GOOD PRACTICE GUIDE FOR PENETRANT TESTING
A help to choose the most suitable technique

Paper written by Patrick Dubosc and Pierre Chemin in 2012 and updated in 2013

1- INTRODUCTION

Penetrant Testing is a Non-Destructive Method (NDT), simple in its principle, but, which requires following the rules to get reliable results.

You will find in this paper some useful advice. In no way, this paper can be considered as a standard or as a specification.

This paper is far from exhaustive. We only want to draw your attention to issues we feel as important. That is why we recommend that you read the documents we have referenced, as well as the relevant and applicable standards, specifications and procedures issued, or accepted, by your primes.

Feel free to send us your comments and remarks.

We thank you in advance.

2- CHOOSE YOUR SUPPLIER/MANUFACTURER

There are a large number of suppliers and manufacturers. Better to choose among those with the highest standards.

The criteria to choose a supplier/manufacturer are:

- Its range of products shall be wide: standard materials such as: a Level 2 water-washable fluorescent penetrant, but also special materials such as high and low temperatures penetrant materials, thixotropic penetrants materials, etc.

- The supplier shall be able to supply products that meet all, or almost all the requirements of the relevant European, ISO standards and codes, and that are also approved by many primes.
  Indeed, a user may work for different primes. Therefore, it is important that the materials that he is to use be approved by ALL the primes he works for. In the late '70s, some aerospace subcontractors had a specific PT process line dedicated to a single aircraft engines manufacturer [(1)].
  It is difficult for a supplier, and risky for the user, if only one approval is missing.

- The supplier shall be able to supply complete systems, i.e. both equipment and products/accessories/meters/reference test blocks.

- It shall have a Research and Development (R and D) Department.

- It shall have an efficient technical support and assistance to customers.

- It shall be efficient in solving problems and/or non-conformities occurring on the customer's process line.

- It shall have a Quality Assurance System certified to ISO *9001*.

- It shall have an environmental management system and take advantage of certification, valid, in accordance with ISO *14001*.

- It shall have an HSE (Health, Safety, Environment) Manager and a REACh (REACh stands for: **R**egistration, **E**valuation and **A**uthorisation of **Ch**emicals Substances) coordinator.

- Etc.

Of course, this does not come for free.

Make provision to audit your PT materials supplier every year.

3- QUALIFICATION AND CERTIFICATION OF PERSONNEL

To carry out reliable inspections, the personnel (operators, inspectors, etc.) shall have the required skills.

An in-house training, plus training in renowned training centres is essential. In France, it is anticipated that the training centres will have to be approved by the French Confederation for Non-Destructive Testing, (COFREND).
In most countries, training centres are approved by certification bodies, and they provide theoretical training and practical training.

Note that the system of qualification is quite different in the USA and in Europe. Large areas and industrial sectors in the world work after the US system, in which Level Is and Level IIs are certified by their employers, while the European system certifies even Level Is through a third body. Obviously, this leads to some differences in the training process. We describe here the way it is done currently in Europe.

Several criteria are a basis for choosing a training centre.

- First, the industrial sector in which the trainees work: aerospace, foundry, railways maintenance, etc.

- Further, while the theoretical training provided by the training centres is somewhat on a par, the song may be different when dealing with the practical side of the training. This depends on the skills and industrial experience of trainers, but also on the quality and quantity of the available equipment, accessories, artificial parts or real parts, etc. Some training centres invest heavily every year in recent equipment that help to assure of a relevant and high-quality training.
  Others recover equipment from industrial companies, which either replace or no longer need it. This may include, for example, PT process lines that, after being overhauled, may be convenient, as a teaching tool for training.

In most cases, the personnel are certified in accordance with the EN *473* or ISO *9712* standards or equivalent. Nevertheless, some individual contractors, though not certified, but with a good expertise, may also be valuable trainers.

4- SURFACE PREPARATION AND PRECLEANING

PT allows for the detecting open-to-surface discontinuities only.

However, contaminants can clog and/or mask discontinuities.

Therefore, getting rid of these contaminants prior to a PT process, without altering the mechanical characteristics and the fatigue limit of the parent metal, is mandatory.

