Performance of Water-Washable, Fluorescent Penetrants on Water-Basis as Compared to Traditional Water-Washable, Fluorescent Penetrants on Petroleum-Basis

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Abstract. There are mainly economic, environmental and technological reasons that lead to the development of water-based penetrants. The process costs for a water-based penetrant are lower than those for products containing petroleum distillates. Furthermore, water-based penetrants offer the environmental advantages of a low VOC and of readily biodegradable surfactants. Their dilutions fulfil all the requirements of the German regulations of the local waste-water authorities. Part 1 of the report describes the development of a new generation of water-based penetrants. During the formulation of these products, requirements regarding environment, Health & Safety, corrosion protection and performance had to be considered.

1.1 Introduction:

The new water-based range of three fluorescent penetrants are Level 0.5, 1 and 2 respectively and can be used instead of any water-washable fluorescent penetrant for non-aerospace applications. The series is water-based which means that water represents approximately 50% of the ingredients. By definition, the products are free of any petroleum distillate.

1.2 Technical Challenges to Formulate Water-Based Penetrants:

Petroleum distillates have very good characteristics which make them especially appropriate for use in fluorescent penetrants. Their low surface tension at different temperatures contribute to crack penetration and they can easily solubilise fluorescent dyes. Compared to petroleum distillates, water has a very high surface tension inducing worse wetting properties and in addition worse penetrating capacities, especially on polished surfaces. Because of its chemical properties, water is more corrosive than petroleum solvents. In addition, fluorescent dyes used for penetrant testing are not water-soluble. Therefore, in order to fulfil the requirements of the specifications, the formulations of the water-based fluorescent penetrants are different and contain specific surfactants, corrosion inhibitors and special additives. In addition, the formulation of a water-based penetrant has to overcome a contradiction: as it contains a minimum of 50% of water, a water-based penetrant is hydrophilic and is readily water-soluble. However, to fulfil the requirements of the specifications, the
penetrant in the cracks must resist over-washing while the excess of penetrant must be easily removed from the surface. So, specific surfactants must be used in order to achieve a perfect hydrophilic/lipophilic balance (HLB) and to meet the sensitivity level and the low fluorescent background requirements.

1.3 Advantages of Water-Based Penetrants

During the last years, environmental issues forced the chemical industry to replace volatile organic solvents by water, especially in paints, and the end-users to use aqueous cleaners instead of solvent cleaners and vapour degreasers. As in all chemicals, the benefits of using water in fluorescent penetrants are obvious:

- Readily biodegradable and more acceptable for waste water treatment facilities.
- Lower waste water treatment costs
- Lower shipping and storage costs
- No flammability risks (water has no flash point)
- Healthy environment for users (low odour, not harmful…)

In addition, because of their self-developing properties, depending on the requirements, this new range of products can be used with or without a developer.

Furthermore, water contamination in a water-based penetrant will not automatically generate corrosion problems on light alloys, as is the case for solvent-based penetrants.

1.4 Disadvantages of Water-Based Penetrants

When used by immersion, the evaporation loss is a problem of water-based penetrants, because water will evaporate while the petroleum distillates used in the conventional penetrants are relatively non volatile. Consequently, the penetrant concentration must be checked regularly and water must be added to compensate the loss.

This analysis can be carried out using a refractometer, as already done for hydrophilic emulsifiers which are used between 10 and 20% diluted in water. After analysis, water has to be added to the bath, if necessary, to reach the nominal level of penetrant. In practical life, drag out and consumption of the penetrant is usually high enough to compensate this effect and water additions are not necessary.

As opposed to hydrophilic emulsifiers, the technical risk regarding performance is low, because the water loss results in a more concentrated penetrant and thus a higher sensitivity level.

1.5 Special Environmental Requirements

Products must contain surfactants which are readily biodegradable. This will ensure that the waste water will not have a negative effect on the micro-organisms of the waste water plants.

