid power – Guidelines for determining the required cleanliness level (RCL) of a system
BS ISO 16232-1:2007	Road vehicles – Cleanliness of components of fluid circuits Part 1: Vocabulary
BS ISO 16232-2:2007	Road vehicles – Cleanliness of components of fluid circuits Part 2: Method of extraction of contaminants by agitation
BS ISO 16232-3:2007	Road vehicles – Cleanliness of components of fluid circuits Part 3: Method of extraction of contaminants by pressure rinsing
BS ISO 16232-4:2007	Road vehicles – Cleanliness of components of fluid circuits Part 4: Method of extraction of contaminants by ultrasonic techniques
BS ISO 16232-5:2007	Road vehicles – Cleanliness of components of fluid circuits Part 5: Method of extraction of contaminants on functional test bench
BS ISO 16232-6:2007	Road vehicles – Cleanliness of components of fluid circuits Part 6: Particle mass determination by gravimetric analysis
BS ISO 16232-7:2007	Road vehicles – Cleanliness of components of fluid circuits Part 7: Particle sizing and counting by microscopic analysis
BS ISO 16232-8:2007	Road vehicles – Cleanliness of components of fluid circuits Part 8: Particle nature determination by microscopic analysis
BS ISO 16232-9:2007	Road vehicles – Cleanliness of components of fluid circuits Part 9: Particle sizing and counting by automatic light extinction particle counter
BS ISO 16232-10:2007	Road vehicles – Cleanliness of components of fluid circuits Part 10: Expression of results

NORMATIVE REFERENCES

ISO/TR 16386:1999	Hydraulic fluid power - Impact of changes in ISO fluid power particle counting - Contamination control and filter test standards
BS ISO 18413:2002	Hydraulic fluid power – Cleanliness of parts and components – Inspection document and principles related to contaminant collection, analysis and data reporting
ISO 21018-1:2008	HFP - Monitoring the level of particulate contamination of the fluid - Part 1: General principles
ISO 21018-3:2008	HFP - Monitoring the level of particulate contamination of the fluid - Part 3: Use of the filter blockage technique
ISO 21018-4 *under development*	HFP - Monitoring the level of particulate contamination of the fluid - Part 4: Use of the Light extinction technique
NAS 1638 *(obsolete)*	Cleanliness requirements of parts used in hydraulic systems
SAE J 1227:2013	Assessing cleanliness of hydraulic fluid power components and systems
SAE AS 4059F:2013 *superseded NAS 1638*	Aerospace Fluid Power – Cleanliness classification for hydraulic fluids

1. INTRODUCTION

These Recommendations have been written for the control of contamination and monitoring of cleanliness levels in hydraulic hose assemblies. They relate mainly to those assemblies produced in a production environment but are also applicable, and important, to other sectors of the hydraulic hose assembly industry, including mobile hose replacement, trade counters, hose assemblers and users.

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit. To allow fluid flow between components, they are inter-connected by piping, both rigid (tubes and tube connectors) and flexible (hose assemblies) that consist of hose and hose connectors.

2. SCOPE

This document gives guidance on how to achieve clean hydraulic hose and hose assemblies to assist component manufacturers, assemblers and users in the following areas:

- received hose assembly component cleanliness
- in-process cleanliness control
- final hose assembly cleaning
- cleanliness validation
- delivered assembly cleanliness
- user cleanliness maintenance

It should be noted that this document solely relates to hydraulic components, assemblies and applications under the control of the following ISO technical committees:

- ISO/TC 45/SC 1/WG 3 Hydraulic hoses
- ISO/TC 131/SC 4 Connector and similar products and components

For components, assemblies and applications (including, but not limited to paint, fuel, chemical transfer, compressor, oxygen-charging and other gaseous forms) that are outside the scope of this technical committee, the customer and supplier shall agree on the processes required to ensure that products and assemblies are supplied to the required level of cleanliness using best commercially viable practices.

3. RECOMMENDED HYDRAULIC HOSE ASSEMBLY CLEANLINESS LEVELS

3.1 General

The cleanliness level of manufactured hydraulic hose assemblies (i.e. high production volume as opposed to low volume service hoses) will, in most cases, be specified by the customer reflecting their requirements for the total system cleanliness, where the hose assemblies will be used.

This level is referred to as the 'Required Cleanliness Level' (RCL) and is an important parameter in the management of the system cleanliness throughout its life.

The RCL specified is dependent upon the contaminant sensitivity of the systems components, the operating pressure levels, and the life and reliability of the machine where the hydraulic system is installed.

As the RCL is a specific customer's requirement it is unreasonable to impose this upon hose manufacturers who work on bulk or batch production principles, but may rarely know of the customers' requirements. It is sensible, therefore to achieve a lower minimum standard for 'normal' production throughput, and then put into place additional processes towards the end of the production process that will achieve the higher levels of cleanliness, if specified by the customer.

3.2 Production Cleanliness Levels for Hose Assemblies

For finished hose assemblies the required cleanliness is defined by three levels of system sensitivity as shown in Table 1 below:

Table 1 - Required Hose Cleanliness Levels for System Sensitivity Levels

Sensitivity	***System Application for the hose***		***ISO 4406 Code***	***Converted SAE AS 4059 Table 1***
	Type	***Pressure***		
Low	Low pressure gear pump systems	< 180 bar	20/18/15	10
Medium	High pressure, hydraulic piloted, piston pump load sensing systems	< 280 bar	18/16/13	8
High	High and ultra-high pressure, solenoid operated systems	> 280 bar	17/15/12	7

Specifying RCLs in terms of ISO 4406 codes presents problems to OEMs, and manufacturers, as both require some knowledge/guidance on the number of particles much larger than the >14 µm(c)/15 µm limit within the standard ISO 4406. The only other 'international' source for guidance is SAE AS 4059 which goes up to 70 µm (c)/ >100 µm, see ISO/TR 16386 for an explanation of the dual sizes. Even then data on larger sizes may be required and there is no published guidance, see Annex A.

3. RECOMMENDED HYDRAULIC HOSE ASSEMBLY CLEANLINESS LEVEL

3.3 Suggested Maximum Particle Counts for Various Levels of Contaminant Sensitivity

In an attempt to overcome limitation stated within 3.2, members of the BFPA Technical Committee - Contamination Control (TC 6) have used current particle count data and particle size distributions to generate representative maximum particle numbers allowed for the three sensitivity levels stated within Table 1.

The methodology is explained within Annex A and the following comments should be noted:

- Like all particle size distributions, the numbers of particles reduce greatly as the size of the particle gets larger. This means that the concept of "zero particles" at these sizes does not exist in a statistical sense.
- The preferred volumetric unit at ISO is 1 mL. The data at these sizes are very small and result in decimal numbers at the larger sizes and to lessen this impact, the particle counts have been referred to a volume of 100 mL.
- Microscope particle counts at > 1 µm are as stated within the standard, but this is considered not to be practical.
- The equivalent AS 4059 classes do not duplicate ISO 4406 distribution. AS 4059 Table 1 convention is used.

Table 2 - Maximum Particle Concentrations for Stated Sizes

Sensitivity to Contaminant	***ISO 4406 code***	***Maximum particle counts per 100 mL greater than micron size***									
		Microscope sizes	1	5	15	25	50	100	200	600	1 000
		**APC sizes*	4	6	14	21	38	70	200	600	1 000
		Size code	A	B	C	D	E	F	G	H	K
Low	20/18/15	AS 4059 Class 10	1,000,000	250,000	32,000	5,659	98	148	16,4	0,268	0,0304
Medium	18/16/13	AS 4059 Class 8	250,000	64,000	8,000	1,415	245	37	41	0,670	0,00759
High	17/15/12	AS 4059 Class 7	130,000	32,000	4,000	707	122	18,5	2,05	0,335	0,0038

* APC = Automatic Particle Counter, see section 9.6.5

If a cleanliness specification for the component is not supplied then this can be generated:

a) decide what sensitivity level is to be applied, whether "Low", "Medium", or "High"

b) select relevant row in Table 2 and record the maximum particle numbers at the sizes where data is required

c) derive the wetted volume of the component under test in mL and divide by 100

d) multiply the numbers in (b) above by the volume derived in (c) above

e) analyse the cleanliness of the component using either the methods specified in the Inspection Document, see section 9.3 or those chosen from sections 9.4 (Extraction) and 9.6 (Analysis) and record the result

f) if the number, per component, is above the maximum derived in (c) either re-clean the component(s) or report the data to the customer

4. RECEIVED COMPONENTS CLEANLINESS

4.1 **Bulk Hydraulic Hose** (from source of manufacture)

Air or water used in the manufacture of hose that comes into contact with the hose bore should be filtered to ≤5 µm to preserve the cleanliness achieved during the hose manufacturing process. It is recommended for bulk hydraulic hose that the cleanliness shall be compliant with the medium sensitivity level as defined within Table 1, see section 3.2.

The established level of cleanliness should be maintained during transportation by adequately sealing the hose to prevent the ingress of environmental contamination.

4.2 **Cut Hydraulic Hose** (from storage)

It should not be assumed that tier-2 distribution of bulk product would continue to maintain the medium sensitivity level of cleanliness, see section 3.2**.** If it has not been requested at the point of purchase, or within the contract documentation, then it is recommended that the minimum level of tier-1 supply shall be the medium level.

Supplied cleanliness level can only be by agreement between the stockist and the purchaser.

4.3 **Hose Connectors**

Connectors shall be delivered free of internal swarf, other loose particulate, plating residue and be compliant with the medium sensitivity level of cleanliness, see section 3.2.

