Using biological methods to assess and monitor refinery effluents

Measuring biological effects from refinery effluents provides more reliable estimates than chemical analyses alone.

Rapidly increasing global population and climate change are raising concerns about the sustainability of long-term supplies of high quality water resources for consumption, farming, industry and conservation. As a consequence, environmental and regulatory pressures are building to ensure that available water resources are used efficiently and wisely.

Because oil refineries are among the largest industrial users of water, European refiners are doing their part to ensure the long-term sustainability of water resources. In spite of continuing reductions in water usage, a recent CONCAWE survey (see Report 2/11) showed that the amount of treated process-related effluent discharged from European refineries in 2008 was approximately equal to that of crude oil processed, on a weight-for-weight basis. A follow-up survey is being conducted to gain more insight into water use, and the results will help to identify good practices for future refinery operations.

Reducing the quantity of water used in refineries is obviously important, but ensuring the quality of water discharged back to the environment is equally important. A large fraction of the water used by the refining industry is ultimately returned to the environment following multi-stage water treatment, so that the effluent does not degrade the quality of the receiving water. According to CONCAWE's 2008 survey, 94% of European refineries have complex facilities that treat their process-related effluents with biological agents prior to discharge to the environment. The remaining 6% use various combinations of filtration techniques to ensure protection of the local environment and compliance with effluent regulations.

A modern wastewater treatment plant

Measures of biological effects

Over a 40-year period, CONCAWE has conducted and reported on surveys of its European member companies in order to learn more about refinery effluent discharges and water treatment facilities. The 2011 report includes results from a comprehensive survey of physical and chemical properties of refinery effluents conducted in 2005, and a more specific survey of selected effluent properties in 2008.

In addition to effluent properties, the survey also requested information on what biological effects measures were being used to monitor effluent quality, and how the results were applied in practice. A 'biological effects measure' is one that evaluates the potential biological impact of specific substances, that may be found in effluents, on organisms commonly found in the receiving water environment. These measures cover a broad spectrum including:

- toxicity studies on refinery effluents and receiving water samples;
- assessments of the persistence and bioaccumulation potential of effluent substances; and
- monitoring studies designed to determine the health of the entire ecosystem within a receiving water environment.

In some cases, these results are needed to satisfy a regulatory requirement for effluent discharge permits while, in others, they are used only for internal performance monitoring by the refinery. In either case, the use of these biological approaches is clearly increasing and will probably increase further under pressure from new regulatory requirements.

Biological effects measures and the EU refining industry

CONCAWE's surveys have shown that the use of biological effects measures is also increasing within regulatory decision-making processes. Although the basic scientific principles have not changed from those identified in earlier reports (CONCAWE Reports 5/79 and 92/56), the range and sensitivity of the measurement techniques have improved. The uses to which these methods are applied today range from toxicity assessments supporting improvements in site effluent treatment, to more specific field monitoring. Monitoring studies typically incorporate more sensitive endpoints, such as biomarkers and statistical techniques, to assess the potential impacts of effluents on biota and ecological status.

The most widely applied biological measures assess toxicity to aquatic organisms. These measures are relevant to protecting ecosystems although their interpretation ultimately depends on the tests used to assess toxicity. As shown by case studies and the feedback from the refinery survey, toxicity measurements made on undiluted effluents can be extended to the environment to complement existing analytical and biological diversity studies and improve the assessment of sediment and water quality.

CONCAWE has contributed to the development of methods to assess both the persistence and bioaccumulation of effluent components. Such tests can potentially improve the risk assessment process for effluent discharges but it is also important that their limitations are recognised and put into context. In this respect, CONCAWE has helped to develop guidance on the use of these methods which has been incorporated into OSPAR's[1] 2007 Whole Effluent Assessment (WEA) guidance.

When undertaking toxicity assessments on refinery effluents, it is also important to ensure that the test results properly reflect the effluent properties and are not influenced by confounding factors. For example, when measuring the toxicity of chemical substances on aquatic organisms, it is important that test parameters, such as pH, temperature, dissolved oxygen, water hardness and salinity, suspended solids, and colour, are all within specified ranges. These ranges may be different for different aquatic organisms.

The regulatory landscape

For many years, environmental regulations have focused on the physical and chemical properties of effluent discharges in order to set compliance limits and monitor performance. These approaches have been successful in reducing the discharge of specific hazardous substances to the environment and have contributed to substantial improvements in water quality across Europe.

As the overall quality of waters receiving effluents has improved, however, attention has increasingly turned to more complex issues such as longer-term bioaccumulation and exposure of aquatic organisms to complex mixtures of substances. These concerns are also important to the refining industry because treated refinery effluents are typically discharged over many years and can contain different hydrocarbon substances in low concentrations. Some of these substances could have a common mode of toxic action and may express their effects additively on the environment.