Furthermore the water-based penetrant itself shall have a low COD (chemical oxygen demand). For the metal-processing and metal-treating industry, there are minimum requirements, which can be locally different and more rigid. The “waste water regulation” attachment 40 describes the requirements for waste water, in this case the rinse water of an NDT plant, using, for example, a level ½ material:

Typically the rinse water has a concentration of 0,1 % (V/V) –
<table>
<thead>
<tr>
<th>No.</th>
<th>parameter</th>
<th>value</th>
<th>unit</th>
<th>limit</th>
<th>norm</th>
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<tbody>
<tr>
<td>1.</td>
<td>general requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>pH-value</td>
<td>approx. 9</td>
<td></td>
<td>6.5-10</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>settled materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>filtrable materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>organic compounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>low volatile lipophilic compounds</td>
<td>159</td>
<td>mg/L</td>
<td>250</td>
<td>DIN EN ISO 9377-1</td>
</tr>
<tr>
<td>2.2</td>
<td>mineral oil based hydrocarbons</td>
<td>0.53</td>
<td>mg/L</td>
<td>20</td>
<td>DIN EN ISO 9377-2</td>
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<tr>
<td>2.3</td>
<td>adsorbable organic halogens (AOX)</td>
<td>&lt; 0.03</td>
<td>mg/L</td>
<td>1</td>
<td>DIN 38409-22</td>
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<tr>
<td>2.4</td>
<td>high volatile hydrocarbons</td>
<td>n. B.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>phenol, complete</td>
<td>n. B.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>anorganic compounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>to</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.22</td>
<td></td>
<td>n.B.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>spontaneous oxygen demand</td>
<td>&lt; 1</td>
<td>mg/L</td>
<td>100</td>
<td>DIN V 38408-24</td>
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<tr>
<td>5.</td>
<td>colour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>gases</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

n.B. = not part of the formulation

The rinse water of the level ½ product does meet the general requirements (1.), the requirements concerning organic and anorganic compounds (2. & 3.) and the spontaneous oxygen demand (4.).

Rinse water of the product is only slightly coloured; thus, it also complies to item 5. Item 6. (gases) is not applicable.

As a summary, we can state that the rinse water of the level ½ product does fulfil all requirements of the “waste water regulation”.

Part 2 shows a comparison of both product lines on test pieces and on real parts provided by the industry, i.e. tests of wetting properties, water washability and sensitivity on several substrates and on different surfaces.

Typical target industries for water-based penetrants are the aluminium casting and forging industries, other light-metal industries and ceramics.

### 2.1 Comparison of Sensitivity

All trials regarding sensitivity were carried out in accordance with prEN ISO 3452 Part 2 (2004), Table 7:
- dipping in penetrant and 5 min penetration time with a 5° - 10° angle
- rinsing with a water pressure of 1.2 bar and a temperature of 22 °C under UV-light
- drying 5 min in an oven with a temperature of 50°C
- dipping 5 s in dry developer with additional 5 min developing time

2.1.1 Comparison on Reference Block 2.

The pictures show that the sensitivity of the fluorescent water-based penetrants is slightly better on reference block 2 than the sensitivity of the petroleum-based versions.
2.1.2 Comparison on Reference Block 1 (50µm, 30µm, 20µm and 10µm)

The sensitivity of the fluorescent water-based penetrants is close to the sensitivity of the petroleum-based versions.

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2.2 Wetting Properties

The wetting properties of the fluorescent water-based penetrants on the polished surface of reference block 1 are as good as the wetting properties of the fluorescent petroleum-based penetrants. All pictures were taken after 20 minutes.

2.3 Washability and Background Fluorescence

All trials regarding washability and background fluorescence were carried out with a water pressure of 1,2 bar and a temperature of 23 °C.
Washability and Corresponding Background Fluorescence Level 0.5

Level 0.5 water-based

Level 0.5 petroleum-based

Washability and Corresponding Background Fluorescence Level I

Level I water-based

Level I petroleum-based
2.4 Comparison on Production Parts

The next pictures show different comparisons on production parts.

Ceramics - Level I water-based  
Ceramics - Level I petroleum-based
Summary. Water-based penetrants have the following technical properties, e.g.

- excellent water-washability,
- low background fluorescence
- high sensitivity

They are especially appropriate for casted and forged aluminium parts and ceramics.

The new product range is at least as good as petroleum-based penetrants and offers the following advantages in respect to Health & Safety and Environment:

- Readily biodegradable and more acceptable for waste water treatment plants
- Lower waste water treatment costs
- No flammability risks (water has no flash point)
- Acceptable environment for users (low odour, not harmful…)

Aluminium casting - Level I water-based
Aluminium casting - Level I petroleum-based

TAM panel - Level II water-based
TAM panel - Level II petroleum-based