In one of our papers [(2)], we suggest some techniques of stripping/etching and precautions to take. Specifically, we recommend carrying out a mild chemical etching, if necessary, after the mechanical cleaning to help the dissolution of the smeared metal.

The ISO *3452-1* standard gives useful recommendations for the surface preparation of parts before PT.

After stripping/etching, degreasing prior to PT is an ESSENTIAL and DECISIVE step to ensure a reliable inspection.

We have published a paper dealing with degreasing prior to penetrant testing [(3)].

Note that if the ISO *3452* series standards and the SAE-AMS *2644E* specification do not state requirements on the solvents used to clean parts before PT, some primes state maximum allowable contents for impurities (e.g. chlorine, fluorine, sulphur, etc.) for these solvents as for other PT materials.

5- MATERIALS

They must be reliable. Their quality and performance shall be stable over time and batch after batch. This assumes that the manufacturer is able to detect any drift.

For its part, the user shall also be able to detect such problems, to finger out a possible failure of his supplier.

5.1- MATERIALS MANAGEMENT

Some points deserve a special attention. In particular, check that:

- The certificates of conformity of the materials contain at least the product name, the batch number, the “use before”-date [(4)], the reference to relevant standards/codes/specifications, possibly the date of manufacture, etc.

- The laboratory Test Reports include at least:

    - The product name.
    - The batch number.
    - The “use before” date.
    - The reference to relevant standards/codes/specifications.
    - The descriptions of tests and their relevant standardized test methods.
    - The acceptable upper and lower limit values.
    - The test results.
    - etc.

- When applicable, the analysis certificates for halogens, sulphur, sodium, potassium, etc.

Batch management of materials is important and shall take into account the “use before” dates. This requires carefully storing materials in the warehouse and taking out the materials the “use before” dates of which are the closest. Some people think the rule is "first in, first out." This implies that the delivered materials have a “use before” date that is not earlier than the same previously delivered materials. However, it already occurred that some suppliers, whose warehouses were mismanaged, did not follow this rule of thumb.

Therefore, when receiving a shipment, the user shall thoroughly check:

- That the packaging is in good condition.

- That data match (labels, certificates, test reports).

- That the materials are not out-of-date, as already seen.

In our opinion, the residual life of a material, as required by some primes, shall be at least six months before its “use before” date.

The expiry date, set by the manufacturer, assumes that the material is kept as per the storage conditions stated by the manufacturer as mentioned in paragraph 7.2. *Storage,* of the material safety data sheet filled in in accordance with the Annex II *Guide to the compilation of safety data sheets* of the Regulation (EC) N° *1907/2006* [5].

As a safety rule, the quantities of materials taken from the warehouse shall be used within the same day.

5.2- PT PRODUCTS COMPATIBILITY WITH MATERIALS

PT being a non-destructive testing method [6], it is implied that PT products shall have no adverse effect on materials on which they are applied.

The ISO *3452-2* standard and the SAE-AMS *2644E* specification detail the tests to check that penetrant materials are noncorrosive to some metallic alloys.

In some cases, the areas under inspection on parts are close to areas where the products should not be. Thixotropic PT materials [7] are designed to overcome this problem.
If non-thixotropic PT materials are used, areas that are not under inspection shall be masked.

However, PT is used on some non-metallic materials [8].

For any further information, we recommend you read our paper dealing with the PT products compatibility with materials [9].

Furthermore, we published a paper dealing with the compatibility of PT materials with liquid oxygen [10].

If in doubt on exotic materials, do not hesitate to perform preliminary compatibility tests to avoid any nasty surprises!

5.3– CLASSIFICATION OF PENETRANTS’ SENSITIVITY

Along the time, the ISO *3452-2* standard has almost completely duplicated the SAE-AMS *2644E* specification regarding the classification of penetrant materials.

The SAE-AMS *2644E* specification has an Annex, the Qualified Products List (QPL), when the ISO standard does not include any QPL.

Aerospace manufacturers require that PT products be listed in the QPL-SAE-AMS *2644*; sometimes they issue their own QPL, which displays only some of the AMS QPL products [(11)].

Their suppliers and subcontractors shall always comply with this requirement.

5.4- USING THE MATERIALS

The user shall comply with the PT processes stated in the relevant standards and specifications.

