E U R O P E A N
C O M M I S S I O N

T H E R M I E

e demonstration component of the Joule-Thermie Programme

Pollution Control Technologies

Limiting the environmental impact of the hydrocarbons industry

HC

Directorate General for Energy (DG XVII)

JOULE-THERMIE

The JOULE-THERMIE programme was launched in 1995 as the European Union's first 'integrated' programme, bringing together the resources of the European Commission Directorates-General XII (Science, Research and Development) and XVII (Energy). This programme is funded by the European Union's Fourth Framework Programme for Research and Technological Development, one of the most extensive research funding initiatives available to European companies and research organisations.

The JOULE-THERMIE programme runs until 1998 and has a total budget of 1,030 MECU of which 566 MECU are allocated to the THERMIE demonstration component of the programme for the support of projects and assosciated measures. THERMIE is focused on the cost-effective, environmentally-friendly and targeted demonstration and promotion of clean and efficient energy technologies. These consist of renewable energy technologies; rational use of energy in industry; buildings and transport; a clean and more efficient use of solid fuels and hydrocarbons. Essentially, THERMIE supports actions which are aimed at proving both the technologcal and economical viability and validity of energy technologies by highlighting the benefits and by assuring a wider replication and market penetration both in EU and global markets.

Colour Coding

To enable readers to quickly identify those Maxibrochure relating to specific parts of the THERMIE Programme each Maxibrochure is colour coded with a stripe in the lower right hand corner of the front cover, i.e.:

- RATIONAL USE OF ENERGY - RUE
- RENEWABLE ENERGY SOURCES - RES
- SOLID FUELS - SF
- HYDROCARBONS - HC
- GENERAL - GEN

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Front Page photo: Shore test of Evergreen mock-up at 8,700 BOPD – Fuel is an industrial heating oil with a S.G. of 0.92 / 0.96 and viscosity of 50 cP @ 25°C.

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CMPT

The Centre for Marine and Petroleum Technology
For the European Commission
Directorate-General for Energy (DG XVII)

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CONTENTS

1.	**INTRODUCTION**	**5**
2.	**INTERNATIONAL OIL POLLUTION LEGISLATION AND CONVENTIONS**	**5**
3.	**OIL SPILLS ON WATER AND LAND**	**6**
4.	**SEPARATION TECHNIQUES**	**10**
5.	**PRODUCED WATER**	**11**
6.	**DRILL CUTTINGS**	**13**
7.	**FLARING**	**15**
8.	**ENVIRONMENTAL MODELLING**	**15**
9.	**DETECTION AND MONITORING METHODS**	**18**

1. INTRODUCTION

In the past two decades there has been increasing concern about pollution of the environment. We have come to realise that waste of all kinds dumped on the land, into seas and rivers, or emitted into the air cannot easily be taken out again. The harm done by this waste is often cumulative and its long-term effects are difficult to estimate.

Accidents over the same period have shown the hydrocarbon industry to be particularly vulnerable to accusations of causing pollution. A major tanker disaster makes a horrifying mess and the pictures of oiled sea birds and animals are distressing to many. The clean up of the spilled oil can take years and cost vast sums of money. In this context the only sensible approach is to avoid pollution as far as possible.

Potential pollution sources in the hydrocarbon industry are many and varied. In the exploration phase, there is the noise of seismic investigations, now thought to be affecting the larger marine mammals that rely on sound to communicate over long distances. Drilling brings its residue of drilling mud and cuttings, as well as flaring if the exploration is successful, with the attendant problems of oily discharge on the sea and greenhouse gases vented to the air. The carbon tax in Norway has helped to reduce flaring.

In the production phase, a wide range of oilfield chemicals are used to maximise oil flow. As fields mature, the proportion of water in the oil increases. Water injected into the reservoir to maintain pressure and keep the oil or gas flowing eventually reappears through the production wells, bearing a range of the chemicals put down the hole, as well as others that it has picked up from the formation. This produced water has been the subject of much research and technology development.

The product from mature fields also tends to become increasingly sour, containing more sulphur, as time goes by. Hydrogen sulphide is a safety problem on an installation, and a pollution problem at the refinery. Refineries that process sour crude have to employ measures to deal with the sulphur and prevent it escaping to cause acid rain.

Throughout these operations there remains a risk of accidental oil spills. In any case, spilt oil is money wasted as well as poor operational control and bad publicity. Some clean up techniques include recovery measures to collect and use the oil but in the case of major oil spills it is rarely possible to save more than a small fraction of the lost oil. The protection of the environment from pollution should always be the primary objective.

Pollution control is an increasingly regulated aspect of marine activity and the principle instruments are discussed below.

2. INTERNATIONAL OIL POLLUTION LEGISLATION AND CONVENTIONS

The European Union controls the safety and health of workers in the offshore industry through the 'Boreholes' Directive (92/91/EEC) which sets out minimum requirements for the safety and health of workers in the mineral and extracting industries through drilling. It places a requirement on the owner of an installation to make a safety assessment of the risks associated with the workplace. Although intended for worker protection, the risk assessment will cover events with pollution implications such as escape of oil and gas and well control.

A directive on pollution control, the *Integrated Pollution Prevention and Control (IPPC) Directive* (96/61/EC) was passed at the end of 1996 and will start to come into force at the end of 1999, although all the provisions will not be mandatory for existing installations until eight years after the date of publication. Its purpose is to prevent or reduce emissions to air, water and land, and applies to refineries, coal gasification and liquefaction plants and petrochemical plants, amongst others. The implications on the offshore industry are likely to be minimal but any installation that falls within the scope of the directive will eventually require a permit to operate. The permit will be based on the concept of Best Available Techniques (BAT) which can be amended as technology advances, taking into account economical considerations.

The IPPC definition of pollution is broad: "substances, vibration, heat or noise which may be harmful to human health or the quality of the environment, damage property or interfere with amenities and other legitimate uses of the environment". The pollution control technologies referenced in this brochure are restricted to hydrocarbon and chemical spillage or controlled discharge, but in the light of the above definition current projects on noise and vibration control for example could well be included in a future work on the same subject.

The International Maritime Organization was set up by the United Nations to regulate international shipping. It has promoted measures to reduce oil pollution from shipping, arising either from tanker accidents or through routine washing of tanker compartments and bilge tanks. The requirements are embodied in an international convention for the prevention of pollution from ships, the MARPOL 73/78 Convention. In some particularly sensitive marine areas any discharge of oil into the sea is prohibited, and the waters of North-west Europe, including the North Sea and Irish Sea, will be considered for adoption as a special area in September 1997. There is also the requirement that newly built oil tankers should have double hulls to safeguard against spillage if there is a collision or grounding incident. The oil transport business is well supplied, so that fewer tankers are being built than expected when this measure was introduced. The double-hull requirement is now being gradually extended to older tankers.

A further IMO convention, the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC) 1990 has been adopted to facilitate the provision of assistance to countries threatened by major oil pollution incidents. International resources will be mobilised to mitigate the consequences of major oil pollution incidents from ships, offshore platforms, sea ports and oil handling facilities that threaten the marine environment. The obligations include a duty to report incidents, the maintenance of pollution control measures and the sharing of technology. Many of the technologies described in the main body of this report can contribute to national preparedness capabilities.

Marine pollution from the European offshore industries is regulated by two international conventions, the Oslo Convention of 1972, the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, and the Paris Convention of 1974, the Convention for the Prevention of Marine Pollution from Land-based Sources. These two conventions are in the process of being united in a single convention, The Convention for the Protection of the Marine Environment of the North-east Atlantic (OSPAR Convention) which was agreed in 1992 and should come into force in 1997.

The recent activity of the joint Oslo and Paris Commissions and the Helsinki and Barcelona conventions has focused on two subjects, offshore chemicals and the disposal of offshore facilities. In 1994 a PARCOM decision was adopted on the Substances/Preparations Used and Discharged Offshore, which specifies that they should be subject to strict regulatory control by national authorities. This was followed by the adoption in 1996 of decision 96/3, a harmonised mandatory control system for the use and reduction of the discharge of offshore chemicals. This specifies a procedure by which national authorities shall regulate the use and discharge of offshore chemicals, a detailed harmonised offshore chemical notification format and requirements for a pre-screening procedure for offshore chemicals. The screening procedure will determine which offshore chemicals should be subject to permission, substitution, temporary submission with the aim of seeking less hazardous alternatives and ranking, according to a model such as CHARM (the Chemical Hazard Assessment and Risk Management Model). In the future the OSPAR working group will be looking at drilling fluids and considering the revision of its objectives and strategy with regard to hazardous substances.