5. STORAGE, PACKAGING AND TRANSPORTATION OF COMPONENTS

The supplier is to exercise care at all stages of the package, storage and transport processes to ensure that the required level of component cleanliness is maintained. More specifically, that responsibility includes the following:

- providing adequate packaging for component storage and shipment
- using appropriate storage conditions
- using appropriate shipping methods

If deterioration in component cleanliness occurs between the time of release by the supplier and the time of receipt by the purchaser, then the supplier and purchaser shall jointly investigate the cause and take corrective action.

Storage periods for any product should be kept to a minimum. Stock rotation is therefore essential and the 'first in/first out' rule applied.

Hose and connectors shall be stored in a clean and dry environment – bulk hose shall not be stored outside. Bulk hose should either have the ends capped, be kept in the original shipping carton, or sealed plastic wrap, until required to be used. The end caps prevent additional contaminants entering the coil of hose, including microbial contaminant.

Connectors shall be stored in sealed bags, boxes, or closed bin drawers. Special care shall be taken for connectors which seal on rubber seals, such as O-rings, bonded and other types of rubber seals shall be stored in a clean, dry, stable and dark environment so as to reduce the chance of degradation and prevent additional contamination of the product.

It is best practice to store O-rings in the plastic bags that they are received in from the supplier.

Any items returned to storage (e.g. bulk hose) should first be cleaned and protected to prevent damage by the ingress of contamination and also to ensure that they do not contaminate other stored items.

All caps, plugs and other methods used to protect hose and end terminations from damage and the ingress of contamination should be stored in sealed bags, boxes or closed drawers.

NOTE 1*: unused powder free disposable gloves are often used on site to stop contamination entering.*

6. MAIN HYDRAULIC HOSE ASSEMBLY PROCESSES AND CONTAMINATION ZONES

The flow chart below identifies the processes involved in the manufacture, supply and installation of hydraulic hose assemblies with the contamination zones to be controlled to meet efficiently the required cleanliness levels.

Processes	***Contamination Zones***					
1.→ Delivered Components	→	**Received Cleanliness**	→	**Storage Ingress**	→	**Environmental Debris**
2.→ Hose Cutting	→	**Cutting Debris**	→	**Cutting Blade Condition**	→	**Machine Cleanliness**
		↓				
		Extraction Method	→	**Filter Maintenance**		
3.→Hose Skiving	→	**Skiving Debris**	→	**Machine Cleanliness**	→	**Mandrel and Blade Condition**
		↓				↓
		Extraction Method				**Mandrel/ Blade Lubricant**
4.→Hose Cleaning	→	**Cleaning Machinery**	→	**See item 11**		
5.→ Ferrules/Connectors Mounting	→	**Lubricant Application**	→	**Environmental Debris**	→	**Hose End Condition**
						↓
						Preparation
6.→ Inserts Pushing	→	**Pushing Machine Cleanliness**	→	**Environmental Debris**		
7.→ Ends Orientation	→	**Machine Cleanliness**	→	**Environmental Debris**		
8.→ Pre-installation	→	**Debris Ingression**	→	**Connector Cleanliness**	→	**Environmental Debris**
9.→ Crimping	→	**Plating Debris**	→	**Machine Cleanliness**	→	**Environmental Debris**
10.→ Pressure Test	→	**Fluids Cleanliness**	→	**Machine Cleanliness**	→	**Environmental Debris**
11a.→ Flushing/Cleaning	→	**Fluids Cleanliness**	→	**Machine Cleanliness**	→	**Machine Turbulent Flow**
		↓				
		Fluids Types (Water/Oil)	→	**Fluids Temperature**	→	**Filter Maintenance**
		↓				
		Fluids Additives				
11b.→ Air Blast Cleaning	→	**Timed Process**	→	**Nozzle Design Cleanliness**	→	**Filter Maintenance**
11c.→ Sponge Pellet Cleaning	→	**Sponge Type**	→	**Nozzle Design Cleanliness**	→	**Filter Maintenance**
		↓				
		Sponge Storage	→	**Sponge Retrieval**		

6. MAIN HYDRAULIC HOSE ASSEMBLY PROCESSES AND CONTAMINATION ZONES

The flow chart below identifies the processes involved in the manufacture, supply and installation of hydraulic hose assemblies with the contamination zones to be controlled to meet efficiently the required cleanliness levels.

Processes	***Contamination Zones***					
12.→ Protective end terminators	→	**Protective End Terminators Cleanliness**	→	**Environmental Debris**		
13.→ Packing/Kitting	→	**Protective End Terminators Remain**	→	**Environmental Debris**		
14.→ Transportation	→	**Hoses Remain Protected**	→	**Environmental Debris**		
15.→ Handling and Storage	→	**Hoses Remain Protected**	→	**Environmental Debris**		
16.→ Installation	→	**Hoses Remain Protected until Installed**	→	**Connector Cleanliness**	→	**Environmental Debris**
				↓ **Sealing Tapes and Fluids**		
17.→ Handling between above processes	→	**Trolleys Cleanliness**	→	**Environmental Debris**		

7. HYDRAULIC HOSE/HOSE ASSEMBLY CLEANING METHODS AND MACHINERY

Various methods and types of machinery for the cleaning of hose and hydraulic hose assemblies are used during both the main manufacturing processes to reduce contaminants prior to connectors' installation and, more importantly, at the end of assembly process, which is then validated for final assembly cleanliness, see section 9.

The pros and cons of the methods, and types of machinery for the cleaning hose and hose assemblies are given below.

NOTE 2*: care must be taken to ensure methods and fluids used in cleaning/flushing (and drying) of hydraulic hose assemblies have to be such that the rubber hose tube is not scoured and/or abraded by the process, or that the cleaning/flushing fluid does not remove or extract components of the rubber damaging the hose tube.*

If in doubt contact the hose supplier/manufacturer for advice.

7.1 Risk Assessment

Risk assessment shall be carried out on all types of flushing/cleaning (and drying) processes, and machinery, to prevent health and safety risks to operators and other people within the vicinity. Machinery manufacturers' recommendations shall be followed at all times. Relevant personal protective equipment (PPE) shall be worn.

7.2 Air Blowing Combined with Extraction during Cutting

Compressed air filtered at point of use to ≤ 5 µm is applied to both ends of the cut hose piece. Methods of applying the air must give protection to operators. Eye protection is required for all compressed air methods. Typical methods used are listed below:

a) by pushing each end of the cut piece of hydraulic hose against a fixed concave cone shaped trigger nozzle to start a timed air blast

b) by using a hand held trigger operated, compressed air gun fitted with a concave cone to produce an air blast for a set time

The use of a concave cone allows the full length of the hose to be cleaned. A convex cone penetrates the hose bore for a small depth thus the air expelled misses a small section. For this reason the hose is blown in both directions.

In both cases above, the opposite hose end should be pointed in a downwards direction or into a collection chamber to prevent direct exposure to other operators and general environmental contamination.

Air Blowing methods are usually complemented by local extraction systems that are fitted directly to the hose cutting machine to prevent/reduce cutting debris entering the hose bore. A typical extraction rate of 3m/second should be maintained. This system should contain a filtration system to remove and collect particles and general debris. This (these) filtration system(s) shall be regularly maintained to ensure its continued effectiveness.

NOTE 3: *Spark Arresters shall be fitted between the hose cutting machine and the extraction filter to prevent ignition of collected rubber particles in the filter*.

7. HYDRAULIC HOSE/HOSE ASSEMBLY CLEANING METHODS AND MACHINERY

7.3 Projectiles

Air Blowing a projectile (also known as 'pellet' or 'pig') through the cut length of a hose using a pellet launcher/gun, attached to a compressed air supply, can remove a number of contaminants generated by the process. These include cutting and skiving debris, residual contaminants such as mandrel release agent from the hose manufacturing process, and lubricants used on the mandrel of the skiving process. A range of pellets are available for removing specific contaminants, see Figures 1, 2, 3 and 4.

The above process shall be repeated from both ends of the hydraulic hose cut length to ensure that the location area of the compressed air pellet nozzle, on the first pass, is cleaned on the second pass of the pellet. This cleaning process must be repeated until the blown projectile is visually clean, see Figures 5, 6, 7 and 8.

Figure 1 **Standard Series (S)**	**Figure 2** **Coupling Series (C)**	**Figure 3** **Abrasive Series (A)**	**Figure 4** **Grinding Series (G)**
			
Standard series projectiles are intended for the cleaning of hose, tube or pipe without end fittings or restrictions	Coupling series projectiles are intended for the cleaning of hose assemblies (hose with end fittings, adjustments etc. or the removal of loose particles from pipe or tube	Abrasive series projectiles are intended for the cleaning of metal pipe (not hose) and tube to remove light rust and scale. They are recognised by the abrasive pad fixed to one end of the projectile	Grinding series projectiles are intended for the cleaning of metal pipe (not hose) and tube to remove medium and heavy rust and build up from the internal surface. They are coated in Silicon Carbide.

NOTE 4: a*bove technical data and pictures supplied by Stauff UK Limited*

The above process is intended to be used prior to the insertion of the hydraulic hose assembly connectors and does not exclude the need for final assembly cleaning processes. If the same projectile process is used, as a final assembly cleaning process, it is possible that a large amount of contamination could be trapped at the insert tail end of the connector, in the hydraulic hose tube liner depression formed by the insert tail after its compression into the hose bore and crimping of the ferrule.