PT is an NDT method that requires an utmost cleanliness.

The word "cleanliness'' means:

- The surface of the part under inspection shall be rid of everything that is not the parent metal.
- The workstation shall be clean.
- The operator's/inspector's hands shall be clean. Do not eat food of any kind while performing a PT inspection.

Materials shall be used according to the instructions stated in paragraph 7.1. *Handling* and as appropriate in paragraph 7.3. *Specific use(s)* of the material safety data sheet filled in in accordance with Annex II *Guide to the compilation of safety data sheets* of the Regulation (EC) N° *1907/2006*[(5)].

Storing spray cans [(12)] requires some rules are followed.

To do a neat job is, for instance, to apply the products only on the areas under inspection, as far as possible, and to apply the smallest possible quantity [(8)].

Applying penetrants is generally quite easy. However, some materials require specific application means to achieve reliable results. For instance:

- The hydrophilic emulsifier [(13)] [(14)].
- The dry developer [(15)].

- The non-aqueous wet developer (NAWD) [16].

5.5- GLOBAL SYSTEM PERFORMANCE

The global system performance test is carried out using reference test blocks such as:

- Type 2 of the ISO *3452-3* standard.
- Known defect standards, such as PSM-5® test panels, twin KDS® test panels [17].
- Any other part with known discontinuities.

The global system performance is assessed by performing comparative tests between in-use materials and the same new and unused materials, by following exactly the same PT process parameters, every day with the first parts or the first basket containing parts, and at the end of each shift or of each day to make operators sure that all the parts were processed in accordance with the specified criteria.

Twin KDS® test panels allow the side-by-side comparison of in-use materials with new, unused materials, because the test panels of a same pair are strictly identical.

Other test panels (such as the Type 2 of the ISO *3452-3* standard, the PSM-5® test panel, etc.) are not strictly identical, even if they come from the same manufacturing batch.
Then, these reference test blocks are processed with new, unused materials and photographed. These reference photographs are used to assess the results got with in-use materials.

These full–scale reference pictures, visible under UV-A radiation when using a fluorescent penetrant, shall be made by some expert PT materials suppliers, which have specialized equipment/lighting/procedures to take pictures; better than asking professional photographers to do the job. Many professional photographers know nothing about either PT or the exact conditions required for taking pictures for this application.
Laboratory conditions lead to constantly better results than on-site's. That's why we ask for doing the pictures in the REAL working conditions: comparing day-to-day pictures to the references is more meaningful [18].

In all cases, the appearance of crack indications pattern, their colour and the level of background are compared.
Note that photographs may inaccurately reproduce cracks and colours.
Furthermore, it is a good idea to take a picture of the reference test blocks at least once a year, with brand new products, to counter a slow drift in the appearance/pattern of the indications. Otherwise, it would be more and more difficult to match the photograph taken when performing the global performance test with the original photograph.

In alternative to photography, some standards and specifications allow for the using of a peelable developer [19]. Why not? However, do you know of a PT supplier having such a developer?

Note also that sometimes Type 1 reference test blocks of the ISO *3452-3* standard are used while they are rather designed to check the sensitivity.

To ensure that the results are reproducible, the reference test blocks shall be cleaned [20] immediately after each test. This cleaning should not modify the cracks.

5.6- IN-USE MATERIALS CHECK

A periodic check of in-use materials is required to ensure their conformity to the relevant standards and specifications and to ensure the reliability of discontinuities detection. These checks deal mainly with in-use materials used in manual, semi-automatic and automatic process lines. However, they generally do not apply to "single-use'' materials, such as those in spray cans.

Some tests require only a visual assessment:

- The penetrant appearance: a milky aspect of a water-washable penetrant shall make the user suspect the presence of water in quantity higher than its water tolerance. Do not mistake ''water tolerance'' for ''water content''[21]

- The appearance of the dry developer and the absence of lumps, its moisture content [40] and the number of fluorescent specks, etc.