This further intensification of the regulations will make research activity into the toxicity, treatment and disposal of produced water in offshore fields even more important in the future than it is at present.

As a result of the furore caused by the proposed dumping of the Brent Spar, a moratorium on disposal was adopted by majority vote ending the agreement of an overall policy. The UK and Norway did not support the moratorium. The decommissioning and disposal of offshore installations is likely to be a growing problem into which a good deal of study is being put, but it contains wider issues than pollution control technologies.

3. OIL SPILLS ON WATER AND LAND

A variety of techniques have been proposed to clear up relatively small amounts of oil from the surface of water. The choice will depend on the quantity of oil to be collected, the calmness or roughness of the water and the means of deployment at hand. They include boom systems, skimmers, pumps, dispersants and absorbents.

For major spills the recommended treatment is to spray the oil with dispersants, but some experts believe that these detergent-based materials cause as much damage to marine life as the oil itself. The grounding of the oil tanker *Braer* on the Shetland islands early in 1995 dumped 85,000 tons of oil on the coastline, but it was dispersed far more rapidly than expected by rough seas. Of course any long-term effects on the local environment have yet to be determined. Aerial spraying of dispersants and demulsifiers can treat a large area and specialist companies exist to provide this service.

Synthetic absorbent materials have been developed which soak up oil and chemicals but are not wetted by water. They are available as boom systems that can surround a spill on water, and as smaller pillows, mats and sheets, that can be deployed in places inaccessible to machinery. The material will float on water without sinking or breaking up, and is easy to collect and remove. Loose natural fibre absorbents and other more bulky materials can also be made from recycled waste material, giving a double environmental benefit. The oil can often be extracted and recovered from absorbent materials.

Booms made from absorbent materials are a special type of the general protective category of boom, which are used to isolate oil spilt on water until it can be pumped out and recovered. There are two main types - fence booms with rigid components, and more flexible curtain booms - and both require built-in flotation. Booms made of net are able to contain heavy crude, and can be made to trail down below the surface so that they remain effective even in rough seas.

The oil contained by such booms can be recovered from the surface of the water, and the design of extraction equipment has been the subject of a number of

THERMIE projects. Details of individual products are given below but the objective is always to produce a robust device that will collect oil without too much water, and remain effective in all weather conditions without getting clogged by the oil itself or marine or industrial debris.

One way of accessing all the above types of cleaning technology is through the British Oil Spill Control Association (BOSCA), a trade association set up in 1981 to represent British companies supplying equipment and services. They deal with all aspects of marine, inland and industrial pollution prevention and control, not only in the UK but in other countries. BOSCA maintains the national equipment register listing the products and services of its member companies for use by the UK oil spill control authorities, and aims to ensure that the same information is included in appropriate European registers and inventories. The thirty or so UK member companies cannot be covered individually in this brochure, and indeed there is an element of overlap in the equipment provided.

Some BOSCA member companies carry out their own research and development. The National Environmental Technology Centre (NETCEN), part of AEA Technology plc, is one member which has been active in pollution control research for over 30 years. One strand of this research is to monitor response to a pollution incident, covering such factors as the extent of oil pollution at sea and on the coast, the effectiveness of dispersants and atmospheric concentrations of hydrocarbon vapour. NETCEN provided these services in the wake of the *Sea Empress* grounding on the coast of Wales, and co-ordinated the official observers from EU member states. As a result of its experience NETCEN is able to provide a real-time assessment of the effectiveness of the pollution control measures being employed to deal with a major spill.

One factor in this assessment is NETCEN's Oil Spill Information System (OSIS) a database containing the results of extensive sea trials and laboratory weathering studies. OSIS models the expected fate of spilt oil in real incidents based on the properties of the crude itself and the local conditions prevailing at the time (see Fig 1). OSIS is also a valuable tool in environmental impact assessments of company operations. NETCEN has conducted environmental impact assessments for many governments and multi-national companies in Europe and other parts of the world.

NETCEN has developed new technologies such as mechanical recovery systems for vessels of opportunity, aerial dispersant application and the use of emulsifiers at sea. It will also make a risk assessment of a company's activities, with scenarios to cover damage to environmental resources, health and safety, direct costs of the cleaning operation, as well as the risk to the company's image and reputation from a pollution incident.

In Norway, Frank Mohn Flatøy AS markets Framo environmental protection equipment. This includes an emergency offloading system to empty disabled tankers and help to control the pollution that can result from tanker accidents. The Framo offloading system is completely self-contained, portable and has a high capacity in relation to its size and weight.

The Norwegian Clean Seas Association (NOFO), an organisation formed by oil companies operating in the Norwegian offshore sector, has funded development of

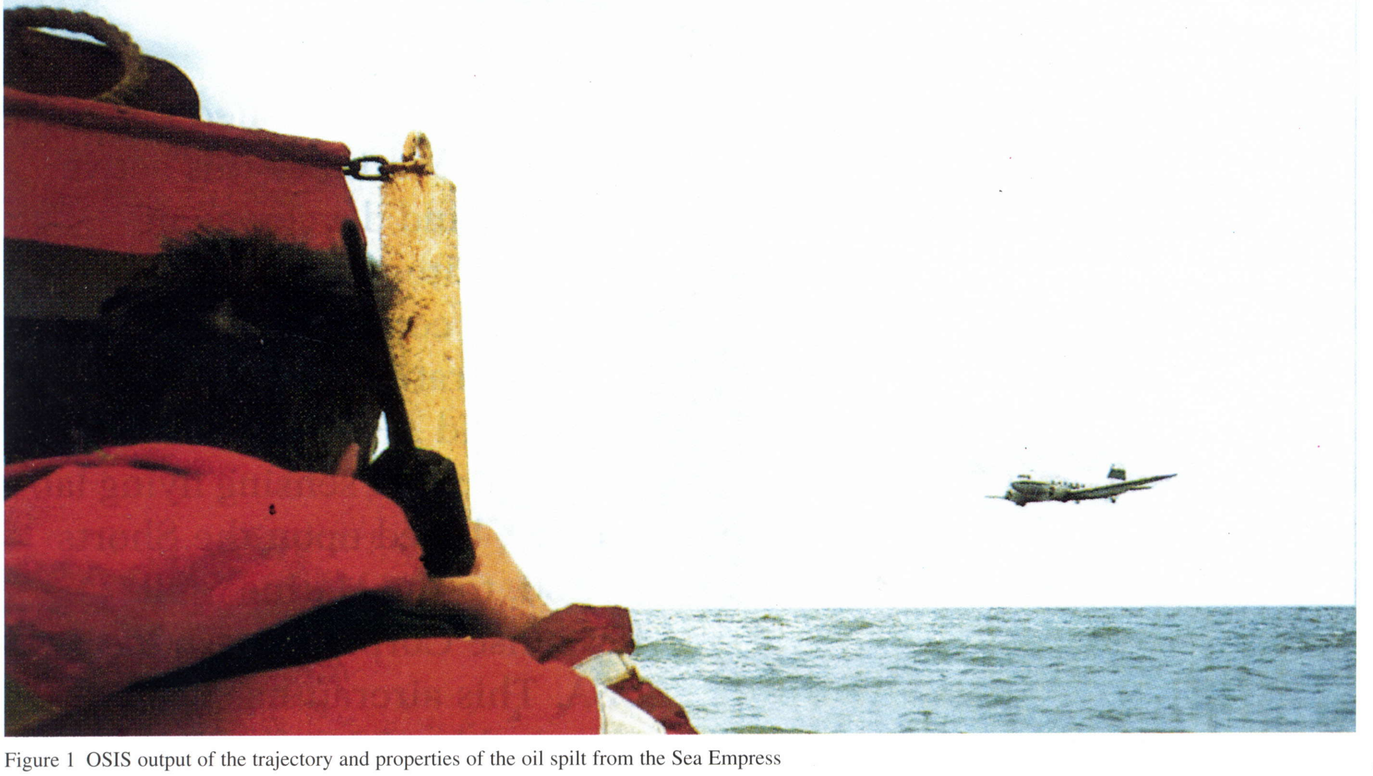

Figure 1 OSIS output of the trajectory and properties of the oil spilt from the Sea Empress

Fig 2 A Framo Transrec 250 system with a treatment capacity of 250 tons/hour

oil spill containment and clean-up equipment. One product of this programme is the Framo/NOFO Transrec oil skimmer and transfer system, an integrated oil skimmer, transfer and emergency offloading system (see Fig 2). It is claimed to be one of the most effective oil spill control systems in the world, especially when used with a dedicated oil spill combat vessel. The system comes in four sizes, with the largest size able to handle 350 tons per hour of spilt oil.