NOTE 5: *it is important to verify the projectiles have passed through the hose. Advanced launchers are available with a projectile verification system.*

NOTE 6*: projectiles shall not be re-used.*

7. HYDRAULIC HOSE/HOSE ASSEMBLY CLEANING METHODS AND MACHINERY

7.3 Projectiles

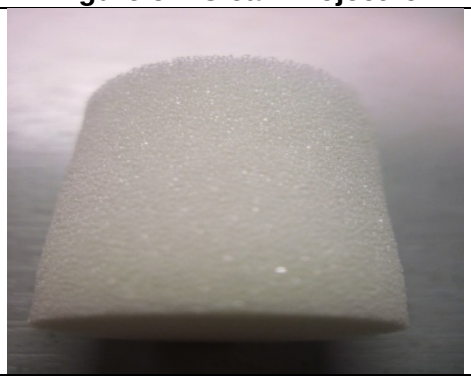
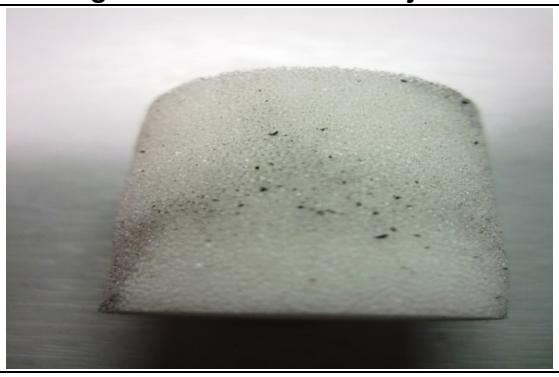
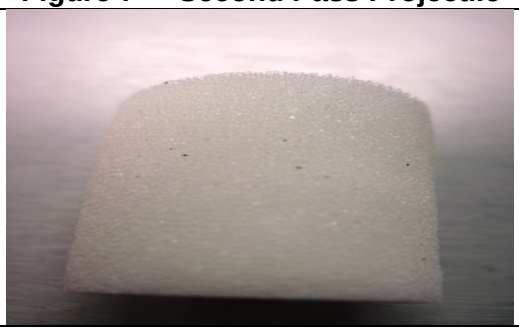
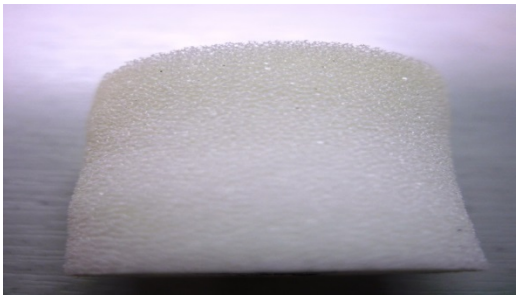
Figure 5 – Clean Projectile	Figure 6 – First Pass Projectile
	

Figure 7 –- Second Pass Projectile	Figure 8 – Third Pass Projectile
	

7.4 Water Flushing/Cleaning

Flushing/cleaning (and drying) machines are designed to generate a turbulent flow of fluid to pass through the hose to remove debris and other contaminants. The fluid passes through either a single filter or a series of filters to ensure the fluid used to flush/clean the hose-assembly is one cleanliness level lower than the specified RCL.

Compressed air used to clean cut hose pieces or connected to flushing/ cleaning devices has to be clean, dry and filtered through a ≤5 µm filter to prevent fluid and airborne debris contamination.

NOTE 7*: if the flushing/cleaning machine does not have a drying facility then the hose should be blown out using compressed air dried to at least -20 °C dew point.*

Flushing/cleaning (and drying) rigs using either cold or heated water can be manually or automatically operated. The manually operated rigs usually use cold water, requiring an operator to hold the hose assembly in one hand, then flush and dry using a gun with the other. This process requires suitable work instruction and timing plan to control the process and minimise operator error.

Additives have to be added to the water to prevent frothing due to turbulent flow generated. A small amount of detergent is usually added to aid cleaning and also, anti-corrosion fluid is added to prevent connectors suffering from corrosion from any residual water in the hose. Some automated systems are equipped with an oil mist spray function to lubricate the connectors following the flushing and drying process.

7. HYDRAULIC HOSE/HOSE ASSEMBLY CLEANING METHODS AND MACHINERY

7.4 Water Flushing/Cleaning

Regular maintenance of this fluid is necessary to ensure that the concentration of additives is correct as evaporation of the water may increase it.

NOTE 8*: it is important that any fluids used are hose tube compatible, and filtered, to ensure it does not damage the hose as well as increase the contamination level above the RCL.*

7.5 Oil Flushing/Cleaning (and Drying)

Automated oil flushing/cleaning (and drying) rigs are used. In some cases using heated, low viscosity hose tube compatible fluids. The fluid in these rigs is usually in a re-circulatory tank where the fluid is filtered and the cleanliness level monitored electronically prior to being used in the flushing/cleaning process. It is advantageous if the device monitoring cleanliness level of the turbulent fluid passing through the hydraulic hose assembly has an automatic cut-off when specified cleanliness level is reached.

NOTE 9: *final hose cleanliness validation (see section 9) is necessary to ensure the flushing/cleaning (and drying) operation is effective and meets required cleanliness level*.

In addition the following elements also have to be considered:

All fluid filters, immediately upon indication, should be fitted with blockage indicators and changed to maintain optimum performance of the filters and to avoid the passing of contaminants to the hose assembly being flushed.

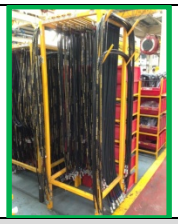
NOTE 10*: WARNING! Care shall be taken to ensure methods and fluids used in flushing/cleaning (and drying) of hydraulic hose assemblies are such that the rubber hose tube is not scoured/abraded by the process, or that the flushing/cleaning fluid does not remove or extract components of the rubber damaging the hose tube. If in doubt contact the hose supplier/manufacturer for advice.*

8. CUSTOMER GOODS RECEIVING, STORAGE AND INSTALLATION PROCEDURES

8.1 Goods Receiving

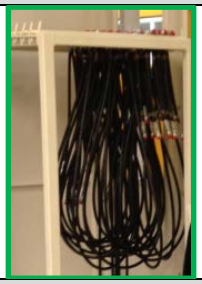
Delivery containers shall be lidded and internally clean.		
Containers that are internally contaminated shall be quarantined together with their contents, and supplier containment measures initiated.		
Hoses that are quarantined (except bagged kits) shall be individually wiped with a lint-free wipe – one per hose, then the wipe discarded.		
Check that the protective plugs/caps/covers are sealed and secure (including bagged hoses).		
Reject any hoses delivered without protective end plugs/caps/covers.		

8.2 Storage

Hoses supplied loose shall be stored on clean racks.		
Hoses supplied bagged shall be appropriately sealed in their bags.		
Hose end fittings shall remain capped at all times.		

8. CUSTOMER GOODS RECEIVING, STORAGE AND INSTALLATION PROCEDURES

8.2 Storage

Hose end fittings shall NOT touch or drag on the floor.		✗
Long hoses shall be coiled – ensuring loops of at least twice the Minimum Bend Radius (MBR).		✓

8.3 Kitting and Line Storage

Stock rotation – all stock shall be dispensed on FIFO (First in/First out) principle.		
Bagged hoses shall be identified, removed and fitted consecutively.		
Loose hoses shall NOT be allowed to touch or drag on the floor at any stage.		✗

NOTE 11: *hydraulic hose assemblies that inadvertently touch the ground shall be inspected and, in the event of contamination, wiped clean with lint-free wipes. The hose shall be handled with care so that contaminant does not enter the hydraulic system during assembly.*

8. CUSTOMER GOODS RECEIVING, STORAGE AND INSTALLATION PROCEDURE

8.4 Line Assembly

Bagged hoses shall be identified, removed and fitted consecutively.		
Hoses shall NOT be allowed to touch or drag on the floor.		

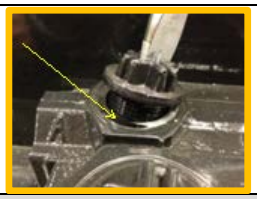
NOTE 12: *hydraulic hose assemblies that inadvertently touch the ground shall be inspected and, in the event of contamination, wiped clean with lint-free wipes. The hose shall be handled with care so that contaminant does not enter the hydraulic system during assembly.*

Each hose shall be routed with their protective end plugs/caps/covers intact.		
Hoses shall not be left uncapped at any time during installation unless it is being connected.		
Each hose shall be fitted individually: • the cap on other hose end removed • the hose connector inspected for any contaminant • the cap on the mating adaptor removed and the hose fitted immediately to this mating adaptor • appropriate tightening, marking and torqueing procedures shall be followed.		

8. CUSTOMER GOODS RECEIVING, STORAGE AND INSTALLATION PROCEDURES

8.4 Line Assembly

***NOTE 13**: when removing port protection from painted hydraulic component ports extreme care shall be taken to avoid paint flakes from entering the component ports.*

		**Watch for!** 
Identical procedures shall be followed for the other end.		
Hoses that have not been used and are returned to stores uncapped shall be returned to the supplier for re-cleaning and capping.		

9. CLEANLINESS VALIDATION METHODS

9.1 General

The process of validation involves two stages – extraction and analysis.

Extraction is where the particles inside the hose assembly are removed and collected, and the contamination level is determined by ***Analysis*** where the extracted fluid is analysed for its concentration and/or characteristics.

This section briefly explains the function of each process and describes the procedures that are most appropriate for hydraulic hose assemblies and fittings, and gives an indication on how to present the data.

9.2 Component Cleanliness Standards Used in Industry

As there are a number of component cleanliness standards currently used within the hydraulics industry, some knowledge of their development is necessary to avoid possible confusion.

