CHEMICAL ENGINEERING TRANSACTIONS Volume 17, 2009
Editor Sauro Pierucci

DOI: 10.3303/CET0917062

Proposed criteria to select Best Available Techniques (BATs) for oil spill response

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An oil spill is the accidental or intentional release of petroleum products into the environment as a result of human activities such as drilling, manufacturing, storing, transporting, waste management. Such event is not unusual and is regrettably widespread all over the world. Even if oil spills are actually just a small percent of the total world oil pollution problem, they represent the most visible form of it. In a previous work a survey has been carried out on Best Available Techniques (BATs) currently used both for oil spill prevention and oil spill response. A first attempt was performed in order to suggest criteria for BAT selection. The aim of this paper is to improve those criteria and to arrange them in a more structured way. The criteria have been weighted according to AHP (Analytical Hierarchy Process) method, a well-known approach for prioritizing and ranking alternatives.

1. Best Available Techniques (BATs) used for oil spills response

This work concerned a research activity about the marine environmental defence and the loss of biodiversity as a consequence of spills in maritime oil transport, in collaboration with the Italian Ministry of Environment.
Recently a review has been carried out on Best Available Techniques (BATs) currently used for oil spills response. Containment and clean-up techniques must be employed when a marine oil spill occurs in order to limit its spreading on water surface; spreading phenomena depends on many factors such as the quantity of oil, its viscosity and the weather conditions (Bilardo and Mureddu, 2004). It is also crucial to contain quickly the spills so as to minimize danger to human beings, environment and property. Booms are the most used containment techniques, also if they are less effective with waves higher than one meter or currents faster than one knot per hour (U.S. Environmental Protection Agency).
A physical recovery of oil from water surface, usually by skimmers, sorbent materials and dispersants, follows the containment, or occurs at the same time (International Tanker Owners Pollution Federation Limited); however, a number of techniques, as in situ burning and bioremediation, have been recently promoted as alternative or complementary measures (Guidi et al., 2008).
Skimmers are mechanical devices used for remove floating oil from water surface. They may be employed from shore or operated from vessels.

Please cite this article as: Guidi G., Gugliermetti F. and Violante A.C., (2009), Proposed criteria to select best available techniques (bats) for oil spill response, Chemical Engineering Transactions, 17, 367-372 DOI: 10.3303/CET0917062

Sorbents are insoluble materials or mixtures of materials used to soak up liquids by means of the mechanism of absorption, or adsorption, or both. Absorption allows to pick up and retain liquid throughout the molecular structure of the material, while adsorption involves only the surface of the material.
Dispersants are a group of chemical product designed to be sprayed onto oil slicks to accelerate the process of natural dispersion; they are often used when mechanical recovery is not feasible and their effectiveness increases if applied straight after a spill, before the lightest oil components have evaporated.
In situ burning is the term given to the process of burning oil slicks, commonly used along with mechanical recovery on open sea. This method enables to remove great amounts of oil from sea surface, but there are a number of problems limiting the feasibility of this technique such as the generation of huge quantities of black smoke and possible sinking of viscous and dense residues.
Oil as well as many natural substances biodegrade over a period of time into simple complex such as carbon dioxide, water and biomass. Bioremediation is the term referred to a series of processes used to accelerate natural biodegradation. Bioremediation should not be used on oil on the sea surface because any materials added are likely to be quickly diluted and lost from the slick. Natural biodegradation can be most usefully accelerated when bioremediation is used on land. Here the physical, chemical and biological factors affecting bioremediation can be controlled in order to offer optimum conditions for biodegradation.
A promising method for oil spills clean-up is based on a magnetic separation technique that use the material "CleanMag". The material has been developed by Prof. George Nicolaides at the Technology Education Institute of Piraeus in Greece. It is a nanocomposite magnetic material, with oleophillic and porous characteristics and has an apparent density lower than water. Because of its oleophillic properties oil is right away adsorbed upon contact with the material.

2. Proposed criteria for BAT selection

Many techniques can be used in order to reduce oil spills damages. When a oil spill occurs and lots of techniques are available, it is worthwhile to choose the technique which turns out to be the most suitable in the context situation. Simple and user-friendly criteria will be helpful in making this choice; Guidi et al. (2007) proposed a methodology based on three different criteria, to be applied in sequence, to arrive at the more acceptable technique; the aim of this paper is to improve the method, based on main, technical and impact criteria, by developing a more structured analysis and, above all, introducing a weight to each impact criteria by Analytical Hierarchy Processes (AHP).
Parameters such as time of intervention (prompt or next), typology of the spilled oil (light, medium or heavy) , conditions at sea (calm, choppy or icy) are assumed as main criteria in the BAT selecting process. In situ burning, for example, should be used straight after a spill, before the lighter volatile and inflammable fraction in the oil has evaporated; on the other hand techniques based upon the use of dispersants have small effect on heavy oils, while if a spill occurs in water containing a layer or piece of ice, in situ burning can often take away much oil than conventional techniques.

For the main criteria it is possible to sketch out a table showing the relationship between them and both the main containment and clean-up BATs , as reported in Table 1. When a BAT satisfy each criterion an X is marked in the corresponding box.
BATs overcoming this screening phase should fulfill the technical criteria such as actual availability, feasibility and compatibility with other techniques.
It is essential to verify if the technique is available in the area where oil spill occurred or if it must reach the area from a considerable distance. Another important characteristic to take into account is the technique's feasibility, in term of logistics and other operational aspects. It is important to verify the presence of specialized workers and facilities in support of the technique, essential to the technique's carrying out.
Finally BATs should meet with the impact criteria, for instance the impact on human health, on environment and the economic one. These criteria consider the proximity of built-up areas, the presence of economic activity (such as fishery and tourism), environmental protected areas, submerged archaeological sites, the loss of biodiversity and the cost of the technique.