The Finnish company Lamor Corporation has developed a range of solutions for different situations. They are all based on the well proven Lamor brush disc system, which combines high oil recovery capacity with a low free water pick-up. The Lamor Offshore System (see Fig 3) is a free-floating stiff-brush unit, connected to a twin oil boom arrangement with a net attached to the oil boom skirts. A favourable V-configuration is achieved by a floating spreader boom with flexible rubber floats on both ends. The jib, the booms and the skimmer can be deployed from any vessel, connected by four strong belts, and installed in only 30 minutes. No permanent attachments to the vessel are needed. The entire system is hydraulic and normally delivered with a diesel hydraulic power pack.

The standard size Lamor Offshore System is supplied in a 20 inch steel storage container with a standard (ASTM or UNICON) oil boom connector and is therefore easy to connect to a twin boom sweep for wider coverage.

The Lamor Miniskimmer is a light, portable oil skimmer, designed to recover floating oil from harbours, estuaries, rivers, lakes and rocky shore-lines and uses the same brush system. The oil pick-up rate is 20 m^3/h - 30 m^3/h depending on the choice of oil transfer pump, and the thickness and viscosity of the slick. The Miniskimmer can be attached to a small workboat with the power pack onboard, hooked either on to the side of the boat or to the bow. Driving the boat at about two knots forces the oil into the collector. An additional feature is the hydraulically driven propeller behind the brush skimmer. Clean water separated through the brush is channelled to the propeller creating a current towards the brush wheel even when the boat is stationary. Operation is entirely hydraulic and the Miniskimmer is supplied complete with its own diesel hydraulic power pack, electric starter, oil discharge pump and ancillary equipment.

Fig 3 The Lamor Offshore System

Fig 4 Oil Swallow

The Lamor Rock Cleaner is a one-man unit designed for oil spill clean-up operations where larger units are difficult to operate, such as rocky shorelines, harbours, oil terminals, ditches, roads, factories, airports and vessels. The traditional way to clean up oil spills in such places is with shovels, buckets, mops, pads and a lot of man power. The Lamor stiff-brush technology combined with the handy small size makes it possible to lick oil from the water as well as from land, concrete, asphalt, oil booms etc. As the rock cleaner is made of stainless steel it can also be used for clean-up of many chemicals.

A hydraulic motor rotates a small stiff-brush drum. Oil stuck to the brush is cleaned by a blade, flows to an internal suction nozzle and is sucked through a hose. The cleaner can be connected to many different power sources and vacuum pumps or to a vacuum truck.

A novel skimmer that can be attached to the bow of any tugboat and operate in any weather conditions has been designed in the THERMIE Poseidon project by the Spanish company Francisco Javier Jauregui. Poseidon is a dynamic system, which enables it to operate in any sea conditions, and is intended to deal with 'black tides' of oil on water. It will have a very large capacity, which will give the system the potential to be operated at an economic cost through the value of the recovered oil.

The floating skimmer incorporates a rolling support inside two tracks attached to the bow of the collection vessel. This device enables it to move freely in open seas and continue to function during pitching and rolling. Its aspirating pump can operate at up to 480 cubic metres per hour and take up solids of up to 30 mm diameter. The mouth of the aspirator is automatically controlled by an infrared water-in-oil detection system which adjusts it to the depth of the slick and minimises the water taken up. The spill is directed into the skimmer by a small boat deploying a sea curtain, or boom, to contain the spill. For maximum efficiency, two booms should be used each connected to a floating device placed a few centimetres in front of each jaw of the skimmer.

Four units are to be tested in different sea conditions. If the volume of the spill exceeds the storage capacity of the deployment vessel, the oil can be transferred to floating tanks or to a towed tanker.

Oil Swallow is a recent development from the Dutch company Water Pollution Control Systems B.V. based on new hydraulic pump technology (see Fig 4). High efficiency for clearing oil and chemical spills from the surface of water at an economic cost is claimed by the company. The recovery capacity is up to 840,000 litres per hour at a pressure of up to 10 bar, depending on the thickness and viscosity of the spilled oil and the configuration of the discharge hoses to emergency storage, which can be a tanker or float bags. Among the characteristics of Oil Swallow are good stability and buoyancy in heavy seas, fast deployment and speed in the water, and continuous operation. International patents are pending.

Another Dutch company, SAS, offers waste oil recovery and refinery slops treatment systems as part of its services. It has developed a range of portable equipment on wheels or tracks designed to treat polluted soil or water in situ so that only the crude oil, which is valuable, is transported away, rather than large volumes of contaminated matter, most of which has to be dumped. In a collaborative project with the companies Pieralisi of Benelux and Schelde-Delta, SAS has designed a system to treat the lagoons of waste oil and refineries residues that have been collected over the years. It is no longer acceptable to leave waste oil lying around in this way and many old lagoons require removal and treatment. The SAS system can handle a feed of about 10 m^3 per hour of wastes containing typically 10% of solids and 90% of oil and water. The end product is 98% clean oil, clean water and clean sand.

Land contaminated with spilt oil from leaky pipelines is a serious problem in parts of the former Soviet Union. With assistance from the THERMIE programme this equipment has been successfully marketed in Russia and the other countries of the former Soviet Union, and SAS is collaborating on projects to assist in clearing up an extensive spill on land.

A biological clean-up technology was introduced by Central Mudplant and Fluid Services BV of Holland

Fig 5 Wastebuster II mounted on its frame

in 1994. Wastebuster is a water purification system that digests oil and fat in a multistage process. The waste stream is fed into a ventilated treatment vessel through a patented coalescence filter and immediately attacked by a range of living organisms. Unlike most biological processes, this reaction is relatively fast, due to the addition of a catalytic nutrient and the continuous aeration. As well as fats and oils, the process consumes heavy metals and aromatic compounds, producing carbon dioxide and purified water that can be recycled or discharged into sewers, subject to local regulations. The unit can be supplied mounted on a skid for rapid installation (see Fig 5).

AEA Technology is sponsoring a project at Newcastle University, UK to study the bio-degradation of the aromatic components in spilled oil. The bacterial populations involved in bioremediation will be analysed. Gene probes targeted at a key gene in aromatic hydrocarbon degradation will be designed and used to determine the diversity of the hydrocarbon-degrading organisms, and how they change with time during a bio-remediation programme.

When oil is washed up on to a beach it kills some of the natural bacteria in the sand and cuts off food sources for others. The Centre for Documentation, Research and Experimentation on Accidental Water Pollution in Brest, France, has found that spreading fish meal on oil-soaked beaches can remedy this situation by feeding the starved bacteria and giving them time to adapt to the crude oil. Having survived on fish meal, the bacteria then start to consume the oil. First tests have shown that this method of cleaning up oily beaches is faster than both no treatment at all or using detergent. The technique will have further testing in Norway and then in tropical climates.

4. SEPARATION TECHNIQUES

The hydrocyclone is an established space-saving piece of equipment used on offshore platforms to separate oil from water and water from oil. Hydrocyclones for treating produced water were covered in some detail in the *Maxibrochure Oil and Gas Process Technology.*

A new technology for cleaning up oily water, the Forsey-Pimm liquid separator, has been developed by Transfer Surface Recovery Ltd in a THERMIE project. It is suitable for treating polluted water in rivers and marine areas and, although primarily aimed at recovering oil, is technically suitable for separating any two liquids with different specific gravities. The principle of the separator is to move the denser liquid as a high velocity jet up through the surface of the lighter component, which produces an area of low pressure at the surface of the mixture. This causes the top oily layer of the mixed liquids to be dragged towards the jet of water, and then directed into a deflector unit containing a series of complex curves, and hence into a collection unit (see Fig 6). The collected material can then be further processed for re-use.