Others require simple and inexpensive equipment:

- The concentration of water-based penetrants: using a calibrated hand-held refractometer.
- The hydrophilic remover concentration: using a calibrated hand-held refractometer.
- The water-soluble or water-suspendible developer concentration: a hydrometer.
- The dry developer fluorescence: a UV-A source and a disk [14].
- The water-soluble or water-suspendible developer fluorescence: a UV-A source.
- The colour intensity of colour contrast penetrant: a sample of the penetrant to be tested, a sample of the reference penetrant, non-volatile solvent and test tubes.
- The fluorescent brightness of fluorescent penetrant: a sample of the penetrant to be tested, a sample of the reference penetrant, a UV-A source and:
    - Either non-volatile solvent and test tubes.
    - Or a volatile solvent with paper filters.

Others require relatively expensive equipment, as some standards and specifications recommend or require performing various tests on the penetrant used in tanks, such as:

- The monthly measurement of the water content in non-aqueous based, water-washable penetrants. Do not mistake ‘‘water content’’ for ‘‘water tolerance’’ [21].
- The quarterly check of the fluorescent brightness of fluorescent penetrants with a fluorimeter.
- The annual physicochemical analysis of the penetrants to confirm that all the parameters are within the acceptable limits.

These analyses are usually performed by PT materials manufacturers, but also by some suppliers, which have the required expertise and equipment.
The results, compared with the nominal values of a sample of the same new and unused material and with the allowable limit values, are recorded in a laboratory test report.
If the material under test does not comply with the relevant requirements, the material shall be discarded and replaced by brand new material. Nevertheless, when volumes are huge, it may be useful to ask the manufacturer for an “adjustment” of the formula. The manufacturer shall then perform a full battery of tests before certifying the “adjusted” product meets all the relevant requirements.

Note that some manufacturers may agree to extend the shelf life [4] of a product. Nothing prevents a user to ask the manufacturer.
This process is applicable only to never-used materials, kept in sealed containers and in suitable storage conditions.
Before going this way, better to be sure that the product seems to be in good condition. For instance, check a spray can for a continuous-without-surge spray, no clogging of the spray nozzle or of the valve. A liquid material shall be checked for an unusual smell, separation, turbidity, etc.
Otherwise, going on is useless.

5.7- WIPE-OFF TECHNIQUE

This step is intended essentially to check and to interpret indications beyond acceptance criteria. Wipe the indication smoothly using a soft paintbrush or a swab lightly moistened with a volatile solvent such as acetone. Then, spray a light coating of a solvent-based (non-aqueous wet) developer for linear indications (or no developer for non-linear indications). If, within two minutes, the indication is again visible, under ultraviolet radiation, it is confirmed.

This topic was addressed in our paper [22]. We recommend you read it, as it will give you, many pieces of information about this technique, which is extremely important and critical.

5.8- EFFLUENT TREATMENT

PT produces gaseous, liquid or solid wastes, and their treatment is not counterproductive to the method. Indeed, treatment processes have been used for decades and give suitable results.

Gaseous effluents do not generally require a specific treatment, especially since they are less and less important in volume.

In fact, the Council Directive *1999/13/EC* [23], amended by the Council Directive *2004/42/EC*, aims to reduce emissions of volatile organic compounds [24] due to the use of organic solvents in certain activities and installations.
PT materials manufacturers have made serious efforts in this way, for example, by replacing liquefied petroleum gas (LPG) used as propellants by carbon dioxide (CO_2) [25] [26] in spray cans.

Several techniques are used for wastewater treatment [27].

Solid wastes do not raise problems. The preferred techniques are:

- The incineration of rags and papers.

- The disposal of solid wastes in approved landfill sites.

6- LIGHTING AND VIEWING CONDITIONS

Viewing conditions are stated in the relevant specifications. If not, it is possible to refer to the ISO 3059 standard, which details the viewing conditions. In general, when using colour contrast penetrants, the illuminance on the surface under inspection shall be higher than or equal to 500 lx. When using fluorescent penetrants, the UV-A irradiance shall be higher than 10 W/m² with an ambient visible light illuminance less than 20 lx. Viewing conditions shall be periodically checked with a calibrated digital radiometer/luxmeter.

Digital radiometer/*luxmeter simultaneously displaying*
illuminance and *(UV-A) irradiance figures*.

Inspection after the development time is a critical step. Indeed, the inspector shall focus on parts under inspection, interpret the indications, then, accept or reject the parts.