Component cleanliness was standardised by the aircraft industry during the 1960s and the NAS 1638 cleanliness coding system was written to control the amount of dirt introduced into aircraft components. Despite pioneering component cleanliness, the aircraft industry did not feel it necessary to do much on the component cleanliness procedural front as specifying a NAS requirement in components and systems achieved the desired effect: i.e. reliability of aircraft improved and there was control.

It was not until the introduction of SAE J1227 during 1979 that contamination extraction and analysis procedures were documented and the methods described within these recommendations have formed the basis for many industrial, national and International standards. Some sectors of industry still specify this standard.

The last ten years has seen more and more industrial sectors implement a component cleanliness programme as technical and commercial benefits are realised. The fluid power industry was the sole developer of component cleanliness standards through the International Standards Organisation (ISO) technical committee – ISO/TC 131/SC 6 – until 2002, when the automotive industry embarked upon a project to develop their own standards through ISO/TC 22/SC 5. Although the processes developed by these sectors were very similar, the automotive industry considered that their requirements were sufficiently different to warrant new standards. The main reason was that the automotive industry's focus was on the incidence of small numbers of large particles (>1000 µm) so-called "killer particles" residual after production, as they could have serious safety consequences, whereas in fluid power systems these particles should be filtered out during production. This resulted in the publication of the ten parts of ISO 16232 during 2007.

This split development has led to small differences in both terminology and procedures. For instance the process of removing particles from components is called "extraction" within ISO 16232 but the term "collection" is used within ISO 18413. Both groups are committed to rationalising these differences. Some sectors in mobile industry use ISO 16232, others use ISO 18413.

9. CLEANLINESS VALIDATION METHODS

9.3 Inspection Document

This is a document that is a requirement of both ISO 18413 and ISO 16232. It is used to record the agreed inspection method: i.e. extraction, analysis and method of presenting the data, thus eliminating any misunderstanding and disagreements.

NOTE 14*: the Inspection Document's use is recommended.*

9.4 Contaminant Extraction Methods

9.4.1 General

The following sub-sections only give an outline of the extraction methods used, so users' should use the full procedures within the appropriate standards.

The extraction method should be the most suitable for the component being tested and must be selected for the geometry of the component so that:

- the test liquid can reach the controlled surfaces i.e. those surfaces wetted by the service fluid
- it can detach particles from the controlled surfaces and transfer them to the test liquid
- be analysed directly in situ for its concentration or drained into a suitable collection vessel for analysis

NOTE 15*: the agreed terminology is that the liquid is called 'test liquid' in its clean state and 'extraction liquid' when loaded with particles during and after extraction.*

The basis of cleanliness evaluation is to develop an extraction process that works effectively, document it and then use this for the measuring cleanliness of that product or ones similar to it. There are four (4) accepted methods: agitation (slosh test), pressure rinse, ultrasonic agitation and functional test bench (FTB), see Table 3.

ISO 18413 provides both recommendations for selection of contaminant extraction methods. This has been used to select those methods that are suitable for hoses and fittings, see Table 3.

Table 3 – Extraction Methods for Hydraulic Hoses and Hose Assemblies

Part	***Methods of Extraction***			
	Agitation	***Pressure Rinse***	***Ultrasonic***	***FTB***
received hose	NR	NA	NA	R
fittings	NA	R	R	NR
hose assembly	R	NR	NA	R

Key:

A Acceptable
NA Not applicable
R Recommended
NR Not recommended

9. CLEANLINESS VALIDATION METHODS

9.4 Contaminant Extraction Methods

9.4.2 *Agitation (Slosh Test) Extraction Method*

The method is most suited to hollow components like hydraulic hose assemblies. The particles are extracted in the following way:

- partially filling the component with a known volume of test liquid and between 30% to 50% of the component volume
- sealing its openings
- agitating (sloshing) in order to detach the particles from the controlled surfaces (i.e. those surfaces wetted by the service fluid - in this case the internal surfaces of a hydraulic hose assembly) and suspend them in the test liquid, see Figure 9.
- collecting the particles in a clean container for subsequent analysis, see section 9.6 or 9.7

Figure 9 - Agitation (Slosh Test) Extraction Method

The effectiveness of the agitation method depends upon type of agitation, duration of agitation and choice of test liquid.

The method is simple, inexpensive, easy to set-up and most suitable for short hose assemblies with a diameter < 1" (DN 25). It gets more difficult and the results more variable as the hose length increases and a practical limit of 1.5 m placed on the length of hose validated using this method.

The viscosity of the test liquid should be less than 5 cSt at the test temperature.

The hose assembly shall be filled $^{1}/_{3}$ to ½ full with clean test liquid and the ends shall be sealed with non-contaminating plugs. The test liquid viscosity shall not be greater than that of the system hydraulic fluid at maximum operating temperature. The liquid in the assembly shall then be agitated by turning the assembly vertically end for end for ten (10) complete cycles. Following agitation the test liquid shall be drained into a verified clean container.

9. CLEANLINESS VALIDATION METHODS

9.4 Contaminant Extraction Methods

9.4.3 *Pressure Rinse Method*

The particles are extracted from the controlled surfaces by:

- pressure rinsing with a jet of filtered test liquid which moves the particles away from controlled surfaces, see Figure 10
- collecting the particles in a suitable clean container
- analysing the extraction liquid for the concentration of particles, see section 9.6 or 9.7

The method should only be used on surfaces that are accessible and can be penetrated by the jet: e.g. relatively small surfaces, passage ways, and drillings. Different shaped nozzles should be available to suit the surface being rinsed. For instance, needle shaped for narrow passage ways, fan shaped for large surfaces.

It is recommended that this method is only used on hose assemblies when it can be assured that the flow of test liquid is sufficient to penetrate the entire surface of the hose assembly, with a degree of turbulence sufficient to detach residual particles and transfer them out of the hose assembly to a clean collection vessel.

The effectiveness of pressure rinsing depends upon pressure, flow rate, distance, angle, shape/size of the nozzle, rinsing time, and amount of liquid volume per unit area that is used.

Figure 10 – Pressure Rinse Extraction Method

9. CLEANLINESS VALIDATION METHODS

9.4.4 *Ultrasonic Vibration Extraction Method*

The particles are removed from the surfaces by subjecting the item to ultrasonic vibration and allowing them to fall into a cleaned collection vessel for subsequent analysis. The test items can be treated in one of two ways:

a) direct immersion – where the test item is placed in a secondary container holding the test liquid, as shown in Figure 11a

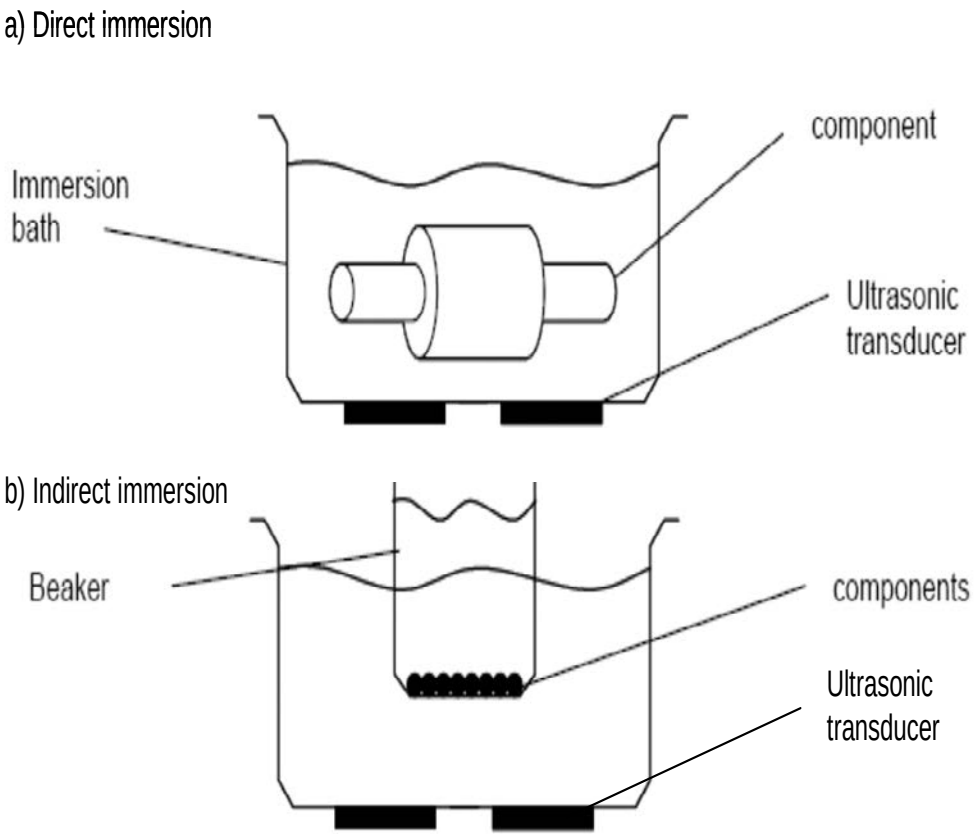
b) in-direct immersion – where the test item is placed into a suitable container which is then placed in the ultrasonic bath or tank, section 9 and Figure 11b

They are then sonicated for a suitable period, taken out of the liquid and residual particles are pressure rinsed [off and back] into the vessel. The extraction liquid in the container or tank is analysed either directly in the container or transferred to another container for analysis.

This method is only suitable for treating hose fittings and clearly the contaminant on the outer (non-controlled) surfaces will be removed and included in the analysis.

The principal characteristics of the ultrasonic equipment are sonication power and frequency and bath size.