The Pimm separator is expected to be a low cost unit that will be suitable for cleaning effluent and industrial tanks as well as dealing with oil spills on water. It has advantages over conventional skimmers in that there are no moving parts, reducing maintenance to a minimum. There is no risk of clogging and the separator is easy to deploy and operate. International patents have been taken out on the device, which has been demonstrated in principle.

A European technology to separate oils from large quantities of water has been patented by Italtraco srl of Milan. The separation device acts as a selective filter in the sense that after the oily water has passed through the material it is virtually free from dispersed oil, but the oil itself does not come into direct contact with the filter. The filter material in fact repels oil, so that the filter never becomes clogged. The filter needs no power, only a static head of about 70 cm of water, and is claimed to have much lower maintenance and operating costs than similar systems in current use. All the oil is recovered, the output water has a high purity and the volume treated can be up to 60 m^3/h.

The development of membrane filters for de-oiling has been a long-term goal which has experienced some difficulties. At the Orkney Water Technology Centre in Scotland, a study supported by a number of major oil companies has assessed the performance of a number of cross-flow membrane filters.

5. PRODUCED WATER

As fields in production mature, the product contains increasing quantities of water; either water originally present in the formation or water that has been injected to maintain reservoir pressure. In the case of offshore fields, discharge of this water is subject to strict environmental conditions, and removal from it of any oil requires equipment that may take up space on the platform and hence be expensive.

A collaborative research programme between the industry and UK universities, The Treatment of Water Offshore (TWO), whose third phase ran from 1993 - 1995, was focused on aspects of water treatment offshore that involved environmental management, especially in relation to the handling and disposal of produced water. The programme, managed by the Petroleum Engineering Department at Heriot-Watt University, Edinburgh, UK, concentrated on two main strands; the environmental impact of produced water discharges and the possibility

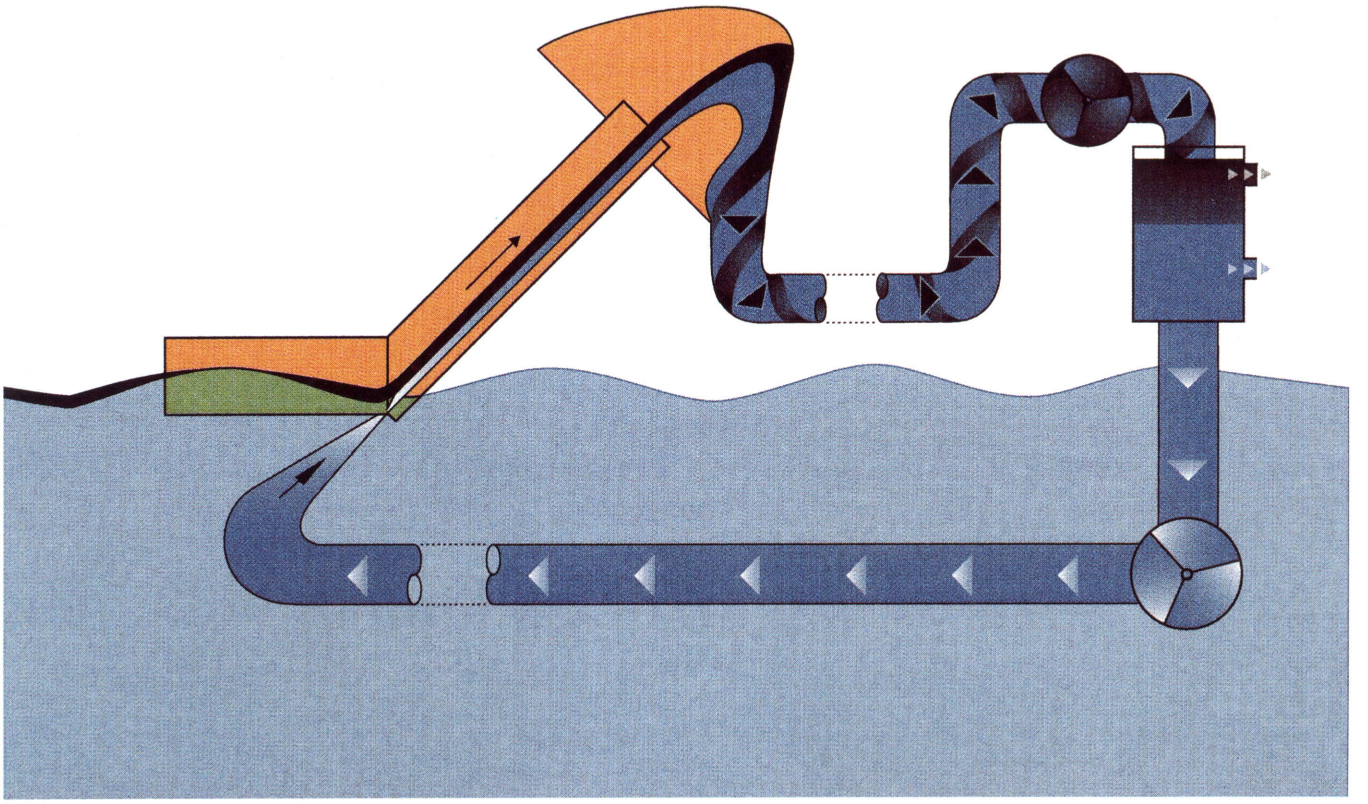

Fig 6 Schematic of the Forsey-Pimm separator

of re-injecting produced water into reservoir wells. In addition to furthering basic knowledge that should help the development of future technology, the programme produced a number of techniques that are close to commercialisation.

One problem that affects the disposal of produced water is toxicity, caused by the various chemicals added to injection water to counteract possible reservoir problems. These compounds include scale and corrosion inhibitors, emulsion breakers, de-oilers and biocides. In order to make sure that discharged produced water meets acceptable standards for effluent toxicity, it is necessary to understand the contribution both of individual chemical components and any additive or counteractive effects. An effective and rapid method for measuring toxicity is also required.

One product developed in TWO is a rapid low cost screening technique for measuring the toxicity of produced water, known as Microtox, which is based on freeze-dried photoluminescent bacteria. The degree of light inhibition that the water produces in a sample of the micro-organism is a simple measure of the toxicity. The test has been used to screen a range of additives and obtain useful information about their potential toxicity to the marine environment. It is seen as a supplement to rather than a replacement for the more sensitive tests recommended by PARCOM and should help operators to fulfil their statutory obligations as simply as possible.

Investigation of the mass balance of chemicals used offshore has developed new analytical methods and determined the distribution of various additives between phases under different operating conditions. In addition to helping operators to choose effective additives, this work has shown that the toxic components of some additives partition mainly into the oil phase and so contribute little toxicity to the discharged produced water. A separate study of the interactions of chemicals used in topsides processing has found that while some chemicals continue to act in mixtures, other combinations react together and nullify the effects of all components. The extent and spread of the interaction revealed will help operators to choose chemical combinations that do not interact.

A new contactor has been developed for removing volatile toxic aromatic compounds such as benzene and toluene from produced water. This is conventionally done by air stripping in packed columns which take up a lot of space. The more compact device uses the principle of enhancing the acceleration field to over 1000 'g', which increases mass transfer per unit volume, by liquid injection as in a hydrocyclone. This avoids the complication of mechanical rotation needed in some high gravity devices. A pilot scale version of the contactor allows a greatly increased flow rate, and has proved to be some 50 - 500 times more effective per unit volume than a packed column. Performance is even better in salty water. This work indicates that considerable platform space and weight could be saved by the new contactor, but the prototype need further development.

Research on the electrostatic de-watering of oils made considerable progress towards the goal of reducing the size of offshore equipment. An electrocoalescer increases the mean size of water droplets to assist centrifugal separation, and if installed prior to a hydrocyclone leads to a compact cost-effective de-watering system.