A reliable inspection requires that:

- The inspector has room enough to perform his (her) duty.

- The inspector's vision examination is periodically performed. As an example, the EN *4179* standard states: every year for near vision and at least every five years for colour perception.
  He or she shall pay attention to the work, which requires to have had a restful sleep or not to be bothered by personal or occupational worries.

- No glare shall impair his (her) vision, with either colour contrast or fluorescent penetrants.

- If in a UV-A inspection booth, the inspector shall wait for dark adaptation of the eyes before beginning the inspection. UV-blocking goggles are recommended, while photochromic spectacles are forbidden.

- In a UV-A inspection booth, there shall be no fluorescent or reflective surfaces [(28)].

- The inspection area shall be clean. In particular, no fluorescent spot is accepted, as detrimental to the inspector's ability to perform a suitable work.

- Do not wear clothes and gloves that fluoresce under UV-A radiation.

- Where possible, do not wear cotton gloves when inspecting parts with sharp edges like turbine blades. In fact, cotton lint may stay on parts and give fluorescent spots [(29)].

7- COMPLIANCE WITH PROCESS PARAMATERS

Penetrant testing requires checking some parameters to ensure a reliable detection of discontinuities.

It is a true delight for auditors, and a kind of sword of Damocles hanging over the auditees' heads, who always worry about getting one or more non-compliance reports (NCR).

We do not want to give figures, as per the periodicity or the acceptable limits: users shall comply with the relevant standards and specifications, as every prime (or so) has its own requirements [(30)].

These parameters are:

- Penetration, rinsing, emulsification, washing, drying, development times, etc [(31)].

In manual processing lines, each step comes with a timer. Digital multi-channel up/down counts timers allow for the management of the different times. Each channel has a specific ring tone for each step.

- Rinsing/washing water and drying oven temperatures shall be checked using calibrated thermometers [31]. Sometimes, the drying oven temperature shall be continuously recorded...even when there is no part inside: watch out for the ‘‘overshoot’’! [32].

- Pressures of air and water used for parts rinsing and/or washing [31].

- Spraying pressures of PT materials [31].

- The appearance of the water used for parts rinsing/washing shall be assessed. Foam is often due to the presence of surface-active agents (surfactants), which may cause a sensitivity drop [27].

8- INSPECTION EQUIPMENT AND ACCESSORIES PERIODIC CHECK

- Compressed air cleanliness and dryness shall be checked, which requires a regular purging of oil separators, air filters, etc.

- The entire process line cleanliness shall be maintained for better working conditions.

- UV-A filter integrity shall be checked. Any cracked or broken filter shall be replaced immediately.

- UV-A radiometer, luxmeter, thermometers and reference test blocks shall be calibrated or verified, and the pertaining certificates shall be kept available for the auditors.

- Similarly, pressure gauges used to measure fluid pressures shall be periodically calibrated.

- A materials levels assessment shall be regularly carried out (see the following chapter).

- The tanks lids or covers shall be in place when the tanks are not in use to avoid materials contamination, which could even make them corrosive.

- Finally, it is recommended to clean penetrant [33], emulsifier and dust storm cabinets at least once a year.

An important point not to forget: a meter defined as an “indicator” does not require a calibration: for instance, the manometer, which measures the pressure of compressed air used to push the dry powder developer down to the electrostatic gun. It is up to the Level 3 responsible for the installation to define which meters are indicators. Obviously, they must be called indicators in the applicable procedure. They could even be labelled as such, to prevent any misunderstanding by an auditor.

9- MATERIALS LEVELS MONITORING

Each tank shall be labelled to identify its contents. The label shall include:

- The full product trade name.
- Its concentration, if a water-based penetrant, a hydrophilic emulsifier, a water-soluble developer or a water-suspendible developer.

Materials levels monitoring is very important because if there are not enough materials in the tanks, some parts areas would be poorly (or not at all) covered with penetrant, hydrophilic emulsifier, developer. This is the reason why penetrant tanks in some automatic process lines are equipped with a self-topping-up device. This is not that easy for the hydrophilic emulsifier, which is used diluted in water, except if using a metering pump. For the dry developer, we do not know of any way.
In automatic process lines in which the penetrant is electrostatically sprayed, we have never seen any self-topping-up device. Some process lines allow for the electrostatic spraying (ESS) application of up to three different penetrants in the penetrant station, for instance, a Level 2 water-washable penetrant and two post-emulsifiable penetrants, a Level 1 and a Level 3, according to the part (s) under inspection.