Figure 11 - Ultrasonic Vibration Extraction Method



9. CLEANLINESS VALIDATION METHODS

9.4.5 *Functional Test Bench Method (End-use Simulation)*

This method uses a purpose-built test facility and the particles are extracted in the following manner:

a) the test item is installed in a validated test bench containing clean test liquid. The particles are removed from the controlled surfaces by circulating test liquid through the test item under turbulent conditions, see Figure 12

b) the particles are kept in suspension and the extraction liquid is either analysed by either directly on-line using a monitor, or samples taken from the facility for subsequent analysis. The extracted particles are analysed in accordance with section 9

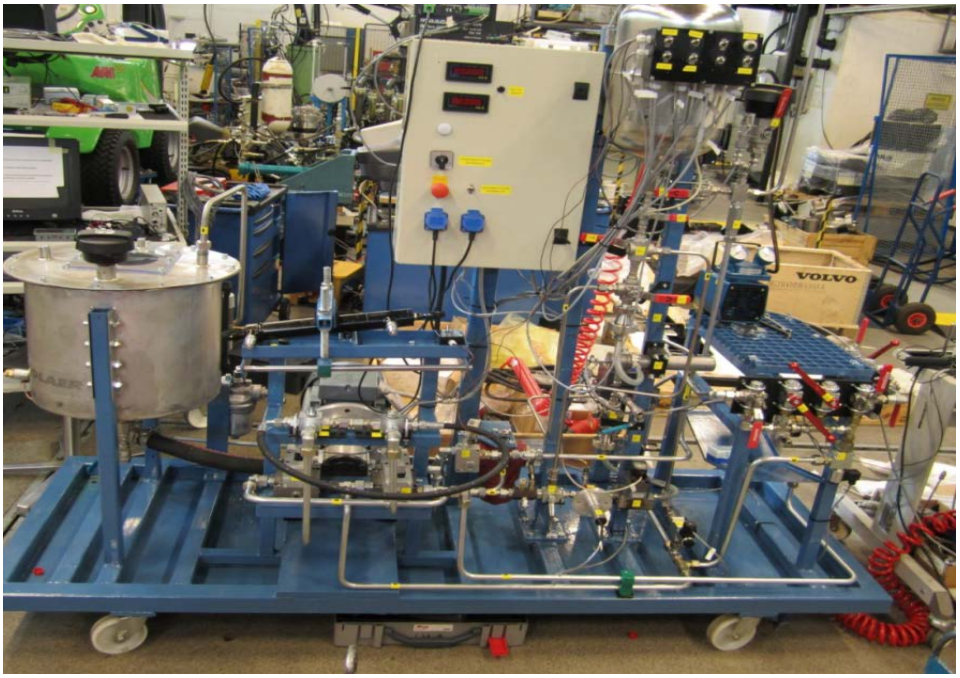
In reality this test is a flushing bench as component manufacturers will rarely subject the component to the variety of conditions seen in service.

This is perhaps the quickest and most cost-effective way of validating the cleanliness of hose assemblies and the results are ready in ‘minutes’ rather than hours as happens with other methods. The benefit is that the progress of extraction can be continuously monitored using on-line techniques and circulation stopped when the contamination level has reached a stable level.

It is, however, the most expensive method even for a basic design that complies with ISO 18413. If compliance with ISO 16232-5 is required then this necessitates an additional analysis rig and will add significant cost.

The effectiveness depends upon flow rate, degree of turbulence in the component, the internal geometry of the component and the characteristics of the test liquid solvency and temperature.

Figure 12 – Typical Functional Test Bench Extraction Method



9. CLEANLINESS VALIDATION METHODS

9.5 Validation of Contaminant Extraction Processes

All of the extraction methods listed within the various ISO standards are consistent in stating that extraction has to continue until the amount removed with the last extraction is <10% of the total extracted; this is termed the 'end-point'. The reason for this is that it ensures the majority of the particles are removed to a consistent level.

Most ISO standards require that the extraction process is validated before cleanliness tests are performed. It is considered that using non-validated extraction procedures i.e. not removing majority of contaminants, is one of the main reasons for different sites getting differing results.

Another function of the validation test is to determine the extraction parameters necessary to remove > 90% of the contaminant. This is so that the extraction parameters can be optimised for the "routine" extraction test, see 9.5.3.

9.5.1 Blank Test

A blank test is performed to verify that the environment, operating conditions and equipment used in the extraction procedure do not contribute a significant amount of contamination to the component being analysed. This should be performed before testing to confirm both the suitability of the environment for testing and also that the equipment is cleaned to the appropriate level. When this is confirmed a process blank is performed using identical conditions, to those applied during testing of the component but, with the component omitted.

Most ISO component cleanliness standards state that the blank value should be less than 10% of either the presumed, stated or measured value for the component. This, however, gives little margin with the so-called 'end-point' which is also <10% cleaner equipment and process blanks are, therefore, recommended.

If the blank level exceeds 10% of the cleanliness of the component then there are three possible causes:

1. either the environment is too dirty, in which case either the location should be provided with cleaner air or the tests be performed in a cleaner location

2. the equipment is too dirty and re-cleaning is necessary

3. the contamination level of the component is too low and it is necessary to increase the number of test components analysed in order to collect more particles, thus fulfil the 10% criterion

9. CLEANLINESS VALIDATION METHODS

9.5 Validation of Contaminant Extraction Processes

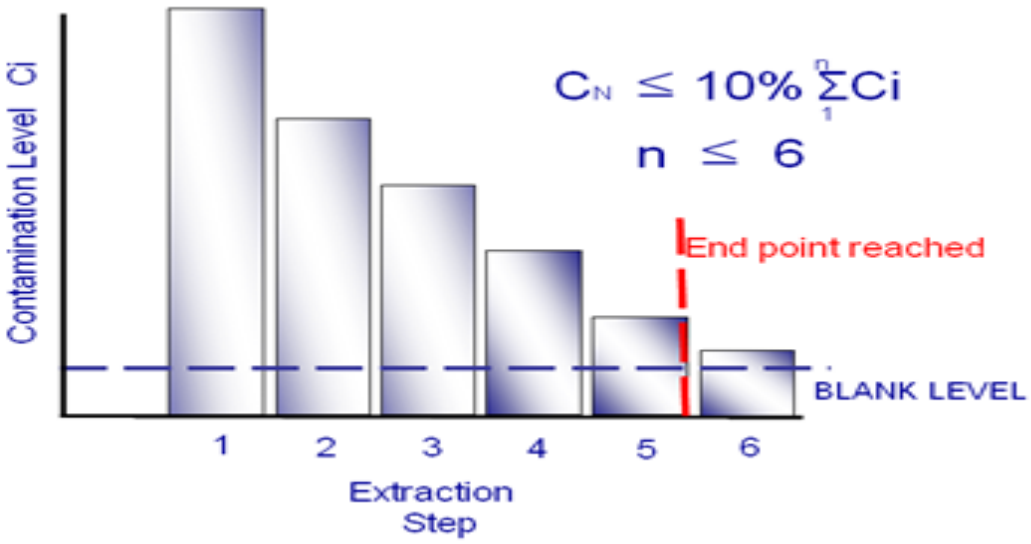
9.5.2 Validation Methodology

The validation process is:

- the operator has to firstly decide what extraction method is most suitable for the product being tested and then decide what the best extraction parameters are for that process, see section 9.4
- the extraction is then performed on the test item and the result measured using the selected method described in section 9.6. This is labelled C_1
- repeat above to give C_2. The second result is checked to see if the 'end-point' is reached i.e., is $C_2 < 10\%$ of C_{total}
- if $C_2 < 10\%$ of C_{total} the process has been validated and the extraction is complete
- if $C_2 > 10\%$ of C_{total} then the extractions are repeated until it is achieved
- the ISO component cleanliness standards state that this criterion has to be achieved in six (6) extractions otherwise the process is considered not to be cost-effective and the extraction parameters changed
- an example of an extraction test result is seen in Figure 13 which shows that the 'end point' is reached after five (5) extractions

NOTE 16*: the need to complete the extraction within six (6) extractions is made on the basis of work efficiency in batch testing and there is nothing to stop operators performing extractions beyond the six (6) stated within the standard.*

Figure 13 – Extraction Validation Methodology



9. CLEANLINESS VALIDATION METHODS

9.5 Validation of Contaminant Extraction Process

9.5.3 *Routine Extraction Method*

This method is a logical development of the above validation method and is designed to save time, hence costs, where evaluation of cleanliness is required on components that are similar to those used in the validation test.

The 'routine' method works on the principle that if it takes, five (5) extractions to achieve the 'end point', then it is likely that five (5) continuous treatments will achieve the same state of cleanliness. The extraction liquid is then analysed and a further smaller extraction is required to confirm that the 'end-point' is reached. If not, then further extractions must be performed until it is. Thus, potentially, the extraction can be achieved in only two steps.

Examples of how this is applied to the extraction methods given within section 9.4 are:

- agitation (sloshing): cannot be condensed as the same volume (or proportion of the test item volume) must be used each time for process consistency, but there is no need to analyse the washings after each extraction. For example, if the validation took five (5) extractions to reach the 'end point' then these 'sloshes' are done consecutively without analysis in between followed by a single slosh and analysis to confirm the 'end point'

- pressure rinse: if it took four (4) pressure rinses each with a volume of 100 mL, then a pressure rinse performed with 400 mL (4 x 100 mL) could achieve the same result. It then requires a single pressure rinse with 100 mL and analysis to confirm the 'end-point'

- ultrasonic vibration: if it took three (3) extractions, each of five (5) minute duration in the validation, then a single sonication of fifteen (15) minutes is performed followed by a single sonication of five (5) minutes and analysis to confirm the 'end point'

- functional test bench method: if on-line monitoring is performed then circulation continues until the data is stable. If samples are extracted from the facility for off-line analysis then circulation is performed for the total period of time of the validation test, and two samples are taken five (5) passes apart ($t=5*V/Q$). These should agree within 10% at the smallest size monitored, if not circulation is continued for at least five (5) passes

9. CLEANLINESS VALIDATION METHODS

9.6 Contaminant Analysis Methods

A variety of contaminant analysis methods and data reporting formats are available to produce the required component cleanliness data depending upon the ISO standard specified and the industry being served.