Produced water re-injection (PWRI) is considered to be a more environmentally acceptable disposal method than discharge into the sea, but before it can be done on a large scale, the effect of oily water on the reservoir formation needs to be understood. The TWO programme studied the performance of disposal wells over time by examining the effect on sample cores in a high-pressure rig. The damage to the cores was found to be dependent on the pore size in the rock sample - when cores had low permeability, oily water had a similar effect to clean filtered sea water, but at higher pore sizes the oily water produced 50% more damage to the permeability. These results are useful in predicting the lifetimes of disposal wells.

A project on injectivity aspects of produced water examined the effects of oily water flowing along a fracture and through the fracture faces. The phenomena observed are complex, but the effect on permeability of the formation was found to result primarily from two mechanisms. Firstly, oil droplets form a thin internal filter cake in the rock that reduces the flow, and secondly the external filter cake on the fracture face is affected by the presence of 'wormholes' which can assist the flow.

A fourth phase of TWO is currently being put in place with considerable interest from sponsoring oil companies.

AEA Technology, Winfrith UK, is also looking at injectivity, in a study jointly sponsored by several industry clients. The overall impact on the production operation of injecting hot, oily contaminated effluent water into the reservoir is little understood. Other injectivity problems include emulsion or particulate blocking, and closure of thermal fractures. Experimental studies on emulsion and particulate systems and theoretical analysis of fracturing will address these unknowns. Potential formation damage mechanisms will be investigated and guidelines on the specification of produced water of suitable quality for injection will be produced.

A number of research projects in Norway have focused on produced water. The Norwegian Oil Industry Association (OLF) funded an analysis of samples of produced water provided by oil companies operating in the Norwegian sector of the North Sea. The work began in 1991 and had the objective of determining their toxicity and biodegradability, through an estimation of the minerals, heavy metals, radioactivity and organic soluble compounds.

A similar project, *"Water production and treatment of produced water"*, was funded by the Norwegian Petroleum Directorate in 1993. Its objective was to determine the water treatment capacity of Norwegian installations and evaluate the technologies used. The potential for reducing the quantities of produced water was also evaluated and the information obtained was released to environmental agencies to further the goal of increasing environmental control.

BP Norge has supported a study by Aker Engineering AS on re-injecting produced water, mixed with sea water to minimise damage to the formation. Use of the normal water injection facility would enable the disposal of produced water at a low cost. Initial trials studied the effect on well injectivity, reservoir scouring and scale formation, and indicated no serious problems. A full scale field trial is planned that should help to gain experience for implementing produced water re-injection and integrating water injection/produced water and re-injection water treatment facilities. The trial should also demonstrate the advantages of PWRI to the industry.

A study sponsored by the UK Natural Environment Research Council and Amerada Hess is currently investigating the acute effects of production water on fish, especially juvenile fish and fish larvae, which could be more vulnerable than mature stocks. The study will look at sublethal effects and recovery rates from exposure. Using production water and analyses provided by Amerada Hess, the researchers will determine the concentration at which there is no observable effect.

The detection and monitoring methods discussed in the final section are frequently designed to estimate the oil content in produced water after it has been treated.

6. DRILL CUTTINGS

The drilling mud used to lubricate drill bits accumulates together with the spoil from the well-bore in heaps around the well-head. As well as possible interference with trawling and other work on the sea bed, the heaps of cuttings can also pollute the marine environment because of additives used in the mud. If oil-based mud, made into a slurry with an emulsion of mineral oil and water, is used, then the oil adheres to the cuttings. If the piles are disturbed, this oil can be absorbed by marine organisms and become part of the food chain.

Environmental concerns have led to the replacement of oil-based mud by water-based mud for simple formations, but harder formations still require the use of oil-based mud. Mineral oils can take up to twenty years to degrade, so a team at the Department of Civil and Offshore Engineering, Heriot-Watt University, in conjunction with Enterprise Oil, is investigating the use of vegetable oil in drilling mud. In a project known as VOODOO, (Vegetable Oils for Offshore Drilling Operations), the team has shown in the laboratory that rape seed oil is a promising substitute for mineral oil. It can survive and provide adequate lubrication at the pressures and temperatures typical of a North Sea well, but is also much less toxic and more rapidly biodegradable than mineral oil. The new drilling mud will shortly be tested in the field.

More immediate ways have to be found to deal with existing spoil heaps of contaminated cuttings. In particular the spoil heaps produced in drilling exploration wells can impede the installation of permanent production facilities and pipelines. IME Ltd of Aberdeen in a joint THERMIE project with Pneuma SRL of Italy have developed a dedicated subsea drill cuttings removal system that can raise and transport solid material as a slurry. The project is based on a simple, efficient and reliable pump, the Pneuma® pump, a positive displacement 'piston' pump, originally designed for relatively shallow water.

The pump was adapted to operate in water up to 200 m deep, the depth limit of most of the earlier platform developments, through the incorporation of a number of new design features. These include a remote suction head, submerged distributor and enhanced LARS and verification/tracking systems. The pump body can be sited on the sea bed or at mid-water depth. Two models have been produced, with capacities of 80 m^3/h and 180 m^3/h respectively (see Fig 7).

The system can excavate mixtures of gravel, silt and clay for reflow hundreds of metres away from their original

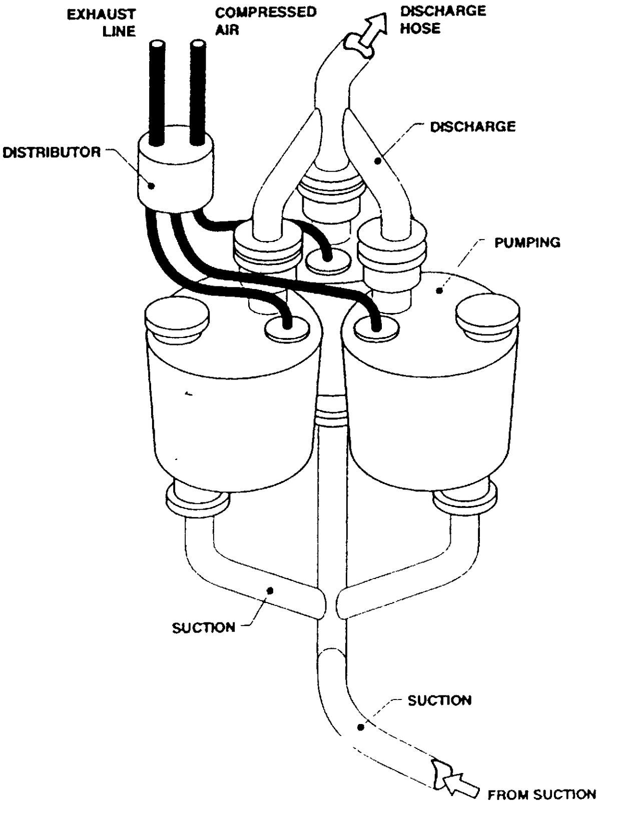

Fig 7 Arrangement of the Pneuma hydrostatic pump

position, or to tanks on the surface. The overall design is robust with few moving parts, and the suction head would be screened to keep out any large pieces of debris such as welding rods, wire rope and scaffold poles.

The study also considered the cost and viability of various disposal options, although not within the THERMIE project. While land fill and seabed disposal remain possible, the conclusion was that the most viable and cost-effective method of disposing of the recovered drill cuttings was to re-inject them into prepared abandonment wells through the same facility that deployed the reflow system.

Underwater Excavation Ltd, Aberdeen, now part of the PSL Group, has developed an excavation tool JETPROP, which removes and spreads cuttings. The tool consists essentially of a hollow pipe fitted with propellers. It is deployed by a drill string or umbilical and maintained at a few metres above the sea bed (see Fig 8). A pump on the surface vessel pumps water through jets on the propeller vanes and rotates the propeller, directing a jet of water downwards which moves and spreads the cuttings. The system is also used for excavating pipeline trenches.