EU Member States are applying biological measures in different ways to regulate effluent discharges. Some adopt a risk-based approach, using the biological measures to demonstrate the acceptability of potential impacts on the environment, while others adopt a hazard-based approach to set limits or reduce emissions based on the intrinsic properties of the treated effluent. As EU environmental legislation increasingly focuses on the use of biological measures, better harmonisation of legislative approaches should be expected.

Studies to monitor ecosystems and establish the environmental quality of water bodies will almost certainly increase and, when conducted well, can provide a robust baseline to monitor future changes in water quality. Several EU refineries have been conducting such monitoring studies since the 1970s and have found them to be valuable for demonstrating the performance of their treatment facilities and the associated improvements in water quality. These also provide environmental baselines to assess impacts if unexpected spills or releases were to occur.

Until quite recently, the regulation of European water resources has been administered by EU Member States. Water use and discharge permits have often been managed by regional or local authorities, albeit within a national framework. The new EU Water Framework Directive (WFD) (Directive 2000/60/EC) will establish requirements for regulating water resources on a cross-border scale. Under the WFD, Member States will need to develop River Basin Management Plans (RBMPs) setting out specific objectives and implementation measures. The RBMPs will also link the WFD to other water-related legislation, including the Birds Directive, the Habitats Directive, the Environmental Impact Assessment Directive, the Drinking Water Directive and several others. The WFD is currently in the implementation stage with many steps still required to achieve a 'good status' rating for all European waters by 2015.

Daphnia magna*, a freshwater flea, is widely used as a laboratory animal for ecotoxicity testing.*

[1] The Oslo-Paris (OSPAR) Commission resulted from the Convention for the Protection of the Marine Environment of the North-East Atlantic.

The WFD requires the ecological quality of receiving waters to be assessed, and specifies that biological effects measures can be used to complete these assessments. Many tools are already available for this purpose, as described in CONCAWE Report 2/11. A new project, called NoMiracle (Novel Methods for Integrated Risk Assessment of CumuLative stressors in Europe), was initiated recently to develop models for more integrated risk assessments of chemical substances and mixtures. (See: http://nomiracle.jrc.ec.europa.eu/default.aspx.)

Learnings from case studies

In this complex area of research and regulation, learning from previous experience is very important. In the appendices to CONCAWE's Report 2/11, six case studies are described in which biological assessment methods have been applied to refinery effluents and receiving waters. Three more appendices describe methodologies and data quality issues.

The use of biological effects measures that are directly relevant to receiving water ecosystems would appear to be a logical approach. However, the case studies showed that differences in site-specific conditions require some flexibility in the selection of the most appropriate biological measures. Furthermore, the sensitivity of the methods used and the endpoints examined also need to be consistent with the purpose and objectives of the work. Measures of biological effect developed for use on specific chemicals under simple exposure conditions may not always be relevant under real-world conditions where stresses on the ecosystem can make it very difficult to establish causes and effects.

It is important, therefore, that biological measures are not used in isolation; combining their use with, for example, chemical and physical analysis of an effluent and receiving water environment can greatly increase understanding. Finding out what is 'relevant' is not straightforward, however, given the spectrum of response parameters that could be investigated at different levels and within different parts of the ecosystem. Much careful planning and expert judgment is required when designing a test or monitoring study if the results are to achieve the study's objectives.

In these case studies, the toxicity of the effluents examined did not raise any specific concerns beyond those that would be expected based solely on the effluents' hydrocarbon content. They also showed that the toxicity and impact of refinery effluents on receiving waters has been reduced through continuing improvements in effluent treatment facilities. Where biological effects measures have identified properties of undiluted effluents that are of concern, this has led to higher water treatment costs than those required to meet chemical-specific targets.

The use of standardised measurement methods within a site-specific assessment will help to ensure that the results are relevant and can be interpreted against established criteria. The use of accredited laboratories to carry out the work will also ensure that the studies are considered to be reliable by regulatory authorities.

In conclusion

It is clear that the European regulatory landscape is changing with respect to the hazards and risks of refinery effluents and the environment. Biological assessment will increasingly be incorporated into monitoring and control schemes such as the WFD, the Marine Strategy Framework Directive (MSFD, 2008/56/EC) and the requirements of OSPAR, many of which view biological effect measures as tools to be applied in combination with (and not instead of) chemical substance-oriented approaches.

A major advantage of applying biological assessment to undiluted effluent or receiving water samples is that the data they provide can be used to assess the overall hazards and risks of complex media that are difficult to address otherwise. There are potential disadvantages, however, namely that adverse environmental effects may be incorrectly interpreted from the use of inappropriate or poorly designed monitoring studies. If this were to occur, risk reduction measures, such as additional water treatment facilities, might be demanded, even though they may provide little additional environmental benefit.