Both ISO 16232 and ISO 18413 describe three basic contaminant analysis methods:

- gravimetric
- particle size and distribution
- chemical composition

The largest particle size is included in particle size evaluation. The Inspection Document, however, should state the analysis method, see section 9.3.

The major difference separating ISO 16232 and other standards currently is the requirement to analyse all of the extraction liquid so that all particles in the extraction liquid are analysed and the larger 'killer' particles, typically at much lower concentrations, are not missed.

NOTE 17*: only an outline of procedures is given here so that the process is easily understood. For use the reader should consult the appropriate standard.*

9.6.1 *Preparation of Membrane Filters for Analysis*

A number of the techniques discussed within this section separates the contaminant in the extraction liquid by vacuum filtering through a membrane filter which deposits the contaminants on the surface where they can be seen and analysed. The process is performed using filtration apparatus described within ISO 4407 section 5.3 and is outlined below:

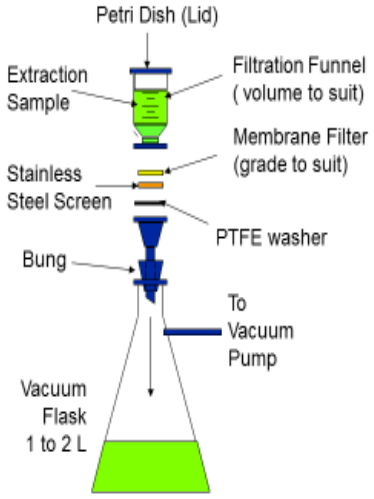
- clean the vacuum apparatus and assemble with a new membrane filter as shown in Figure 14
- prepare the sample, add to the funnel and vacuum filter until the fluid level is about 5 mm from the surface of the membrane filter. Carefully rinse the inner surfaces of the funnel with filtered test liquid
- slowly filter and continue with vacuum for about one (1) minute to dryness
- transfer membrane filter to a Petri slide using tweezers, and label

9. CLEANLINESS VALIDATION METHODS

9.6 Contaminant Analysis Methods

9.6.1 *Preparation of Membrane Filters for Analysis*

Figure 14 - Preparation of Membrane Filters for Analysis



9.6.2 *Gravimetric Analysis Method*

This method determines the weight of contaminant extracted from the component and deposited on a membrane filter. The mass of contaminant is determined by subtracting the initial weight of the membrane filter from the final weight. The process is as follows:

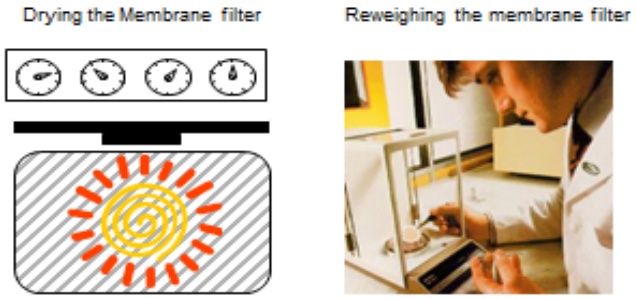
- dry the membrane filter, firstly in an oven at 80°C for 1 hour, then in a dessicator
- weigh directly from the desiccator and obtain the stabilised weight (W_1)
- assemble the membrane filter in the filtration apparatus; agitate the sample of extraction liquid and prepare the membrane filter as detailed within 9.6.1
- carefully remove the membrane filter, place in a suitably covered container and dry the membrane firstly in an oven at 80°C for one (1) hour, then in a dessicator for thirty (30) minutes
- remove the membrane filter and weigh directly from the desiccator to obtain the stabilised weight (W_2)
- calculate the amount of contaminant $W= W_1-W_2$ and express it in a suitable format

9. CLEANLINESS VALIDATION METHODS

9.6 Contaminant Analysis Methods

9.6.2 *Gravimetric Analysis Method*

Figure 15 - Gravimetric Analysis Method



***NOTE 18**: ISO 16232-6 specifies a 5 µm filter as small particles are not considered important to the automotive industry as they are to the fluid power industry. ISO 4405 uses a pore size of 0.8 µm.*

***NOTE 19**: the membrane filter prepared here can only be used for other analyses if the concentration of particles is suitable for the technique being used, e.g. for microscope counting, the density of particles should not be such to create overlapping particles.*

9. CLEANLINESS VALIDATION METHODS

9.6 Contaminant Analysis Methods

9.6.3 *Particle Size Distribution by Microscope*

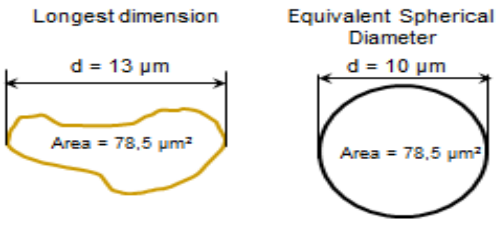
Here the contaminant in the extraction liquid is filtered through a membrane filter and particles deposited on its surface. The individual particles are sized and counted at stated sizes.

There are two techniques available to do this:

a) *Manual*

An operator views the membrane filter surface, usually with a binocular microscope and sizes and counts the individual particles. The particles are sized on the basis of their longest dimension as shown in Figure 16 where it is compared to the equivalent spherical diameter (ESD) used in other techniques.

Figure 16 – Particle Size Parameters



Microscope counting is the technique by which all other counting methods are validated. Unfortunately the nature of manual counting is such that it can induce operator fatigue and reduce both the accuracy of counting and the throughput of samples. To overcome this, most manual counting techniques allow statistical counting, where the particles are sized and counted in selected areas of the membrane, then the result is factored up. This is described within ISO 4407.

***NOTE 20**: WARNING! Statistical counting can mean that critical and larger particles may be missed.*

9. CLEANLINESS VALIDATION METHODS

9.6 Contaminant Analysis Methods

9.6.3 *Particle Size Distribution by Microscope*

b) *Automatic Microscope Particle Counting Using Image Analysis*

An image of the field of view of the membrane filter given by the microscope is taken, digitized and stored in a computer. The image can be recreated on a display monitor for the operator to see. The digitised image is then analysed using 'image analysis' software to give a number of characteristics of each particle: e.g. longest dimension (length), shortest dimension (width), perimeter length, area, equivalent spherical diameter (ESD).

Although the view can be manually selected and initiated, it is more usual to have a microscope with motorised stage and focus so that the process is fully automatic. This way the whole membrane can be analysed, hence complying with the requirements of ISO 16232 and in a relatively short time. The time to do this depends upon a number of factors, but is typically between fifteen (15) to thirty (30) minutes compared to 'days' to perform the same process manually.

The major demerit is the high cost for a basic unit which is trebled for a fully automatic instrument.

NOTE 21*: ISO 16232-7 does not allow manual counting and stipulates image analysis, see 9.6.3 b).*

NOTE 22*: ISO 16232-8 gives the option of counting using the scanning electron microscope (SEM) with an image analysis software package.*

9.6.4 *Longest Particle Dimension by Microscope*

The extent of this analysis is limited to the size of either a single particle or a specified number of the largest particles. Although this requirement can be satisfied with the equipment described within section 9.6.3, it can be performed at a relatively low cost with less sophisticated equipment as:

- a coarse filter disc can be used in place of a membrane filter provided that the surface is relatively flat and it is compatible with the test liquid
- a relatively inexpensive monocular microscope can be used, the magnification can be 25 times for these sized particles
- an inexpensive imaging system can be used for capturing images for inclusion in documentation

9. CLEANLINESS VALIDATION METHODS

9.6 Contaminant Analysis Methods – continued…

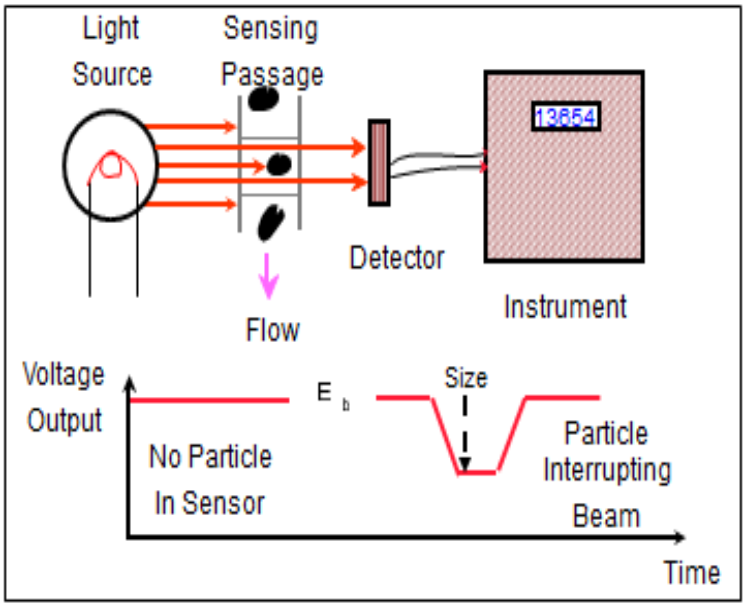
9.6.5 *Particle Size Distribution Counting Using an Automatic Particle Counter (APC)*

The number and size of particles in the extraction liquid can be determined by an automatic particle counter (APC) using a light extinction sensor. This technique is only applicable to measuring particles contained in clear and single phase liquids as the presence of optical discontinuities will cause errors.