JETPROP derives from the Remote Underwater Excavator (RUE) developed in a THERMIE project. There are several distinctive features of this system. Firstly it is neutrally buoyant in water, enabling it to 'fly' to areas that are inaccessible by moving along the seabed, such as the inside of platform structures. A further development is to make the hydraulic operating system run on sea water instead of oil. As well as doubling the power of the excavator with no corresponding increase in the size of its umbilical, this development would be environmentally advantageous in that any burst hoses or leaking seals would not bring the risk of environmental pollution.

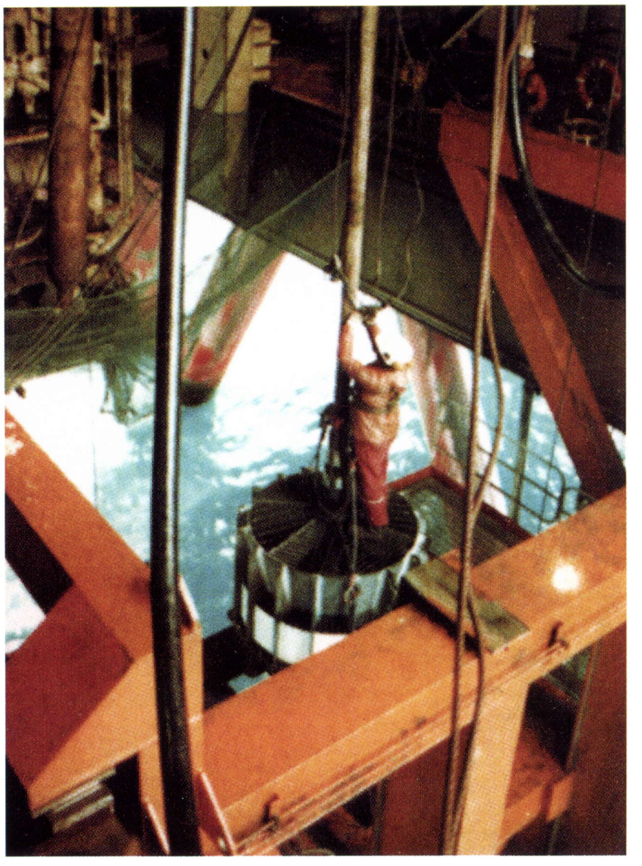

Fig 8 JETPROP for removing drill cuttings and rock dumps

The policy adopted by Central Mudplant and Fluid Services BV of Orca, the Netherlands is to recover all the drilling mud it supplies together with the entrained cuttings and treat them in a specially developed distillation technique (see Fig 9). The wet cuttings are separated into solids and waste water, reducing the quantity of material that requires treatment. All products of the cuttings treatment can be recycled. High quality oil is condensed out as well as distilled water suitable for making new water-based mud. The solid residue is an impermeable clay that can be used in construction projects in building and civil engineering.

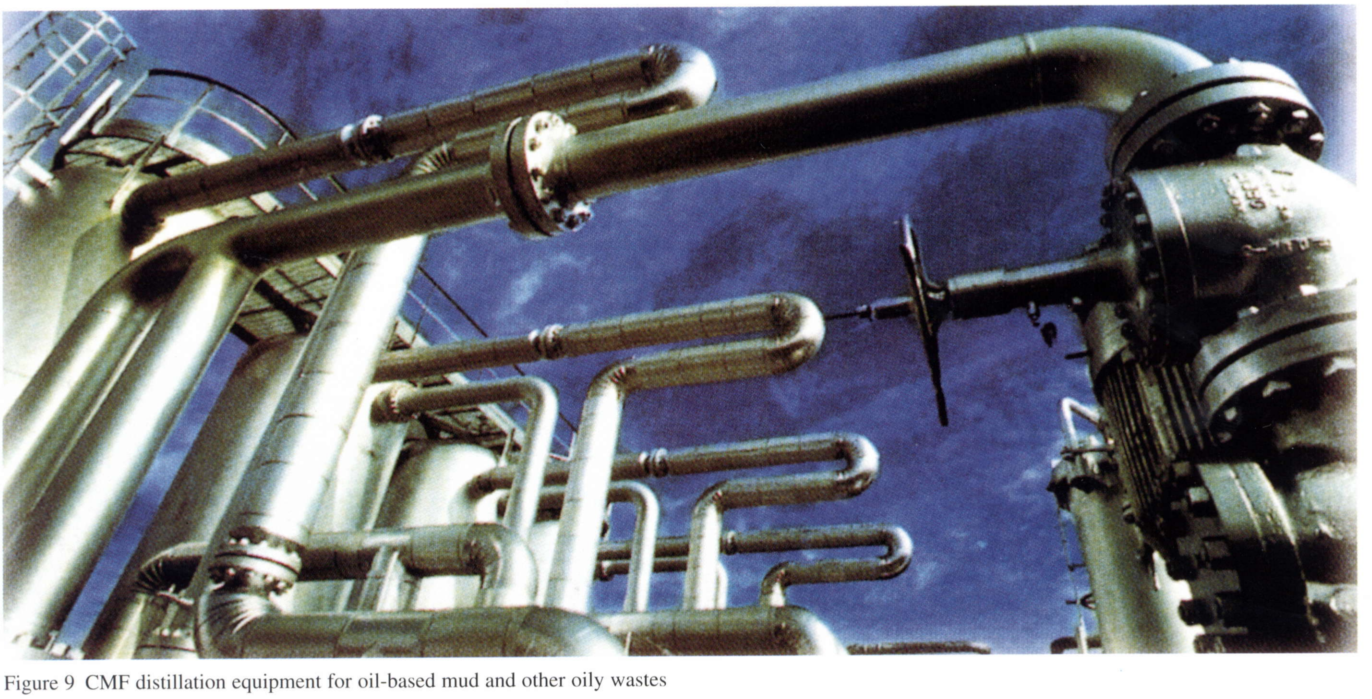

Figure 9 CMF distillation equipment for oil-based mud and other oily wastes

7. FLARING

A THERMIE project has tackled the problem of incomplete combustion in the flare jet. If the liquid hydrocarbon produced during well testing is not totally combusted, a fine mist of unburned oil droplets is dispersed and settles on the water. As increasing environmental requirements demand near-zero emissions to the sea and to the atmosphere, the only current alternative to replace the normal 'open flame' oil burners is not to flare off the oil, but to collect it in a tank for subsequent shipping to a remote process facility. The disadvantages of this approach are high costs and complex logistics.

A joint project between Schlumberger Wireline and Well Testing and the Institut Français du Petrole (IFP), has developed an efficient burner for flaring, the Evergreen burner, with the potential to meet a requirement of discharge to the sea and the atmosphere that is close to zero. IFP has carried out extensive computer flame modelling to support the design of the burner, which has 12 separate nozzles set along the generatrices of a cone. Oil and compressed air are mixed in the nozzles and exit at high speed to produce 12 highly turbulent jets (see Fig 10). Instantaneous ignition, even in windy conditions, is guaranteed by a flame front generator system coupled to twin gas-fired pilots. The result is an extremely stable flame. The burner is mounted on a cantilever swivel for easy inspection and maintenance.

Fig 10 The Evergreen burner installed offshore

The burner has been extensively tested onshore with varying qualities of fuel. Its capacity is up to 9000 BOPD without any fallout or smoke, and no water needs to be added to the fuel or the flame. Two prototypes have now been installed on drilling rigs in the North Sea for operational testing.

Vos Process Systems of The Netherlands offers the Symex range of vapour recovery systems used in the petrochemical industries to prevent the escape of volatile organic compounds into the atmosphere. They are based on the principle of adsorption on to active carbon, a technique developed in the USA in the 1970s to recover hydrocarbon vapours from gasoline loading terminals. The systems are fully automated and comply with national and European emission regulations. As methane, for example, is a far more damaging greenhouse gas than carbon dioxide this type of technology has an important role to play in environmental protection.

8. ENVIRONMENTAL MODELLING

The management of a major pollution incident at sea is highly dependent on accurate prediction of the movement of the oil which will depend on prevailing winds and currents and more transient environmental conditions. Regular monitoring of environmental and meteorological parameters is vital in order to set up accurate models to calculate the fate of an oil slick. All countries around the North Sea operate fixed monitoring systems for study and management of the marine environment, which are capable of delivering valuable data for the study of the dynamics of this marine system. However, most of them were set up on a local or national scale, and apart from meteorological information, there has been little exchange of data between them. The European Commission has therefore supported the formation of a European Workshop, known as SeaNet, to exchange information on fixed monitoring networks in the North Sea Region. Its secretariat is based at the North Sea Directorate in The Hague, The Netherlands.