10- CLEANING AFTER INSPECTION – RESTORING THE INITIAL CLEANLINESS

Generally, parts’ cleaning is not required after inspection.

However, for some specific applications, it is necessary to restore the initial cleanliness of the part.

Quite often, when a developer has been applied, the developer powder shall be removed by blowing dry and oil-free air.

Keep in mind that only a part of the penetrant, which entered the flaws [32] bleeds out. This means that some penetrant is retained in discontinuities. It may be detrimental for the following process [34], or even for the parts functioning.
Then, a suitable parts’ cleaning is required.

11- CORROSION PROTECTION AFTER INSPECTION

Some metallic alloys are susceptible to corrosion, i.e. magnesium alloys, non-stainless steels, etc.

Therefore, the metallic surfaces shall be protected against corrosion before receiving their final protection, such as painting.

There are mainly two kinds of corrosion preventives:

- Temporary corrosion protection for indoor storage using a water-displacing corrosion preventive.
- Long-term corrosion protection for outdoor storage using a film-forming corrosion preventive.

All these materials shall be silicone-free (especially if the parts are to be painted later) and easily solvent-removable.

12- OPPORTUNITIES TO MAKE THESE TECHNIQUES GREENER

What can be done?

12.1- REDUCING THE PENETRANT MATERIALS CONSUMPTION

For the “on-the-spot” inspection, spray-cans are the most convenient means.
Though materials in spray cans are more expensive than the same products in bulk, spray cans for such an application are cheaper when considering material losses and labour costs [8].
It is also the best way to prevent any accidental pollution of the PT chemicals by chlorine, fluorine or sulphur containing materials [8].
Therefore, using spray cans reduces the waste of materials as well the volume of effluents to be treated.

When materials are used in process lines, the drag-out losses of materials shall be minimized for at least two main reasons:

- To reduce the waste of materials.

- To reduce the effluent treatment cost.

Two factors are to be considered:

- The right positioning of the parts: the recessed surfaces, blind holes, etc. shall be facing down. When impossible, it will be necessary to turn the part upside down so as the retained material goes back to its tank.

- The design of the parts carrying devices (jigs, baskets, parts' positioning device in baskets, etc.). The aim is to minimize the contact area between the part and its support to limit masked areas. For instance, when inspecting aeroengine blades, the mesh of baskets shall be as large as possible, keeping in mind that the smallest part shall be larger than the mesh.

12.2- REDUCING QUANTITIES AND GLOBAL VOLUME OF PACKAGING AND OVERWRAP

Be they made of cardboard, plastic, metal (steel, tinplate, etc.) or wood, packaging and overwrap are recyclable.

Year after year, the volume of our packaging, be they domestic or industrial, tends to increase, although some manufacturers undertake some efforts to reduce them.

Although essential, packages are an additional cost, which we would like to reduce.

Hence, a question: what can we do to reduce their quantities and their overall volume?

Generally, chemical waste and used packaging are charged per kilogramme, though transport is charged according to the number of pallets. Therefore, the higher the volume, the higher the transport cost.

One way is, where technically possible, to order materials as concentrates, such as water-based fluorescent penetrant (50 % packaging volume reduction).

Using 500 mL spray cans, instead of 300 or 400 mL ones, may seem the right way, but it is not that simple [(35)]. Where technically possible, using 500 mL spray cans is a real source of savings.

Reducing the number and overall volume of packaging would lead to switch to 200-litre drums. In some factories, one can see penetrant drums lying on their side, fitted with a tap, each user coming to draw out the quantity of material he needs.
Moving 200-litre drums, however, requires handling equipment.

One the other hand, non-aqueous wet developers (NADW) containing solids in suspension in a carrier liquid need to be vigorously shaken before use. This is why they are supplied in 5 litre- and less often 25 litre-containers.

Note also that PT materials are supplied in brand new packaging to prevent any risk of accidental pollution.