Table1: Main criteria

CRITERIA		BAT						
		Booms	Skimmers	Sorbents	Dispersants	In- situ burning	Bioremediation	Clean-Mag
Time of intervention	Prompt	X	X	X	X	X	X	X
	Next	X	X	X	X	X	X	X
Typology of spilled oil	Light	X	X	X	X	X	X	X
	Medium	X	X	X	X	X	X	X
	Heavy	X	X	X		X	X	X
Conditions at sea	Calm	X	X	X	X	X		X
	Choppy							X
	Icy	X	X			X		X

Near built-up areas clearly it is not possible to use in situ burning because it produces huge quantities of black smoke, possibly causing danger to human beings, environment and property.
In the areas, where the presence of economic activities such as fishery and tourism is very important, it is indispensable to use techniques acting quickly, before the oil spill arrives at shoreline. A good technique satisfying this parameter is the one based upon the use of magnetic material, capable of absorbing oil rapidly.
In areas with presence of submerged archaeological sites it is not impossible to use aggressive techniques such as dispersants or in situ burning, that could cause irreparable damage to these sites. In areas at loss of biodiversity it is not recommended the use of

aggressive techniques, while it is suggested the use of booms and magnetic material. The economic impact of the BAT takes into account not only the material cost of technique, but also the cost for training of response workers.

3. Analytical Hierarchy Process method

BATs accomplishing main and technical criteria, should also satisfy impact criteria. These criteria may be weighted according to AHP (Analytical Hierarchy Process) method, a well-known approach for prioritizing and ranking alternatives (Saaty, 1980). This method has been developed by Thomas Saaty in the 1970's, at the University of Pittsburgh in Pennsylvania and it is regarded as one of the most successful techniques to solve decision making problems involving multiple criteria (Saaty, 1987). AHP is very useful when teams of people are working on complex problems involving human perceptions and judgments. It has incomparable advantages when important elements of the decision are difficult to quantify or compare or when communication among team members is hindered by their different specializations, terminologies or perspectives.

The core of Saaty's method is an ordinal pair-wise comparison of all criteria. In other words, it addresses in particular preference statements. Per pair of criteria the decision-maker is asked to which degree a criterion is of more importance than the other. By means of these comparisons the method defines the relative position of one criterion in relation to all other criteria. By using an eigenvalue matrix technique, quantitative weights can be assigned to the criteria. The Saaty method employs a semantic 9-point scale (Table 2) for the assignment of priority values. This scale relates numbers to judgements, which express the possible results of the comparison in qualitative terms. In this way, different elements can be weighted with a homogeneous measurement scale.

Table 2: Semantic scale of Saaty

Value	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Through this method, the weight assigned to each single criterion reflects the importance which every party /agent /group involved in the project attaches to the objectives. In addition, the method verifies the fit between the components of the weight vector and the original judgements. From the pair-wise comparison a 'comparison matrix' is derived out of which, through the eigenvector approach, it is possible to calculate the weight vector to be used for a subsequent evaluation and investigation. Finally, the method is able to check the consistency of the matrix through the calculation of the eigenvalues.

4. Results

The evaluation criteria are defined in relation to the concept of BAT's acceptability in the Mediterranean Sea, notably through the identification of three main classes of impacts: human health, environment and economic impact. A scientific group of experts with different fields of specializations was asked to compare pair-wise the relative importance of each impact criterion on the basis of the Saaty scale. From the pair-wise comparisons, a judgemental matrix was formed for each expert. This matrix was used for computing the priorities and the consistency index was carried out. The priorities expressed by experts have been combined using the arithmetic mean. The results are shown in Table 3.

Table 3: Comparison matrix

	Human health	Environment	Economic	Geometric mean	Weight	K Eigenvalues
Human health	**1.00**	5.67	7.67	3.52	0.76	0.99
Environment	0.18	**1.00**	2.33	0.74	0.16	1.14
Economic	0.13	0.43	**1.00**	0.38	0.08	0.91
TOTAL	1.31	7.10	11.00	4.64	1.00	3.03

Each weight value is obtained by dividing the geometric mean of each line by the total sum of the geometric means. K eigenvalues are deduced by multiplying each weight, calculated for human health, environment and economic, by the corresponding total: for example the first K eigenvalue is obtained by multiplying 0.76 by 1.31.
Once known the K eigenvalues, it was possible to define the consistency index (CI):

$$CI = (K_{tot} - n)/(n - 1) \quad (1)$$

where n is the number of components (Table 4). Then, the consistence ratio (CR) is calculated by the ratio of the consistency index to the random consistency index (RI). RI is the random index representing the consistency of a randomly generated pair-wise comparison matrix. It is derived as average random consistency index calculated from a sample of 500 of randomly generated matrices based on the AHP scale. In our case (3 components), RI has 0.58 value.

Table 4: Index values

N°of components	Consistency index	RI	CR
3	0.02	0.58	0.03

It is interesting to note that the consistence ratio is < 0.1, so the pair-wise comparison matrix should be regarded as *consistent enough*. The expert group gave the highest weight (0.76) to human health criterion, followed by environment and the less important was judged to be the economic criterion.

5. Conclusions and further developments

The relative weight of impact criteria was assessed by means of Saaty method. This is a first part of a more complex work aiming at providing a helpful and user friendly tool to authorities in charge of facing the response to oil spills.

In a further development the parameters forming technical and impact criteria will be defined in more detail. AHP method will be applied to technical criteria in order to define their relative weight.

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