SeaNet comprises networks in Belgium, Denmark, France, Germany, Great Britain, The Netherlands, Norway and Sweden (see Fig 11). It aims to promote on-line data exchange between fixed monitoring networks and to standardise data collection, processing methods and validation techniques. With regard to future monitoring, SeaNet works towards the optimum spatial distribution of monitoring sites, co-operation in the development of new techniques and sensors, and acts as a forum for the exchange of experience as well as data.

Among the SeaNet members, the Norwegian State Pollution Control authorities fostered the European SEAWATCH project from 1990 to 1995, which had up to 14 buoys monitoring 24 parameters and transmitting them simultaneously by satellite or radio.

Fig 11 A Belgian coastal monitoring station, part of the 'Monitoring Network Flemish Banks'

The name SEAWATCH is also a registered trademark of Oceanor of Trondheim. It incorporates equipment, software, communications and operating procedures into an integrated system of environmental monitoring which can be customised according to needs and applied anywhere in the world. The system can use data from a range of sources (see Fig 12) and is helping to implement international standards for environmental monitoring. It is designed to comply with the standards of the Global Ocean Observation System (GOOS) being developed by the United Nations and the Intergovernmental Oceanographic Commission. One of the uses of SEAWATCH is to monitor and combat oil spills and pollution at sea. It is capable of integrating simulation models of drift, spread and dispersal of oil with real time data so that those fighting the pollution can base their actions on what is really happening. The system can also be adapted to monitor radioactive sources for the detection of leaks.

Oceanor also provides a range of buoys and other monitoring equipment, software and computer models. It is developing new sensors and other products.

Another company with technology for pollution modelling is Hydromod of Wedel, in Germany. The company carried out a Eureka project, OPMOD, under the Euromar programme which involved computer modelling of coastal waters with the aim of plotting and thus controlling pollution. In conjunction with seven other European companies, OPMOD - which stands for operational modelling system - aimed to develop a low-cost modelling system, based partly on existing monitoring bases and partly on results from a limited number of new measuring devices intended to fill in the gaps and provide a complete coastal model. OPMOD was one of the first international oceanographic modelling systems and was successful in providing high density comprehensive data and predictions for the marine environment and on various parameters and site conditions (see Fig 13).

More recently Hydromod has been incorporating remote sensing measurements into its models. Oil spills, for instance, can be detected by satellites, especially by optical scanners and synthetic aperture radar systems, such as those installed on ERS-1 and ERS-2 or the Canadian RadarSat satellites. Other types of airborne scanners are now routinely used for marine monitoring, especially to check not only on accidental oil spills but also routine spills attendant upon tank washing or emptying of bilges. Such incidents cannot be continuously monitored from the air, and the 'snapshots' obtained can be fed into OPMOD to provide a forecast of the fate of the spill. Conversely if a spill is detected at sea it can sometimes be tracked back to its point of origin by

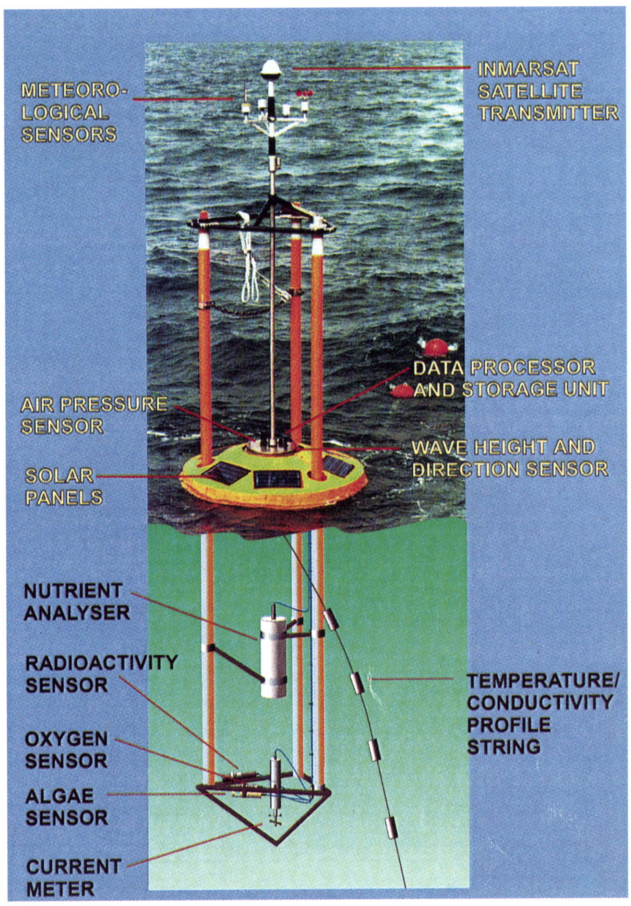

Fig 12 Seawatch data buoy

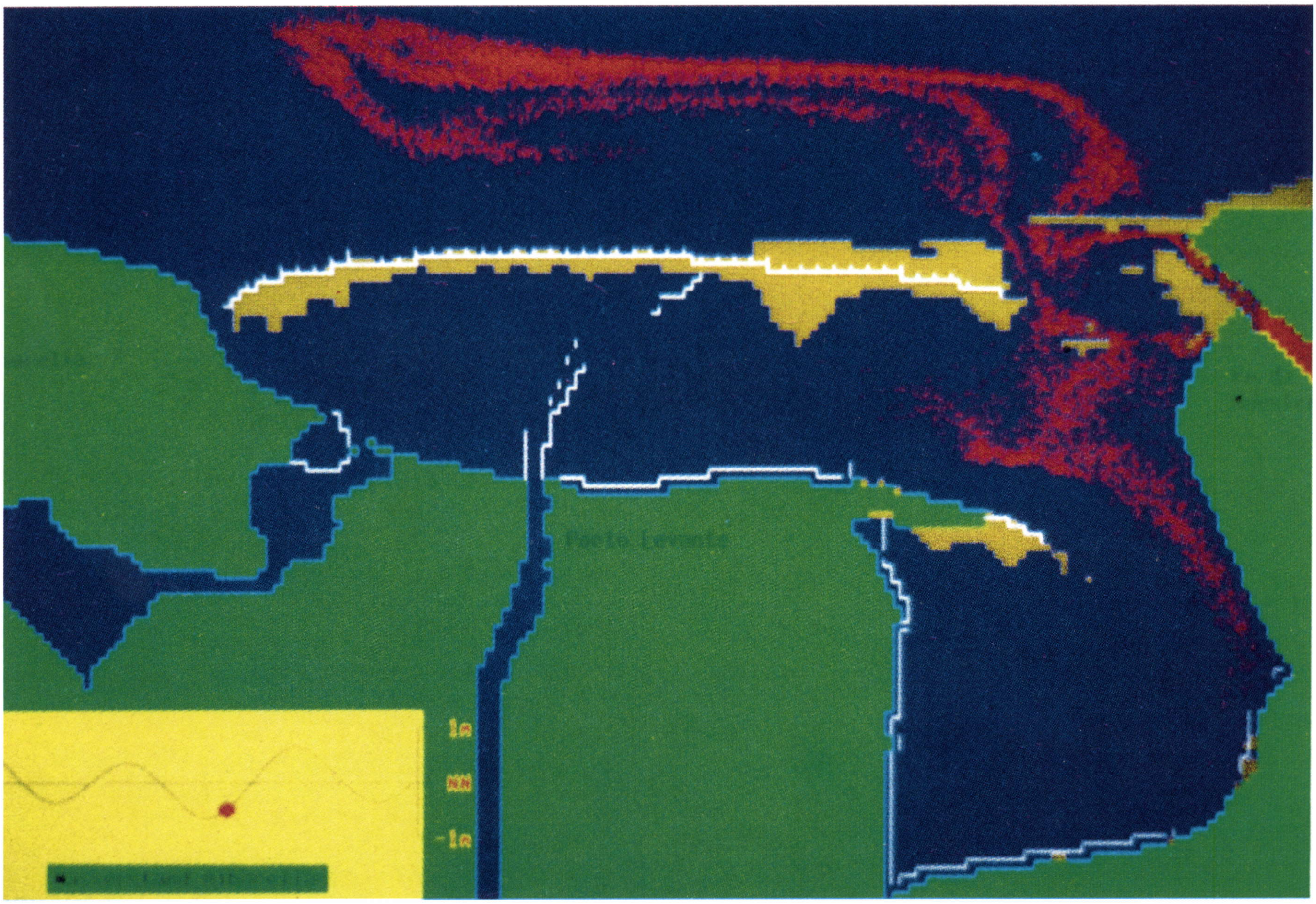

Fig 13 Modelling a coastal pollution incident with OPMOD

running the data through OPMOD. This technique can be applied to sewage discharge, turbid water and drifting objects, from lost equipment to life rafts.