Again, there are differences in the approach between the fluid power and automotive industries as ISO 18413 uses ISO 11500, where a representative portion is analysed in sample bottles. In the automotive standard (ISO 16232-9) the extraction liquid is transferred to an analysis rig which features an in-line APC where the complete volume is passed through the APC and analysed.

The size range of particles that can be measured by using APCs is limited to >70 µm(c), because of the method of calibration specified within ISO 11500 (ISO 11171). The calibration, however, can be extended to other sizes provided that it is agreed and included within the Inspection Document.

Figure 17 – Operating Principle of an Automatic Particle Counter (APC)



9. CLEANLINESS VALIDATION METHODS

9.7 Particle Monitoring Techniques

There are a number of techniques that can be used to assess the concentration particles in both the liquids used in the process and also the component being tested, but their nature is such that they are not considered to be primary particle counting techniques.

***NOTE 23**: these techniques shall not be used for either product validation or certification as they may not measure all of the particle sizes of interest. They can be used to monitor the progress of cleaning where a quick assessment is required.*

These instruments are defined within ISO 21018-1 and cover two basic types:

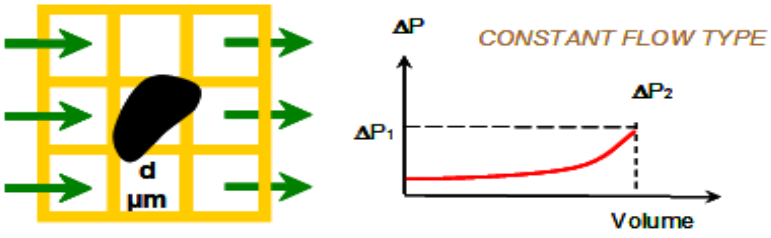
9.7.1 Automatic Particle Counters (APCs)

The principle of the APCs is identical to that described within section 9.6.5, the difference being that these units are calibrated to a secondary standard (ISO 11943) and not to a prime calibration standard (ISO 11171). Also their output may be in the form of contamination codes as with Filter Blockage Monitors (FBMs), see 9.7.2 below.

9.7.2 Filter Blockage Monitors (FBMs)

The main type of FBM works on the basis of particles that are larger than the pore size of the filter (usually a mesh) being removed from the fluid. This increases the degree of blockage of the filter, hence the differential pressure across it. The principle is seen in Figure 18. The increase in differential pressure is then corrected for any changes in viscosity during the analysis cycle then converted into particle counts through calibration as detailed within ISO 21018-3. The particle count data is then converted into a contamination code. After the analysis cycle, the filter is back-flushed to remove the captured particles and is then ready for the next cycle. This cycle is repeated for subsequent meshes. These instruments have a limited number of meshes and current instruments only give data at >6 µm and >14 µm.

Figure 18 – Operating Principle of a Filter Blockage Monitor (FBM)



9. CLEANLINESS VALIDATION METHODS

9.7 Particle Monitoring Techniques

9.7.2 Filter Blockage Monitors (FBMs)

The advantages of these instruments are:

a) They can work on-line and can give a continuous measurement of the cleanliness level in the process that enables either immediate corrective action if the desired cleanliness level is not being achieved or maintained, or cessation of a cleaning process when the RCL is achieved.

b) They are generally unaffected by the condition of the fluid and any errors created by optical interfaces caused by fluid contamination of the test or process fluid such as: air bubbles, water in hydrocarbon fluids, greases in fluids etc.

9.7.3 Particle Concentration Using Comparative Monitors

This is a microscopic technique where a membrane filter is prepared from the sample to be analysed using the process described in section 9.6.1 and is then viewed using a microscope at relatively low magnification, for example: x 40. This technique is detailed within BS 8465 and is summarised below.

The concentration of particles on the surface is then compared to either a photograph or microscope slide representing a known concentration of particles, usually representing a specific contamination code. The operator then decides whether the concentration of particles on the test membrane filter is definitely cleaner or dirtier than the reference membrane filter selected. The reference images that are obviously dirtier or cleaner than the test sample are eliminated leaving a single or pair of reference images closest in cleanliness level to test sample. This is then reported as the cleanliness level.

The advantages of this method are its speed (it takes only about fifteen (15) minutes for the process), relatively low cost and the prepared membrane filter contains the materials from the process, which can be inspected for the types of contaminant, if required.

9. CLEANLINESS VALIDATION METHODS

9.8 Particle Nature Analyses (Chemical Composition Analyses)

The contaminant collected from controlled surfaces is vacuum-filtered and deposited on a membrane filter, see section 9.6.1. The surface is examined to determine the nature and/or chemical composition of the particles with a number of options:

- manual assessment using an optical microscope - if carried out in-house, expert training would be required
- an X-ray fluorescence spectrometer (XRF) - if the contaminant is on a membrane filter, this technique will only give the relative proportions of the chemical composition of the contaminant, unless specific particles can be isolated
- scanning electron microscope (SEM) - equipped with energy dispersion X-ray emission spectroscopic analyser (XDS), is probably the most useful instrument as it can analyse in a general scan or spot analysis of individual particles.

For ISO 18413, the technique is not specified and any technique can be used.

For ISO 16232 the only technique stated is SEM/XDS analysis. If the SEM has imaging analysis software it can perform tests complying with ISO 16232-7 (particle size distribution) and ISO 16232-8 (elemental composition) at the same time.

9.9 Data Presentation and Reporting

The way the data is presented will depend upon the customer's requirements. This should be specified within the Inspection Document that should accompany the work instructions or request. If not, there are two options, see 9.9.1 and 9.9.2.

NOTE 24: *companies are recommended to insist upon an Inspection Document being developed and agreed. This ensures that the tests and data reporting methods are clearly stated.*

9. CLEANLINESS VALIDATION METHODS

9.9 Data Presentation and Reporting

9.9.1 Basic Reporting Format

The report should contain the following minimum information:

- name of organisation doing the test, address, contact details, and authorising signature
- test item(s), part number, number and any other details such as wetted volume (in cm^3), and/or surface area (in cm^2), if available
- test method(s) used either state test method number or transcribe the procedure followed
- test results: report only the total contaminant measured unless otherwise stated:-
  - for gravimetric analysis: report in mg per component
  - for particle size distribution: report total numbers of particles per component at the requested sizes
  - for largest particle size: report in µm
- Report any observations made during the inspection

9.9.2 Reporting ISO Component Cleanliness Standards

At ISO, two separate methods for reporting component cleanliness data have evolved to satisfy the requirements of the fluid power and automotive industries. Although similar, there are small but significant differences in the way that data is reported:

- ISO 16232-10 reports interval or differential counts e.g. 5 to 15 µm, 15 to 25 µm etc.
- ISO 18413, written for the fluid power industry, reports cumulative counts: i.e. the numbers of particles greater than a certain size e.g. >5 µm, >15 µm, >25 µm etc.

NOTE 25: *these will give numerically different results with identical data and that data from ISO 16232 will appear cleaner.*

Some companies within the mobile sector are specifying cleanliness data as per ISO 16232 in the interval mode and others are using the cumulative mode of presentation.

NOTE 26: b*oth sets of standards state how to report tests and data, and contain pro-forma sheets for both data recording and reporting.*

9. CLEANLINESS VALIDATION METHODS

9.9 Data Presentation and Reporting

9.9.2 Reporting ISO Component Cleanliness Standards

This deals mainly with how particle count data is expressed including as a contamination code, see section 9.9.3 with the data expressed as interval size ranges as within ISO 16232 (automotive) compared with the cumulative method that is used within ISO 18413 (fluid power). These two methods give different results (see Note 25).

NOTE 27: *AS 4059 issue F uses both cumulative and differential methods for presenting particle count data.*

9.9.3 Component Cleanliness Coding Systems (CCCS)

The systems are alpha-numeric systems where the size code is represented by letters and the number of particles is represented by a number code. The number code is based upon a geometric power series (constant of two) to describe the range in particle count data numbers from very clean to very dirty in a convenient way. Each code is written as a sequence, enclosed in brackets and separated by slashes, of alpha-numeric pairs specifying all or several sizes. These are briefly described below:

1) The component cleanliness code for ISO 16232 indicates whether the code refers to 1 000 cm^2 of wetted surface or to 100 cm^3 of wetted volume of the component by having a capital letter A or V printed before the parentheses to signify whether the data is related to a unit area or unit volume. If there is no letter then the data refers to the quantity per component. The size range covered is 5 µm (size B) to 1 000 µm (size K).

   For example: ISO 16232 component cleanliness code =

   V (B20/C16/D18/E12/F12/G12/H8/I0/J0/K00)

2) The same alpha-numeric structure with the sequence enclosed in square brackets and the Volume or Area designation being as a subscript to the closing bracket:

   a) short form which represents the data obtained at three sizes, namely >15 µm/ >100 µm/ >200 µm.

   For example: $[18/14/10]_A$

   b) longer form which describes the contamination level at some or all of the designated sizes.