12.3- REDUCING THE VOLUME OF WATER

Reducing the quantity of water is a concern that has been there for a while [36].

The excess of penetrant is removed from the surface with water, unless using a solvent-removable penetrant.

There are two ways:

- When using a water-washable penetrant: the excess of penetrant removal is achieved in one-step by washing the parts with water, after the penetration time has elapsed. . After treatment, water can be recycled [27].

- When using a post-emulsifiable penetrant: the excess of penetrant removal is achieved in two-steps:
    - The water rinse, a step that comes after the penetration time has elapsed. This allows for the mechanical removing of 60 % to 90 % of the penetrant from the surface. The post-emulsifiable penetrant being rather non-miscible with water, rinse water may be easily treated and recycled [29].
    - The final wash, a step following the emulsification time, allows for the removing of the blend ‘‘remaining penetrant/emulsifier’’ from the surface. After treatment, water can be recycled [29].

The main means to reduce water consumption:

- Use penetrants with a lower kinematic viscosity.

- Use penetrants better matching the surface condition (less retention).

- Use penetrants with the best compromise between water washability and resistance to overwashing.

- Thoroughly adjust the parameters and positioning of the equipment. Set water rinsing/washing pressures, temperatures, time and water flow rate at the figures that give the right result while taking into account the requirements of the relevant specifications. Keep in mind that, for instance, the pressure measured on the pipe upstream from any adjustable tap does not give a significant indication of the pressure in the last centimetres/inches before the spray nozzles. Dividing the pressure by 2 lowers the flow rate by 2 and the water consumption by 2. The spray nozzles shall be adequately positioned.

Choosing the most suitable penetrant is ESSENTIAL.
Between two penetrants classified as similar in sensitivity, manufactured by two different manufacturers, sometimes even by the same manufacturer, the washability parameter may significantly vary. Some WW penetrants have a gelification reaction with water, which "protects" the penetrant when inside a discontinuity, while making it quite easily water-washable from the surface. Other penetrants are very difficult to wash, to prevent a removal from any discontinuity; but this leads to huge water consumptions…and to a fluorescent background. We have also already published a paper that explains it [27].

Lowering the volume of water, obviously, leads to a smaller, cheaper and less bulky wastewater installation. Such a result was gotten by users who switched to easier-to-wash penetrants and halved the quantity of water to treat.

12.4– REDUCING ENERGY CONSUMPTION

The Directive *2005/32/EC* [37] dated July 6, 2005, states, among other points:

''Article 1: Subject matter and scope
1. This Directive establishes a framework for the setting of Community ecodesign requirements for energy-using products with the aim of ensuring the free movement of those products within the internal market.

2. This Directive provides for the setting of requirements which the energy-using products covered by implementing measures must fulfil in order for them to be placed on the market and/or put into service. It contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply.''

This Directive does not apply and will not apply to PT process lines because it states that ''the EuP (Energy-using product) shall represent a significant volume of sales and trade, indicatively more than of 200 000 units a year within the Community according to most recently available figures." It deals more with consumer products (television sets, refrigerators, etc.).

However, we quote this Directive as an example, as it encourages the voluntary and preventive initiatives.

In PT, the most energy-thirsty step is parts drying:

- When parts have been precleaned or degreased with inhibited alkaline detergent cleaners [3].

- When parts have been washed off to get rid of the last traces of penetrant on the surface.

The relevant specifications state the parameters (temperature, time, etc.) to meet.

Drying ovens are the means of choice. To lower their energy consumption, they shall be thermally insulated.

An efficient drying requires air circulation. Therefore, drying ovens shall be ventilated, better by recycling a large percentage of the air (to reduce heat loss). The higher the air speed, the faster the parts dry. To have both a high air speed and a powerful flow rate, use a large-diameter fan, turning not necessarily very fast, instead of a small one turning very fast: less noisy, while the airflow goes everywhere in the drying oven.

The parts shall be positioned in such a way as to minimize water pockets (a suction nozzle may be helpful to take water out of recessed areas, blind holes, etc.).
In fact, evaporating water is VERY DIFFICULT due to its high specific heat capacity (by mass), and to its ability to adhere to the surface inside discontinuities.