The state of the art of modelling is such that it is now possible to compute the spatial distribution of the thickness of an oil spill, the rate of drifting and how much oil will have dissolved or sunk. The different types of pollution control measures, such as booms, dispersants and collectors, can also be incorporated in the modelling and their effectiveness simulated and forecast. This offers great potential for optimising the efficiency of clean-up measures as the one offering the best outcome can be selected.

Since OPMOD was first developed, operational modelling has become a key factor in environmental impact assessment (EIA) and global environmental monitoring systems such as GOOS and EUROGOOS. Hydromod is working on an operational modelling project in the EU Marine Science and Technology Programme (MAST) and DG XII has called for proposals in operational oceanography, in which operational modelling plays a significant part. The chosen contractors will start work in September 1997.

In the UK, the Defence Research Agency (DRA) maintains a Centre for Marine Technology at Gosport. It is developing a detailed model of the seas off north-west Europe in conjunction with the Meteorological Office and the Proudman Oceanographic Laboratory. Its sophisticated particle tracking software module can be used with oceanographic models to predict drift in pollution incidents.

Two recent European THERMIE projects cover environmental monitoring. The Netherlands organisation TNO is investigating oil spill tracking using shipboard radar. The advantage of radar is that the position and extent of a spill can be monitored in real time regardless of available light. A similar platform-based automatic monitoring system is also being developed.

The second project is based at the University of Southampton Oceanography Centre and is studying optical remote sensing of oil films on the surface of water. Laboratory studies of imaging spectrometers will be supplemented with field trials of airborne systems with the aim of identifying types and thickness of oils whether on the sea surface or emulsified in the upper part of the water column. This long-term study is also investigating the characteristics of dispersants and dispersant/oil mixtures.

Remote sensing from satellites is increasingly used to monitor changes to the surface of the earth, and detection and tracking of major oil spills on water is one such use. The Tromso Satellite Station, Norway, offers a service based on satellite and aircraft observations that aims to deliver information on possible oil spills two hours after the satellite passes overhead. The service is based on the ERS-1 satellite's SAR low resolution capability to detect even thin pollution layers in wind speeds below 3-4 m/s and thick layers in higher speeds up to 10 m/s. The satellite can spot crude oil emulsion, run-off from pitch deposited on land, drilling fluid from offshore rigs and fishing wastes. Care has to be taken not to confuse natural seepage or even rain cells with pollution, but operator training and advanced pattern recognition techniques improve the accuracy. The satellite covers many parts of Northern European waters, and the development has had international funding.

A research project, Seabed Interaction around a small Submarine Structure (SISS) has demonstrated a marine data acquisition and transmission system based on the Italian cellular telephone network. This system, known as Sentinel-1, is able to gather data from up to 100 sensors, and then pre-process and compress it for rapid transmission. It can then be received through the ordinary telephone network by anyone with a PC, a modem, an ordinary telephone and the appropriate software.

SISS has been demonstrated in a project in the Venetian lagoon, where it was mounted on a pile in 4 metres of water. The pile carried 5 current meters, 2 turbidity probes, 8 sedimeters, 2 conductivity/temperature probes, and a wave gauge, a tide gauge, a dual head-dual axis sonar and a meteorological station. The purpose of this instrumentation was to measure the interaction between sea bottom sediment and a structure to study the resultant erosion but the data collection, verification and transmission system could in theory be applied to the collection of environmental data.

The companies that offer environmental modelling generally also offer a range of risk and environmental impact assessment services based on their models.

9. DETECTION AND MONITORING METHODS

Before water separated from oil can be discharged into the sea, the concentration of any remaining traces of oil must be measured. This type of monitoring can show compliance with environmental legislation and test the performance of the separation processes, and help to improve efficiency.

The standard method is to extract oil with carbon tetrachloride or a freon substitute and then to measure the oil content with infrared radiation, but this is only possible in batch treatment. There is a demand for continuous monitoring downstream of a separation plant such as a hydrocyclone, and Sigrist Photometer AG has recently developed a monitor for traces of oil in water that is based on ultraviolet fluorescence. Some of the large aromatic molecules contained in crude oil have fluorescent properties and can be excited by UV radiation to emit a lower frequency of visible light. Water does not interfere with this effect, creating the opportunity for continuous monitoring by means of a 'windowless' flow cell downstream of the oil/water separation equipment. It is not possible to devise a universal instrument because each type of crude oil has a different composition and therefore a different fluorescent pattern. It is also necessary to calibrate readings with other measurement standards and according to the concentration of oil as the effect is not linear. A further requirement for continuous monitoring is that the instrument should work without drift for a long period of time without frequent maintenance.

An NTNF project is developing a robust optical sensor for continuous on-line monitoring of low concentrations of oil in produced water or water to be discharged offshore. As the analysis is based on extracting hydrocarbons with freon, there is a challenge in obtaining representative sampling and accurate oil content estimation with low operational demands. The project will focus on isokinetic sampling techniques, improving the removal of samples and reducing interference from other components in the water, to achieve high efficiency at low cost. It will aim to reduce fouling and hence maintenance and to take advantage of multi-sensor technology. As well as potential for North Sea platforms, the device could also be used in refineries and to monitor bilge water.

Ecogamma, produced by Omegadati srl and supported by THERMIE, is a technological innovation from Italy for chemical monitoring of field and process water. This system too has to be customised on site to deal with the characteristics of the field in question.

An on-line monitor to detect oil drops or solid particles with a diameter of 1 μm or more in sea water has been developed by Heriot-Watt University, Scotland. Based on a solid state laser, the monitor detects and counts any such particles passing through the laser beam. Its intended use is to monitor sea water that will be injected into a reservoir to improve oil recovery. Such water should not contain oil or particulates which could limit the oil flow by blocking the rock pores, so the monitor would be used to check on the effectiveness of the filtration system.

Early detection of oil leaks in pipelines is important for economic reasons as well as to minimise damage to the environment. The measurement of rate of flow in a steady state presents few problems, but in real conditions frequent transients mean that flow is rarely steady. Polyconsult Servizi SRL of Fano, Italy, has developed an acoustic method of recording transient events in kilometres of pipeline, thus enabling an accurate computation of inventory, and hence the detection of any losses. Transients arise through changes in pressure and temperature. The system's reference base is one atmosphere and 15°C.

The inventory changes due to pressure transients are usually determined through a number of pressure measurements taken along the pipeline, and fed into a computer model to build up a complete pressure profile of the pipeline. Several computer models have been developed, all based on integration of the wave's differential equations for liquid flow in a pipeline.

The model has an alarm threshold to warn of leaks. This is self-adjusting according to the quantity of transients being detected, so that it takes into account the reduction in accuracy as the system departs from the steady state.

The technology is suitable for gas and liquid pipelines, although the modelling is based on liquid systems. The demonstration was part of the THERMIE programme.

ORGANISATIONS FOR THE PROMOTION OF ENERGY TECHNOLOGY

Within each Member State there are a number of organisations recognized by the European Commission as an Organisation for the Promotion of Energy Technology (OPET). It is the role of these organisations to help to coordinate specific promotional activities within Member States. These include staging of promotional events such as conferences, seminars, workshops or exhibitions as well as production of publications associated with the THERMIE programme.

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