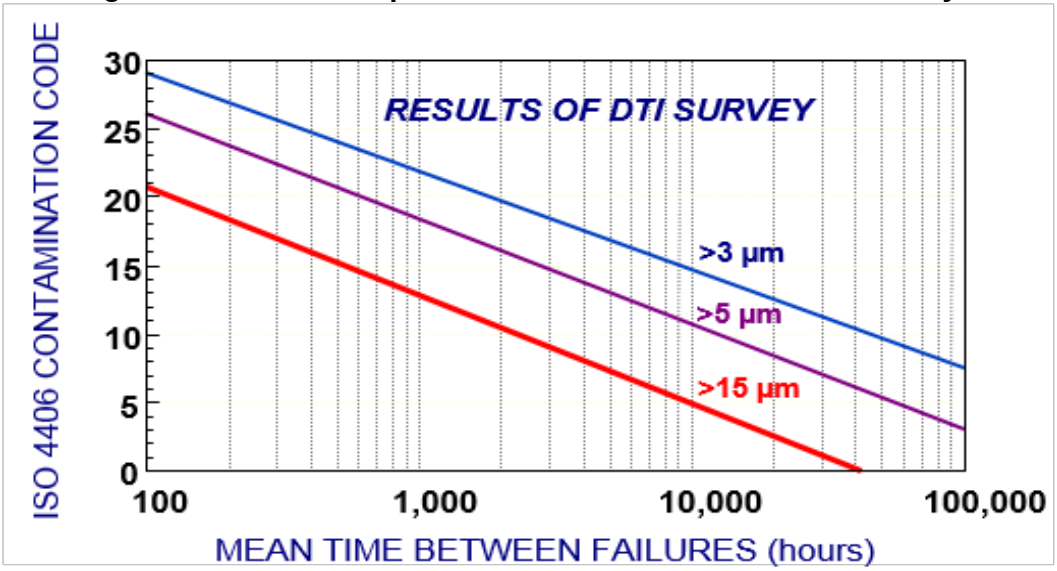
   For example: $[B20/C18/D16/E14/F14/G11]_V$

ANNEX A

A.1 General

As explained in section 3, an increasing number of users of hydraulic equipment are stating that the system be delivered and operate with clean hydraulic fluid to achieve an improved level of reliability and longer component life. The reasoning is seen in data from the survey of hydraulic systems commissioned by UK's Department of Trade and Industry. The report stated that the presence of solid particulate contamination ("dirt") in the hydraulic fluid was the single most important factor governing the reliability of that system. This survey was the first to quantify the relationship between the dirt level as represented by the ISO 4406 contamination code and the Mean Time Between Failures (MTBF) which is presented in Figure A.1.

Figure A.1 Relationship between ISO 4406 Code and Reliability



Note that the ISO 4406 code at the time of the survey involved only two sizes namely >5 µm and 15 µm, but the researchers wanted to look at the influence of smaller particles and added 3 µm.

It is this data that is being used to specify the operational fluid cleanliness level required to give a certain reliability level.

ANNEX A

A.2 Required Cleanliness Level (RCL) of a System

The RCL is an important concept in the management of the hydraulic system as it governs the cleanliness at all stages in the life of the hydraulic system, namely:

- determines the type and extent of contamination exclusion devices
- controls piece part and component cleanliness
- controls the cleanliness of process liquids, hence limits contamination ingression at the manufacturing stage
- controls the contamination during assembly
- specifies the cleanliness level of the flushing process for commissioning and hence delivery to the customer
- determines the 'action levels' to be used as part of the maintenance regime in service

In the main, the RCL will normally be specified by the end user using ISO 4406 contamination coding system. Currently, the level specified for a system is based upon previous experiences, either by that user or the experience of others with similar systems.

For example Figure A.1 shows that an ISO code of 18/16/12 would give an acceptable MTBF of 2,000 hours on mobile machinery (reflecting at least one year's hard duty) without failures related to the hydraulic system.

As the RCL is usually selected on historic data and does not necessarily reflect current expectations, ISO/TC 131/SC 6 is developing ISO/TS 12669 guidelines to determine the RCL of a system and is specific for that system and its users' requirements.

A.3 Differences in Operational and New-build Cleanliness

ISO 4406 was developed during 1974 to define the contamination/cleanliness level of the fluid in the hydraulic system. This is greatly influenced by the filter in that system, hence the fluid's particle size distribution will be characterised by a greatly reducing number of particles as the size increases, and this is partly a function of the cumulative method of data presentation. The rate of decrease depends upon the rating of the filter(s) and how it is performing within the system concerned. It is, however, generally accepted that the distribution can be described by having a two-scale number difference between the scale numbers at the first two sizes and a three-scale number difference between the scale numbers at the second sizes and third sizes, see ISO 12669 Figure 1.

For example: ISO 4406 17/15/12

ANNEX A

A.3 Differences in Operational and New-build Cleanliness

The contaminant distributions in newly built components are such that the numbers of particles still reduce with size, but less so than system distributions and are biased towards the larger sizes. The dirtier the component is, the more the bias, because of this, component coding systems describe the contamination level over a larger size range, for example up to 1 000 µm, see 9.9.3.

Thus, there is a basic contradiction in specifying system cleanliness levels to give recommended component cleanliness levels as they will be near impossible to achieve without a significant increase in production costs. Equally, specifying "typical" component levels is not the correct solution as they will not offer any improvement, so a compromise is required to devise levels that are both an improvement and achievable.

The RCL for the fluid power industry usually takes the form of an ISO 4406 code and as stated in section 3, this presents difficulties to both OEMs and manufacturers, as they require some guidance on the number of particles much larger than the >14 µm(c)/15 µm limit within ISO 4406. The only other international source for guidance is SAE AS 4059 which goes up to 70 µm (c)/ >100 µm, but data at sizes larger than this is usually required. As there is no published guidance, the BFPA formed a Joint Working Group of hose and contamination control experts to develop recommended contamination levels to cover those sizes not specified in ISO 4406, i.e. from >15 µm up to >1 000 µm.

A.4 Determination of Acceptable Levels of Large Particles

A.4.1 General

This section explains the methodology used to derive the data within Table A.2, and details the assumptions made.

Ideally**,** particle size distributions of newly-built components should be publicly available as there is a lot of activity in this field as more emphasis is placed upon component cleanliness and more products are tested as a result. Unfortunately, this data remains the Intellectual Property of manufacturers and is rarely disclosed. This is, perhaps, understandable as component manufacturers do not want others, especially competitors, to know how clean or dirty their components are. Thus, there is no benchmark or guidance available. Even if this data was available, it is doubtful whether all could be used as it will certainly contain 'bad examples' and will bias any guidelines to the dirtier side.

A.4.2 Component Cleanliness Levels

A possible solution is seen in the use of SAE AS 4059. This was originally NAS 1638 and it should be more representative as it was reportedly derived from the analysis of "clean" aircraft components. The particle numbers at >25 µm and above were used in the initial treatment before adjustment, see A.4.4 and those above the end of the published distribution (>100 µm/>70 µm (c)) can be extrapolated to give data at the sizes required.

ANNEX A

A.4 Determination of Acceptable Levels of Large Particles

A.4.3 Particle Size Distribution Assumption

A line fit was made on the SAE AS 4059 Table 2 data between 50 µm and 100 µm using several relationships linking particle number (N) and size (d) and the data compared. It was found that a fit based upon Log (N) versus (Log (d^2) gave the most representative results. This is a relationship developed by Professor E C Fitch of Oklahoma State University in the USA, during the 1970s and incorporated into an earlier version of ISO 4406.

A.4.4 Adjustment of Component Distributions to ISO 4406 Levels

The particle counts at certain sizes of the assumed ISO 4406 system distribution stated in A.3 differ from those of SAE AS 4059 Table 2 and are generally lower if the closest SAE AS 4059 scale number is taken. This is illustrated within Table A.1 below which compares the particle counts in both systems at >15 µm for a range of closest classes.

Table A.1 Comparison of Counts at >15 µm in ISO 4406 and SAE AS 4059 Table 2

ISO 4406 class	***12***	***13***	***14***	***15***	***16***	***17***	***18***
Counts/100 mL at 15 µm	4,000	8,000	16,000	32,000	64,000	130,000	250,000
SAE AS 4059 Table 2 class	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Counts/100 mL at 15 µm	4,864	9,731	19,462	38,924	77,849	155,698	311,396
Factor	0.82	0.82	0.82	0.82	0.82	0.83	0.80

Thus, if the counts at the closest SAE AS 4059 scale number are taken then they could be about 20% higher than those in ISO 4406 and would give a 'dirtier' result. To overcome this, the particle counts derived from extrapolation in A.4.2 were factored by the ratio of the ISO 4406 counts and the SAE AS 4059 at > 15 µm. For calculation a factor of 0.82 was used to give the data below. This data has been extended to cover a range of contamination levels beyond that required by the Working Group.

Table A.2 Calculated Maximum Particle Counts for Larger Sizes

ISO 4406 Code		***Maximum Particle Counts per 100mL greater than µm size***										
	Microscope sizes	1	5	15	25	50	100	150	200	400	600	1000
	APC Sizes	4	6	14	21	38	70					
	Size code	A	B	C	D	E	F	G	H	I	J	K
15/13/10	AS 4059 class 5	32.000	8.000	1.000	177	30.6	4.62	1.33	0.513	0.0418	0.00837	0.0009
16/14/11	AS 4059 class 6	64,000	16,000	2,000	354	61.2	9.24	2.65	1.03	0.0837	0.0167	0.00190
17/15/12	AS 4059 class 7	128,000	32,000	4,000	707	122	18.5	5.30	2.05	0.167	0.0335	0.00380
18/16/13	AS 4059 class 8	250,000	64,000	8,000	1,415	245	37.0	10.6	4.10	0.335	0.0670	0.00759
19/17/14	AS 4059 class 9	500,000	128,000	16,000	2,829	490	73.9	21.2	8.20	0.669	0.134	0.0152
20/18/15	AS 4059 class 10	1,000,000	250,000	32,000	5,659	980	148	42.4	16.4	1.34	0.268	0.0304

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