Drying being used in two different stations of a PT process line, we must consider both cases:

- Before penetrant application, it is ESSENTIAL that nothing remains in the discontinuities. Thus, after cleaning with an alkaline detergent, some specifications state a drying oven temperature up to 120 °C (circa 250 °F) with a surface temperature of the parts which may exceed 100 °C (circa 210 °F) and a drying time which may reach 60 minutes, while other specifications limit the temperature to 70 °C (circa 160 °C) for some minutes. This latter alternative is for us COMPLETELY unsuitable. However, not all the parts can withstand a temperature of 100 °C (circa 210 °F) or more. In this case, it is possible to dry these parts at a lower temperature if the pressure in the drying oven can be reduced, e.g. to 2.5 kPa (ca 0.35 psi), or even one kPa (ca 0.15 psi), which implies that the drying oven is designed for that.
  A provision shall be made for parts cooling down (an additional step): penetrant shall be applied only on parts close to room temperature, usually not more than 40 ° C (circa 100 °F) maximum, especially if the penetrant is applied by dipping the parts into the penetrant tank. Dipping large quantities of too hot parts along the day raises the penetrant temperature. The most "volatile" ingredients of the penetrant will evaporate faster than the rest, somewhat modifying the penetrant formula, and often making it more difficult to wash-off.
  Be cautious: the drying oven set at 100-120 ° C (circa 210-250 °F) is a "hot parts" safety matter (outer surface, door handles, etc.). The temperature of areas susceptible to be in contact with hands should not exceed 50 °C (circa 120 °F). How can one handle baskets or parts at 100-120 ° C (circa 210-250 °F)? A calibrated digital thermometer fitted with a contact probe shall be used to check that the parts have cooled down to 40 ° C (circa 100 °F) or less.

- After the excess of penetrant has been washed off, and before or after developer application (according to the developer form in use). Aerospace industries require a maximum temperature of 70 °C (circa 160 °F), with an "overshoot"[32] of 8 °C (circa 15 °F) maximum (i.e. over-shooting of the set temperature during the warm-up, at start-up before the first "batch" of parts is introduced). Drying time: 10 to 20 minutes, or "sufficient enough to ensure complete drying," according to parts geometry, mass and initial temperature, etc.
  These limits are set due to the possible risk of attenuation (of the fluorescence) by heat, known as ‘‘heat fading’’ [1] [39].

The heating power of the drying oven will depend on the mass of the parts put inside all the daylong. If using electric heating, a good idea is to have three sets of resistors: the three sets switched on for a quickly warm up, then only two groups when the inside temperature is approaching the temperature set-point, and finally, only one, to keep the temperature at the set figure. A thyristor-controlled system is also a good alternative.
Beware: make provision for at least three calibrated temperature probes, or even five, inside the drying oven. Some specifications state that the temperature measured by all the probes shall be in a +/- 2 °C range. To perform the once or twice a year calibration, suitable connectors linking the probes to the outside of the drying oven provide a means to calibrate without any dismantling. Just bring a calibrated meter and the right connector close to the drying oven!

Using energy-efficient lighting is another way to reduce energy consumption. Replacing the mercury vapour- or xenon-based (UV-A) ultraviolet sources by light-emitting diodes (LED) sources, for fluorescent PT, is the most efficient answer.
Thanks to the development of LEDs and their diminishing prices, a good question is: would it not be possible to replace the overhead sources with several mercury vapour-bulbs with 365 nm LED overhead sources?
This would significantly reduce energy consumption, reduce the amount of heat wasted in the inspection booths (i.e. lower the cost of ventilation or air conditioning), reduce maintenance costs (less shutdowns to replace bulbs), stocks of spare parts, etc.

12.5– GREENER MATERIALS: REDUCING THE VOLATILE COMPOUNDS (VOC)

Manufacturers are continuing their efforts to reduce volatile organic compounds (VOC) in their PT materials according to the Council Directive *1999/13/EC*, which was amended by the Council Directive *2004/42/EC* [23].

We recommend you read the article we published on volatile organic compounds [38].

13- CONCLUSION

We hope this paper provided you with additional information to increase your PT knowledge and to get even better and more reliable results.

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